Plant Biosystems, Vol. 143, No. 3, November 2009, pp. 609–620

FIRE REGIMES IN SOUTHERN EUROPE

Selective burning of forest vegetation in Canton Ticino (southern Switzerland)

G. B. PEZZATTI[1], S. BAJOCCO[2], D. TORRIANI[1], & M. CONEDERA[1]

[1]*WSL Swiss Federal Research Institute, Insubric Ecosystems Research Group, Switzerland and* [2]*Department of Plant Biology, University of Rome "La Sapienza", Italy*

Abstract

Detailed knowledge of factors controlling fire regime is a prerequisite for efficient fire management. We analyzed the fire selectivity of given forest vegetation classes both in terms of fire frequency and fire size for the present fire regime (1982–2005) in Canton Ticino (southern Switzerland). To this end, we investigated the dataset in four categories (all fires, anthropogenic winter fires, anthropogenic summer fires, and natural summer fires) and performed 1000 random Monte Carlo simulations on frequency and size. Anthropogenic winter and summer fires have a similar selectivity, occurring mostly at low elevations in chestnut stands, broadleaved forests, and in the first 50 m from the forest edge. In winter half of the fires in chestnut stands are significantly larger than 1.0 ha and the average burnt area in some coniferous forests tends to be high. Lightning fires seem to occur more frequently in spruce stands and less often in the summer-humid chestnut and beech stands and the 50–100 m buffer area. In beech forests, in mixed forests, and in the spruce stands affected by natural fire in summer, the fires tend to be small in size. The selectivity observed, especially the selectivity of anthropogenic fires in terms of fire frequency, seems to be also related to geographical parameters such as altitude and aspect, and to anthropogenic characteristics such as closeness to roads or buildings.

Keywords: *Fire ignition, fire number, fire selectivity, fire size, fuel type, permutation method*

Introduction

Biomass burning and the resulting fire regimes may be considered a major evolutionary force affecting the patterns of vegetation structures and generating ecosystems adapted to disturbance (Pyne et al. 1996; Scott et al. 2000; Caldararo 2002). The resilience and recovery capacity of the ecosystems vary according to the fire regime characteristics such as fire extent, frequency, and severity (Delarze et al. 1992; Díaz-Delgado et al. 2002). Forest managers and fire brigades are increasingly becoming aware of this and of the fact that a sound understanding of fire characteristics and their relationship with land-use and fuel distribution patterns is a prerequisite for preserving ecosystem functionality (Swetnam et al. 1999; Bergeron et al. 2002; Kalabokidis et al. 2002). As a consequence an increasing number of studies have been conducted in recent decades on the spatial patterns of fire locations and their selectivity with respect to natural and cultural landscape features. In particular, the fire susceptibility of different types of land cover has been analyzed in order to discover preferred or avoided land-use classes in terms of burnt area, fire size classes (Cumming 2001; Stolle et al. 2003; Nunes et al. 2005), and to a lesser extent also fire frequency (Botelho et al. 1998; Bajocco & Ricotta 2008).

In North America such research has stimulated a scientific debate on the relative importance of factors such as extreme weather conditions (weather hypothesis) or spatial variation in fuel (fuel hypothesis) in controlling fire behavior (Cumming 2001). In regions where most of the wildland fires are human-caused, e.g., central and southern (Mediterranean) Europe, additional characteristics such as local demography, socioeconomic conditions, land ownership, land management and use (e.g., rural activities involving fire), species composition (e.g., plantations), and vicinity to human activities

---

Correspondence: G. B. Pezzatti, WSL Swiss Federal Research Institute, Insubric Ecosystems Research Group, via Belsoggiorno 22, 6500 Bellinzona, Switzerland. Tel: +41 91 8215232. Fax: +41 91 8215239. Email: boris.pezzatti@wsl.ch

ISSN 1126-3504 print/ISSN 1724-5575 online
DOI: 10.1080/11263500903233292

(wildland-urban interface) have been recognized as influencing the distribution and behavior of fire (e.g., Botelho et al. 1998; Díaz-Delgado et al. 2004). In such conditions, the abandonment of traditional farming activities may result in the long run in a shift in the landscape towards an increase in fire-prone vegetation such as tall shrublands and unmanaged forests (Piussi 1992; Rego 1992; Conedera & Tinner 2000; Moreira et al. 2001). Finally, where emphasis is put on quickly suppressing fires, fire propagation is the result of both natural propagation and fire-fighting activities (Díaz-Delgado et al. 2004).

In this study we first describe geographic and anthropogenic characteristics of fires and forest vegetation classes in Canton Ticino (southern Switzerland), and then test the fire selectivity of the different forest vegetation classes with higher (preferred) or lower (avoided) fire frequencies and burnt area sizes than expected by a random null model.

Material and methods

Study area

Canton Ticino is a 2812 km^2 region located on the southern slope of the Alps in the Italian-speaking part of Switzerland (Figure 1). The area is characterized by a marked altitudinal gradient, ranging from 197 m a.s.l. around Lake Maggiore (Locarno) to 3402 m on the Adula Peak in northern Ticino. The geology of the area is dominated by siliceous rock with small spots of limestone, except in the very southern part where only limestone is present.

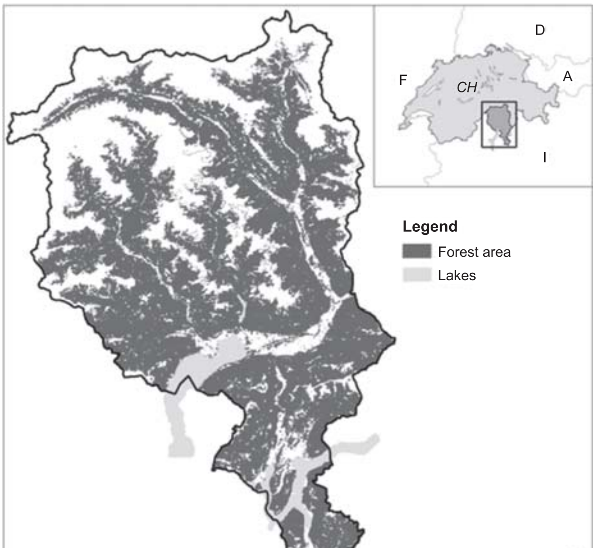

Figure 1. Location of the study area (Canton Ticino).

Southern Switzerland is generally characterized by a warm-temperate and rainy climate, although the precipitation is often concentrated in short and heavy spells and there can be longer periods without rain or even drought. The mean annual precipitation ranges from 1600 to 2600 mm, and the mean annual temperature from 3 to 12°C, depending on the elevation and the geographic position. The precipitation in the main vegetation period (June–September) ranges from 800 to 1200 mm. The duration of sunshine is high (1800–2150 ha/year), although some valleys during winter may be shaded by the surrounding mountains for several weeks. Winds are usually weak, but strong gusts may occur during thunderstorms and when there is a katabatic (descending) dry wind from the north (Föhn) on up to 40 days a year on average. One of the main consequences of the Föhn is a drop in the relative air humidity to values as low as 20% and the quick drying off of the fine fuel.

The forest cover of the area is proportionally high (on average 46.4%, Figure 1). At low elevations (from 200 m up to 900–1100 m a.s.l.), forest vegetation is dominated by chestnuts (*Castanea sativa*), which were first cultivated (and probably first introduced) in the area by the Romans. Chestnut forests are anthropogenic monocultures occasionally interrupted by the presence of other broadleaved species, such as *Tilia cordata*, *Quercus petraea*, *Q. pubescens*, *Alnus glutinosa*, *Prunus avium*, *Acer* spp., or *Fraxinus* spp. At medium elevations (900–1400 m a.s.l.), the forests mostly consist of pure stands of *Fagus sylvatica*, followed by coniferous forests (*Picea abies* and, at higher elevations, *Larix decidua*). On the south-facing slopes the beech belt is sometimes completely missing. The presence of *Abies alba* has been reduced to small patches on north-facing slopes in the central part of the area, whereas pine forests are confined to very particular sites (*Pinus sylvestris* on dry south-facing slopes, *P. cembrae* on the most continental areas of the upper regions). The distribution of the forest vegetation types follows the marked altitudinal gradient with different vegetation belts according to elevation.

Fire history

The study area has experienced forest fires since the late-glacial period (Tinner et al. 1999). The intensification of human activities and the transient change towards warmer summers during the Neolithic caused a substantial increase in fire frequency. During this period, human control of fire is unambiguously documented by significant correlations between charcoal particles and pollen types indicative of human activities (e.g., Cerealia, *Plantago lanceolata*). The introduction of *Castanea sativa* in

Roman times coincided with a radical change in local land-use, at least in the lowlands. Fire was no longer used systematically to clear open spaces in forests. Instead, many wooded areas were actively managed as chestnut groves. Since then, high values of the indicators of anthropogenic activity have no longer coincided with high fire frequencies, which indicates there was an intensive land management with a reduced use of fire during the Middle Ages. There is documentary and toponymic evidence that fire was traditionally used in pastures and pastured woods to improve their quality (clearing and fertilization). Such use of fire was abandoned in the first half of the twentieth century because of the decrease in the number of cattle and improvements in pasturing techniques (Conedera et al. 2007). As in other areas in Europe (Piussi 1992; Rego 1992), after the Second World War a sudden increase in anthropogenic fire frequency took place as a consequence of the widespread abandonment of many traditional rural activities like mowing, pasturing, collecting litter, and timber harvesting (Conedera & Tinner 2000). Since then most fires have affected areas with shrub and forest vegetation.

Forest cover map

Unfortunately, no reliable forest vegetation map of the study area exists. Instead, we used thematic forest maps of different origin, content, and levels of precision and combined them using a hierarchical approach to determine the forest vegetation cover on a 25 × 25 m grid (Table I). The land-use statistic was used to assess the presence or absence of forest, while the other vegetation maps to determine the distribution of the main forest species (*Castanea sativa*, *Fagus sylvatica*, *Picea abies*, *Larix decidua*, *Abies alba*, and *Pinus sylvestris*). Where this information was missing, we referred to the more generic classes provided by the land-use statistics (broadleaved forests; mixed broadleaved-conifer stands; coniferous forests). Wildfires starting in the neighborhood of the forest area were also considered, by including two buffer areas: the belt directly adjacent to the forest 0–50 m from the forest edge and the buffer zone 50–100 m away. In total 11 classes of vegetation cover were defined (Table II), covering 68.0% (191,239 ha) of the whole territory. The remaining 32.0% mainly consists of areas more than 100 m away from the forest edge (31.1%) and of unclassified land (0.9%).

Table I. Source data used for developing the forest vegetation cover map.

Original map	Survey date	Content	Precision (m)	References
Chestnut distribution map	1959–1960	Map of chestnut forests (polygon layer) with respect to the silvicultural system (coppice, orchard, high stands) and the percentage of chestnut crown cover (in 20% classes; cut off applied by cover <20%).	25	IFRF (1959)
Distribution maps of the main forest tree species	1995–2000	Maps of the dominant tree species (polygon layer) based on direct observation in the field.	50–100	Ceschi (2006)
Swiss land cover statistics: degree of forest mixing	1990–1992	This dataset consists of a 25 m dot matrix (raster layer) obtained from the interpretation of aerial photographs. Only four main classes are considered (see text).	25	BFS GEOSTAT (2001)

Table II. Forest cover classes considered (191,239 ha, corresponding to 68% of the whole territory of Canton Ticino).

	Area extent			
Forest cover class	(ha)	(%)	(% of the territory)	Description
Buffer 0–50 m	43,735	22.9	15.6	Forest neighboring areas within 50 m of the forest edge
Buffer 50–100 m	19,601	10.3	7.0	Forest neighboring areas between 50 and 100 m of the forest edge
Chestnut stands	13,054	6.8	4.6	Forest stands with *Castanea sativa* as the dominant species
Beech stands	15,359	8.0	5.5	Forest stands with *Fagus sylvatica* as the dominant species
Spruce stands	13,154	6.9	4.7	Forest stands with *Picea abies* as the dominant species
Larch stands	7092	3.7	2.5	Forest stands with *Larix decidua* as the dominant species
Fir stands	3329	1.7	1.2	Forest stands with *Abies alba* as the dominant species
Pine stands	1076	0.6	0.4	Forest stands with *Pinus sylvestris* as the dominant species
Other broadleaved forests	36,392	19.0	12.9	Mixed broadleaved stands without any specific dominance of chestnut or beech
Mixed forests (broadleaves-conifers)	23,741	12.4	8.4	Mixed stands without any specific dominance of species nor of broadleaves or conifers, which always remains under 75% of total cover
Other coniferous forests	14,706	7.7	5.2	Mixed coniferous stands without any specific dominance of spruce, fir, Scots pine, or larch
Total	191,239	100.0	68.0	

Anthropogenic and geographic parameters

Topographic parameters such as elevation, slope, and aspect have been calculated on the basis of the 25 × 25 m Digital Elevation Model (DEM25, Federal Office of Topography – Swisstopo). Parameters related to human activity such as distance to the nearest road and distance to the nearest building or urban area were taken from the 25 × 25 m grid Swiss Landscape Model based on the National Map 1:25000 (VECTOR25, Federal Office of Topography – Swisstopo).

Forest fire data

In Canton Ticino, forest fires are recorded by the Cantonal Forest Service. The information includes date and time of ignition, duration, ignition cause, area burnt, fire type, forest type, and – for most fires since 1969 – a geo-referenced burnt perimeter. All data are checked for quality and entered in the Forest Fire Database (Pezzatti et al. 2005). For the present study, we consider 24 years of forest fires corresponding to the period 1982–2005. This is not a homogeneous period from the point of view of forest fire prevention as the burning of garden debris has been prohibited since 1989 (Conedera & Tinner 2000). Nevertheless, we consider this an acceptable compromise that allows us to have enough fire events for the statistical treatment of the data.

A total of 1184 events are registered in the forest fires database for this period. For 1162 events information on the ignition point existed, whereas the geo-referenced perimeter of the burnt area was available for a subset of 1100 fires only.

The annual number of fires varies mostly according to the weather conditions, with – as expected – a general trend towards very low fire frequencies (<50 events per year) in the last decade. The burnt area is generally small (<500 ha/year) thanks to a very efficient fire-fighting service. Nevertheless, in fire-prone years such as 1990 and 1997 in particular, fires can get out of control and the burnt area may increase correspondingly (Figure 2).

The monthly distribution of the forest fires highlights the existence of two main peaks in fire distribution (Figure 3): a high frequency of anthropogenic rapid-spreading surface fires from December to April with peak values in March and April and a second peak in July/August with anthropogenic and small-sized lightning-induced (natural) fires (see also Conedera & Pezzatti 2005; Conedera et al. 2006). We therefore performed distinct analyses considering different categories of fires: all fires, winter fires (November to April; mostly anthropogenic), natural summer fires (May to October), and anthropogenic summer fires.

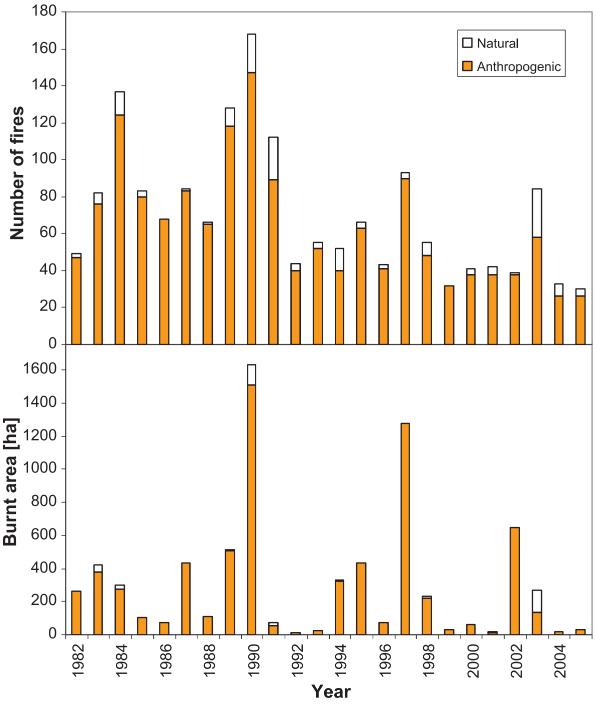

Figure 2. Annual number of fires and burnt area in Canton Ticino (1982–2005).

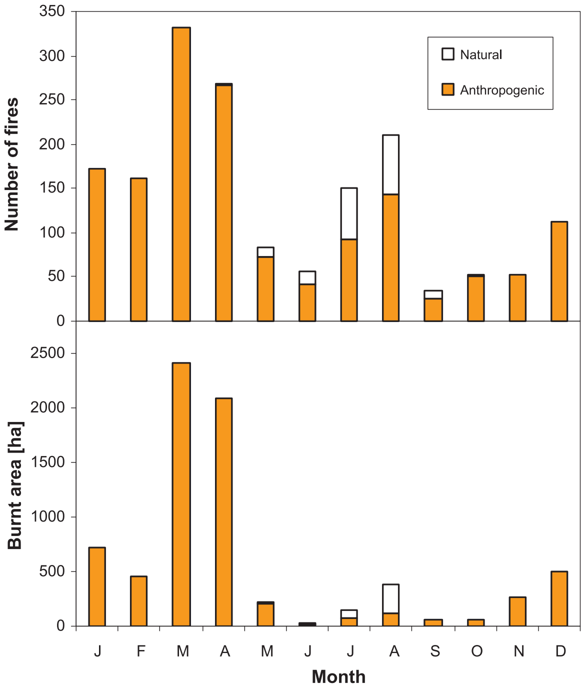

Figure 3. Monthly number of fires and burnt area in Canton Ticino (1982–2005).

To calculate the effective number of events and the burnt area of the forest fires within each forest vegetation type in the period 1982–2005, the forest fire data were overlaid on the forest cover map. Forest fires that started more than 100 m away from

Table III. Dataset of forest fires used for the analysis of fire selectivity.

Season	Events with ignition points	Events with burnt area
All fires	1081	1021
Winter	719	682
Summer	362	339
Anthropogenic	246	234
Natural	116	105

the forest edge were not considered, resulting in the datasets summarized in Table III. The burnt area of each forest fire was assigned to the dominant vegetation class on the basis of the number of 25 × 25 m grid points concerned.

Statistical analysis

Geographic and anthropogenic characterization of fires and vegetation classes. We analyzed both geographical parameters (altitude, aspect, slope) and anthropogenic parameters (distance to the nearest urban area, and distance to the nearest road) for the fire ignition points and for the forest cover classes. Aspect was sinus-transformed in order to obtain a north-to-south gradient. In order to overcome computational limitations, for the vegetation classes, we sampled the source layers of the parameters considered on a 100 m grid, assigning each value to the corresponding forest cover class. Results were then presented as boxplots for each parameter, and the distributions were compared using pairwise Wilcoxon tests and the Holm adjustment for p-values. Boxplots and analyses were performed with the software R, version 2.6.1 (R Development Core Team 2007).

Fire selectivity

Fire selectivity with respect to the forest classes was analyzed using methods originally designed to study resource selection by animals (Manly et al. 1993; Alldredge et al. 1998). According to Moreira et al. (2001) and Nunes et al. (2005), fire may be considered as a kind of "herbivore" exerting variable pressure on different resources (fuel types). If several types of forest vegetation were equally fire-prone, fires would occur randomly in the forest area with an equal proportion of available and burnt forest types. In this sense, fire is considered selective when resources are used disproportionately to their availability (Moreira et al. 2001; Nunes et al. 2005).

To determine fire selectivity with respect to the forest vegetation classes examined, we constructed a Monte Carlo simulation for selected fire categories (all fires, winter fires, anthropogenic summer fires, and natural summer fires) as already proposed by Bajocco and Ricotta (2008) for studying fire selectivity in Sardinia. Fires were randomly reassigned to the forest vegetation classes such that the probability of assignment of each fire to a given forest cover class was kept equal to the relative extension of that class. The null hypothesis is that forest fires occur randomly across the different forest types so that there is no significant difference between the relative abundance of fires in each forest type and the relative extension of each forest type within the analyzed area. The real number of fires in each forest cover class was then compared with the results of 1000 random simulations, each based on the number of fires in the period 1982–2005 for each fire category considered. For each forest cover class, p-values (two-tailed test) were computed as the proportion of Monte Carlo-derived values that were as low or lower (as high or higher) than the actual values.

At the same time, we tested whether the mean and median fire sizes in each forest cover class are significantly different from random. First, we computed the mean and median fire sizes in each forest type. Next, we compared the observed values with a Monte Carlo simulation for which, by keeping the number of fires in each forest cover class constant, we randomly reassigned the burnt surfaces of each fire. In this way we created forests in which the surface burnt by each fire is distributed at random with respect to forest type. The p-values (two-tailed test) were obtained as the proportion of 1000 permutations for which the mean and median random fire sizes of each forest type are as low or lower (as high or higher) than the actual value.

Results

Geographic and anthropogenic characterization of fire and vegetation classes

Figures 4 and 5 show the different distribution patterns of the fire ignition points (1982–2005) in Canton Ticino and of the vegetation cover considered with respect to several geographic parameters (altitude, slope, aspect) and anthropogenic parameters (distance to nearest urban nucleus, buildings, and roads).

The ignition points of winter and summer anthropogenic fires (Figure 4) had similar geographic characteristics (differences not statistically significant). In contrast, summer lightning-induced fires differed significantly from both summer and winter anthropogenic fires, occurring at higher altitudes and on steeper slopes. The distances to human activities (Figure 5) were also significantly different, and as expected were shorter for anthropogenic fires than for summer lightning fires.

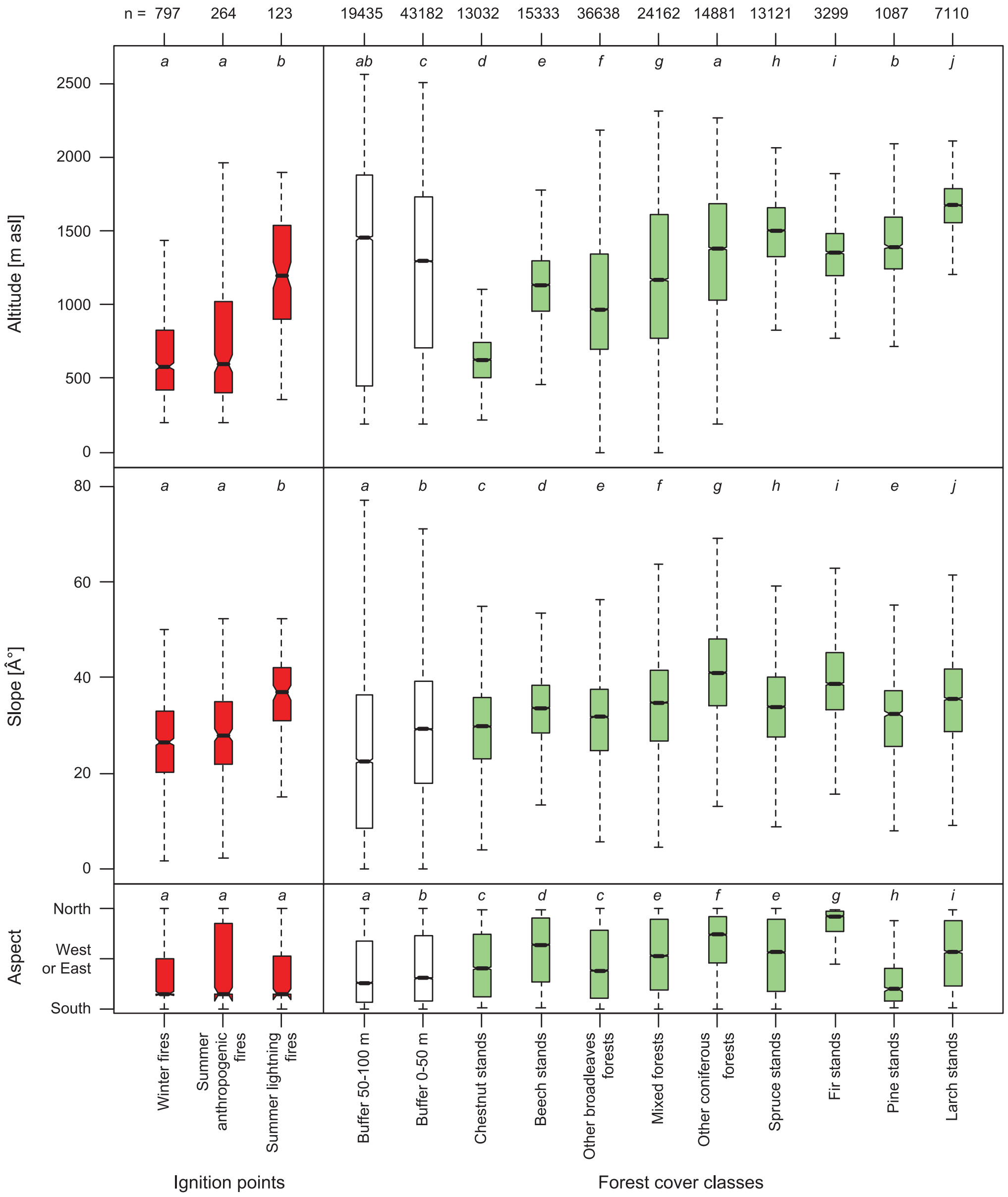

Figure 4. Boxplot distributions of the geographic parameters for the ignition points in Canton Ticino (1982–2005) and for the forest cover classes (outliers not plotted). Letters represent significantly different distributions ($p < 0.05$) according to pairwise Wilcoxon tests, with Holm adjustment for p-values. Labels on the top (n) represent the number of ignition points (for fire categories) or the number of points considered (for vegetation classes).

The type of forest vegetation was found, as anticipated, to be organized along an altitudinal gradient, with chestnut at low elevations, beech and other broadleaved forests at medium elevations, and coniferous forests including spruce, fir, pine, larch stands, and other coniferous forests at medium to high elevations. Fir stands and other coniferous forests tend to colonize steeper slopes, whereas the 50–100 m buffer area from the forest edge is found more often on the lower slopes. Pine stands and both buffer areas favor south-facing slopes, whereas fir stands and other coniferous forests prefer north-facing slopes (Figure 4).

Chestnut and pine stands tend to be the vegetation covers closest to roads, urban areas, and buildings; fir, larch, and other coniferous forests are the most distant (Figure 5).

Comparing ignition points and vegetation classes, we found similarities between the distribution of anthropogenic fires (winter and summer) and that of chestnut stands. The altitude analysis revealed no statistical difference (non-parametric Wilcoxon test with $p < 0.05$), while distance to anthropogenic activities (urban area, buildings, and roads) displayed the closest median values, although statistically different (non-parametric Wilcoxon test with $p<0.05$).

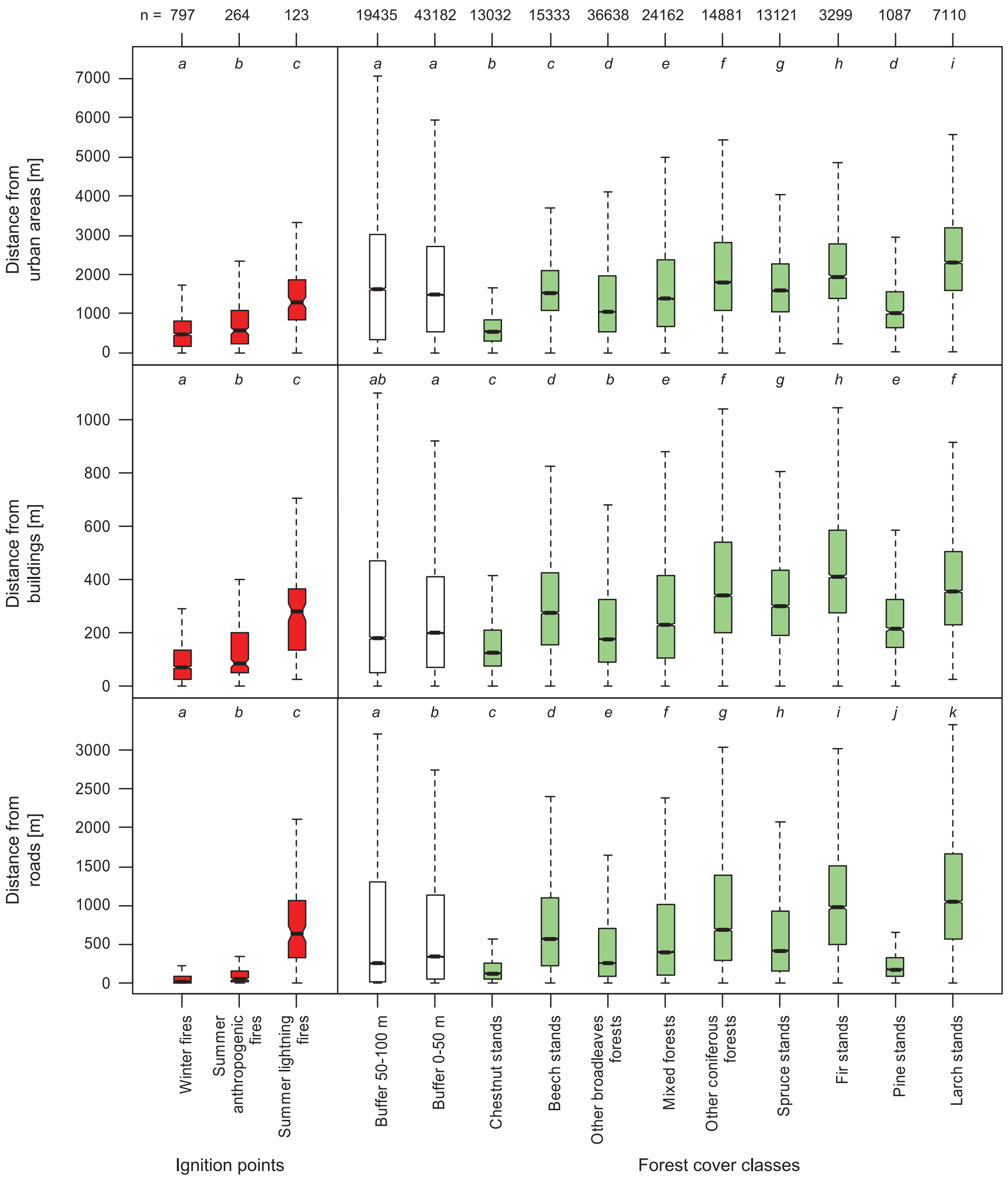

Figure 5. Boxplot distributions of the anthropogenic parameters for the ignition points in Canton Ticino (1982–2005) and for the forest cover classes (outliers not plotted). Letters represent significantly different distributions ($p < 0.05$) according to pairwise Wilcoxon tests, with Holm adjustment for p-values. Labels on the top (n) represent the number of ignition points (for fire categories) or the number of points considered (for vegetation classes).

Fire selectivity

The Monte Carlo simulations highlighted the selectivity pattern of forest covers both in terms of fire frequency (Table IV) and fire size (Tables V and VI).

The frequencies of all fires and of winter fires were significantly higher in chestnut stands, in other broadleaved forests, and in the area next to the forest edge (50 m buffer). Fire events were underrepresented in beech, spruce, fir, and larch stands, in other coniferous forests and in the 50–100 m buffer area along the forest edge. Mixed forests and pine stands are the only vegetation types without any significant pattern in fire ignition frequency. Anthropogenic summer fires display in certain cases similar patterns (preference for buffer area 0–50 m and chestnut stands; avoidance of beech stands, other coniferous forests, and fir stands). The 50–100 m buffer area, the other broadleaved forests, and the spruce and larch stands had, like the mixed forests, no significant pattern. Natural (lightning-induced) summer fires clearly prefer spruce stands and avoid the 50–100 m buffer area, beech stands, and, to a lesser extent, chestnut stands (Table IV).

Table IV. Results from the selectivity analysis on fire frequency for all fires, winter fires, anthropogenic summer fires, and natural summer fires.

		Buffer 0–50 m	Buffer 50–100 m	Chestnut stands	Beech stands	Other broadleaved forests	Mixed forests	Other coniferous forests	Spruce stands	Fir stands	Pine stands	Larch stands
All fires	True value	**329**	***69***	**175**	***28***	**263**	136	**29**	**34**	***1***	6	***10***
	Upper limit	286	144	100	114	253	166	110	110	33	17	65
	Lower limit	199	81	50	54	166	98	48	50	8	0	22
	Significance	***	***	***	***	***		***	***	***		***
Winter fires	True value	**211**	***48***	**142**	***21***	**189**	89	***14***	***3***	***0***	2	***0***
	Upper limit	193	100	70	78	168	116	77	74	26	11	42
	Lower limit	131	44	27	37	100	58	35	27	1	0	10
	Significance	***	***	***	***	***		***	***	***		***
Anthropogenic summer fires	True value	**84**	19	**30**	***4***	52	29	***9***	11	***0***	3	5
	Upper limit	78	41	35	31	69	50	31	30	12	6	19
	Lower limit	34	11	5	8	29	16	8	5	0	0	2
	Significance	***		**	***			**		***		
Natural summer fires	True value	34	***2***	***3***	***3***	22	18	6	**20**	1	1	5
	Upper limit	44	22	17	21	37	28	19	18	7	5	12
	Lower limit	11	3	1	2	9	4	1	1	0	0	0
	Significance		***	*	**				***			

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

Note: True value: effective fire frequency for the period 1982–2005. In **bold** fire frequency significantly greater than random; in ***italics bold*** fire frequency significantly smaller than random; upper/lower limit: upper and lower limit resulting from the Monte Carlo simulations.

Table V. Results from the selectivity analysis on average fire size (ha) for all fires, winter fires, anthropogenic summer fires, and natural summer fires.

		Buffer 0–50 m	Buffer 50–100 m	Chestnut stands	Beech stands	Other broadleaved forests	Mixed forests	Other coniferous forests	Spruce stands	Fir stands	Pine stands	Larch stands
	No. of fires	237	45	231	31	272	127	32	33	2	3	8
All fires	True value	8.04	***1.04***	5.55	5.51	8.63	3.26	21.17	***0.36***	1.51	1.04	0.46
	Upper limit	14.81	26.95	13.89	35.95	12.30	18.23	40.27	35.74	288.50	190.33	—
	Lower limit	2.19	0.76	2.59	0.49	2.53	1.81	0.55	0.65	0.01	0.01	—
	Significance		*						***			
Winter fires	True value	9.24	***1.24***	6.45	8.36	10.99	4.15	**49.27**	1.63	—	0.65	—
	Upper limit	18.64	51.59	17.02	81.14	16.29	28.46	71.11	140.90	—	—	—
	Lower limit	2.44	0.60	2.75	0.65	3.08	1.81	0.25	0.06	—	—	—
	Significance		*					*				
Anthropogenic summer fires	True value	3.71	0.58	1.26	0.40	1.11	3.09	2.19	0.15	***0.01***	1.23	0.84
	Upper limit	5.04	12.69	6.61	18.57	5.86	6.13	13.21	23.53	94.50	54.75	33.70
	Lower limit	0.50	0.09	0.35	0.03	0.38	0.27	0.07	0.03	0.01	0.01	0.01
	Significance									*		
Natural summer fires	True value	**11.39**	1.18	1.00	0.09	1.65	0.52	1.60	***0.13***	3.00	—	0.24
	Upper limit	12.14	57.88	130.00	76.67	14.63	15.14	30.03	14.67	130.00	—	33.10
	Lower limit	0.19	0.01	0.01	0.01	0.12	0.05	0.01	0.11	0.01	—	0.01
	Significance	*							**			

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

Note: True value: effective average fire size for the period 1982–2005. In **bold** average fire size significantly greater than random; in ***italics bold*** average fire size significantly smaller than random; upper/lower limit: upper and lower limit resulting from the Monte Carlo simulations.

Table VI. Results from the selectivity analysis on median fire size (ha) for all fires, winter fires, anthropogenic summer fires, and natural summer fires.

		Buffer 0–50 m	Buffer 50–100 m	Chestnut stands	Beech stands	Other broadleaved forests	Mixed forests	Other coniferous forests	Spruce stands	Fir stands	Pine stands	Larch stands
	No. of fires	237	45	231	31	272	127	32	33	2	3	8
All fires	True value	0.50	0.40	**1.00**	0.50	0.60	***0.08***	0.65	***0.10***	1.51	0.65	0.26
	Upper limit	1.00	2.50	1.00	2.50	0.75	1.00	3.05	2.00	288.50	85.00	—
	Lower limit	0.25	0.10	0.20	0.05	0.25	0.20	0.08	0.04	0.01	0.01	—
	Significance			***			***		*			
Winter fires	True value	0.51	0.45	**1.10**	2.25	0.95	***0.10***	1.20	2.00	—	0.65	—
	Upper limit	1.50	3.50	1.20	5.00	1.50	2.00	10.61	33.00	—	—	—
	Lower limit	0.35	0.10	0.40	0.04	0.50	0.20	0.04	0.01	—	—	—
	Significance			***			***					
Anthropogenic summer fires	True value	0.20	0.05	0.50	0.25	0.30	***0.05***	0.10	0.07	***0.01***	1.23	1.00
	Upper limit	0.55	2.45	0.70	4.23	0.50	0.64	6.00	6.70	94.50	54.75	37.00
	Lower limit	0.05	0.01	0.04	0.01	0.05	0.03	0.01	0.01	0.01	0.01	0.01
	Significance						**			***		
Natural summer fires	True value	0.30	1.10	1.00	***0.01***	0.10	***0.02***	0.60	0.06	3.00	—	***0.01***
	Upper limit	0.70	50.75	130.00	100.00	1.50	1.00	4.05	0.75	130.00	—	10.00
	Lower limit	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	—	0.01
	Significance				***		*					*

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$.

Note: True value: effective median fire size for the period 1982–2005. In **bold** median fire size significantly greater than random; in ***italics bold*** median fire size significantly smaller than random; upper/lower limit: upper and lower limit resulting from the Monte Carlo simulations.

Selectivity patterns are much more complex with respect to fire size. Average fire size is larger than random in other coniferous forests for winter fires and in the 0–50 m buffer area for natural summer fires. However the presence of one of the largest fires (550 ha) among the 13 winter fires recorded in other coniferous forests has determined the high average size of this category, which may not be considered representative. Average fire size is smaller than random in spruce stands and the 50–100 m buffer area for all fires, in the 50–100 m buffer area for winter fires, in spruce stands for natural summer fires, and in fir stands for anthropogenic summer fires (Table V). However, only two fires were assigned to fir stands, which makes this result unrepresentative. Median fire size is larger in chestnut stands for all fires and for winter fires, while it is smaller than random in mixed forests for all fire categories, in spruce stands for all fires and in beech stands for natural summer fires (Table VI).

Discussion

Forest fires display clear selectivity patterns with respect to forest cover. The patterns differ, however, according to the fire season (winter vs. summer) and the source of ignition (anthropogenic vs. lightning-induced fires). Unfortunately, no fire selectivity studies exist for comparable regions. Descriptive fire statistics show, however, similar distribution patterns for most areas on the southern slopes of the Alps (Stefaní 1989; Cesti & Cerise 1992; Bovio 1996).

Winter fires mostly occur at low elevations in chestnut stands, other broadleaved forests, and in the first 50 m from the forest edge. This may be due to the anthropogenic origin of the fires (close to the ignition sources), to the lack of snow cover in winter, to the lack of crown cover in the stands leading to more drying-out of the litter layer by sunshine in winter, and to the fire-prone fuel produced by the trees when shedding their leaves. This is especially true for chestnut stands, for fallow land along the forest edge, and for other broadleaved forests rich in deciduous oaks (Cesti 2005). In chestnut stands, the average winter fire size is not significantly higher than random, but most fires tend to have a size larger than 1 ha (compared to the overall median fire size of 0.6 ha), although this forest type is usually close to some anthropogenic infrastructure, and fire fighting is particularly rapid and efficient. This is probably because of the difficult decomposition of the chestnut leaves, which build up a conspicuous and airy fuel layer that easily dries, thus facilitating a rapid spread of the fire.

Anthropogenic summer fires display a similar pattern for fire frequency as winter fires. The exceptions are other broadleaved forests, spruce forests, larch stands, and the 50–100 m buffer area along the forest edge, which do not show any significant selectivity pattern. Lack of preference for other broadleaves in summer may be due to the dense canopy cover of this forest type, which prevents the litter layer being dried out by the sun's rays. Fire sizes on the contrary showed no significant patterns, which is probably due to the canopy cover being denser in the deciduous forest in summer; the litter on the forest floor therefore dampen and less likely to act as fuel. This prevents from surface fires spreading rapidly.

Lightning fires seem to prefer spruce stands, probably because they tend to grow on exposed sites while the particular shape of the tree seems to attract lightning. Moreover, the presence of a thick humus layer may facilitate the combustion process (Cesti et al. 2005; Conedera et al. 2006). As a rule, however, fires in spruce stands are small in size, probably because of both the compact and almost anaerobic fuel layer at ground level and the unlikelihood of fire crowning (Cesti pers. comm.). In contrast, lightning forest fires tend to be underrepresented in the summer-humid chestnut and beech stands and in the 50–100 m buffer area. In beech forests, where the fuel is also very compact and humid, and in mixed forests, the median fire size also tends to be small.

Conclusions

The approach used to analyze fire selectivity in Canton Ticino allowed us to highlight the fire preference and avoidance patterns of fires occurring between 1982 and 2005 both in terms of the number of expected fires and the average and median burnt areas. The patterns and especially the selectivity of anthropogenic fires in terms of fire frequency seem to be related to geographical parameters such as altitude and aspect, and to anthropogenic characteristics such as the closeness of roads and buildings.

These findings contribute towards the sound analysis of fire risks and potential fire hazards analyses and thus to implementing a modern fire management approach. They should help to set priorities for fire prevention; for example improving fuel regulation or fire pre-suppression, like optimizing the location of water points to supply helicopters involved in aerial fire-fighting activities, thus rendering fire management more efficient and cost effective.

Acknowledgments

This research is part of the Fire Paradox Project. We gratefully acknowledge the research funding we received from the European Commission's Sixth Framework Program. Our heartfelt thanks go to

Giancarlo Cesti for critically revising the manuscript and to Silvia Dingwall Stucki for revising the English text.

References

Alldredge JR, Thomas DL, Mcdonald LL. 1998. Survey and comparison of methods for study of resource selection. J Agric Biol Environ Stat 3(3): 237–253.

Bajocco S, Ricotta C. 2008. Evidence of selective burning in Sardinia (Italy): Which land cover classes do wildfires prefer? Landscape Ecol 23(2): 241–248.

Bergeron Y, Leduc A, Harvey BD, Gauthier S. 2002. Natural fire regime: A guide for sustainable management of the Canadian boreal forest. Silva Fennica 36(1): 81–95.

BFS GEOSTAT. 2001. Waldmischungsgrad der Schweiz. Bern: Bundesamt für Statistik, Sektion Raumnutzung.

Botelho HS, Loureiro C, Ribeiro M, Rego F. 1998. Mapping fire patterns in Tras-os-Montes region In: Viegas DX, editor. Proceedings of the third International Conference on Forest Fire Research and 14th Conference on Fire and Forest Meteorology, 21–24 November, Coimbra, Portugal. pp. 2693–2702.

Bovio G. 1996. Come proteggerci dagli incendi boschivi. Collana “Protezione Civile e Ambiente”. Torino: Regione Piemonte.

Caldararo N. 2002. Human ecological intervention and the role of forest fires in human ecology. Sci Total Environ 292(3): 141–165.

Ceschi I. 2006. Il bosco nel Canton Ticino. Locarno: Armando Dadó Editore.

Cesti G. 2005. I combustibili negli incendi di vegetazione. Collana di monografie sugli incendi boschivi e di vegetazione. Pesaro: Monografia I. De Rerum Naturae.

Cesti G, Cerise A. 1992. Aspetti degli incendi boschivi. Analisi dei comportamenti particolari del fuoco e delle sue tipologie negli incendi boschivi. Esame di una realtà alpina. Quart (AO): Musumeci editori.

Cesti G, Conedera M, Spinedi F. 2005. Considerazioni sugli incendi boschivi causati da fulmini. Schweiz Z Forstwes 156(9): 353–361.

Conedera M, Cesti G, Pezzatti GB, Zumbrunnen T, & Spinedi F. 2006. Lightning-induced fires in the Alpine region: An increasing problem. In: Viegas DX, editor. Fifth International Conference on Forest Fire Research, 27–30 November, Figueira da Foz, Portugal. p. 9.

Conedera M, Pezzatti GB. 2005. Gli incendi di bosco: cosa ci dice la statistica. Dati statistiche e società 5(1): 6–8, 10–13.

Conedera M, Tinner W. 2000. The interaction between forest fires and human activity in southern Switzerland. In: Innes JL, Beniston M, Verstraete MM, editors. Biomass burning and its inter-relationships with the climate system. Dordrecht/ Boston/London: Kluwer. pp. 247–261.

Conedera M, Vassere S, Neff C, Meurer M, Krebs P. 2007. Using toponymy to reconstruct past land use: A case study of ‘brüsáda’ (burn) in southern Switzerland. J Hist Geogr 33(4): 729–748.

Cumming SG. 2001. Forest type and wildfire in the alberta boreal mixedwood: What do fires burn? Ecol Appl 11(1): 97–110.

Delarze R, Caldelari D, Hainard P. 1992. Effects of fire on forest dynamics in southern Switzerland. J Veg Sci 3(1): 55–60.

Díaz-Delgado R, Lloret F, Pons X. 2004. Spatial patterns of fire occurrence in Catalonia, NE, Spain. Landscape Ecol 19(7): 731–745.

Díaz-Delgado R, Lloret F, Pons X, Terradas J. 2002. Satellite evidence of decreasing resilience in Mediterranean plant communities after recurrent wildfires. Ecology 83(9): 2293–2303.

IFRF (Istituto Federale di Ricerche Forestali). 1959. Carta di distribuzione del castagno. Birmensdorf: IFRF.

Kalabokidis KD, Gatzojannis S, Galatsidas S. 2002. Introducing wildfire into forest management planning: Towards a conceptual approach. For Ecol Manage 158(1): 41–50.

Manly BF, Mcdonald LL, Thomas DL. 1993. Resource selection by animals: Statistical design and analysis for field studies. London: Chapman & Hall.

Moreira F, Rego FC, Ferreira PG. 2001. Temporal (1958–1995) pattern of change in a cultural landscape of northwestern Portugal: Implications for fire occurrence. Landscape Ecol 16(6): 557–567.

Nunes MCS, Vasconcelos MJ, Pereira JMC, Dasgupta N, Alldredge RJ. 2005. Land cover type and fire in Portugal: Do fires burn land cover selectively? Landscape Ecol 20(6): 661–673.

Pezzatti B, Conedera M, Kaltenbrunner A. 2005. Die neue Waldbranddatenbank. Bündnerwald 58(6): 37–39.

Piussi P. 1992. Environmental changes in forests. Examples from the south of Europe In: Teller A, Mathy P, Jeffers JNR, editors. Responses of forest ecosystems to environmental changes. First European Symposium on Terrestrial Ecosystems: Forests and Woodland, organized by the Commission of the European Communities Florence, Italy, 20–24 May 1991. London: Elsevier Applied Science. pp. 298–309.

Pyne SJ, Andrews DL, Richard PL. 1996. Introduction to wildland fire. New York: John Wiley.

Rego FC. 1992. Land use changes and wildfires. In: Teller A, Mathy P, Jeffers JNR, editors. Responses of forest ecosystems to environmental changes. First European Symposium on Terrestrial Ecosystems: Forests and Woodland, organized by the Commission of the European Communities Florence, Italy, 20–24 May 1991. London: Elsevier Applied Science. pp. 367–373.

R Development Core Team. 2007. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna; Available from: http://www.R-project.org

Scott AC, Moore J, Brayshay B. 2000. Introduction to fire and the palaeoenviroment. Palaeogeogr, Palaeoclimatol, Palaeoecol 164: vii–xi.

Stefaní A. 1989. Boschi e incendi in Lombardia. Dendronatura 10(1): 41–47.

Stolle F, Chomitz KM, Lambin EF, Tomich TP. 2003. Land use and vegetation fires in Jambi Province, Sumatra, Indonesia. Forest Ecol Manage 179(1–3): 277–292.

Swetnam TW, Allen CD, Betancourt JL. 1999. Applied historical ecology: Using the past to manage for the future. Ecol Appl 9(4): 1189–1206.

Tinner W, Hubschmid P, Wehrli M, Ammann B, Conedera M. 1999. Long-term forest fire ecology and dynamics in southern Switzerland. J Ecol 87(2): 273–289.