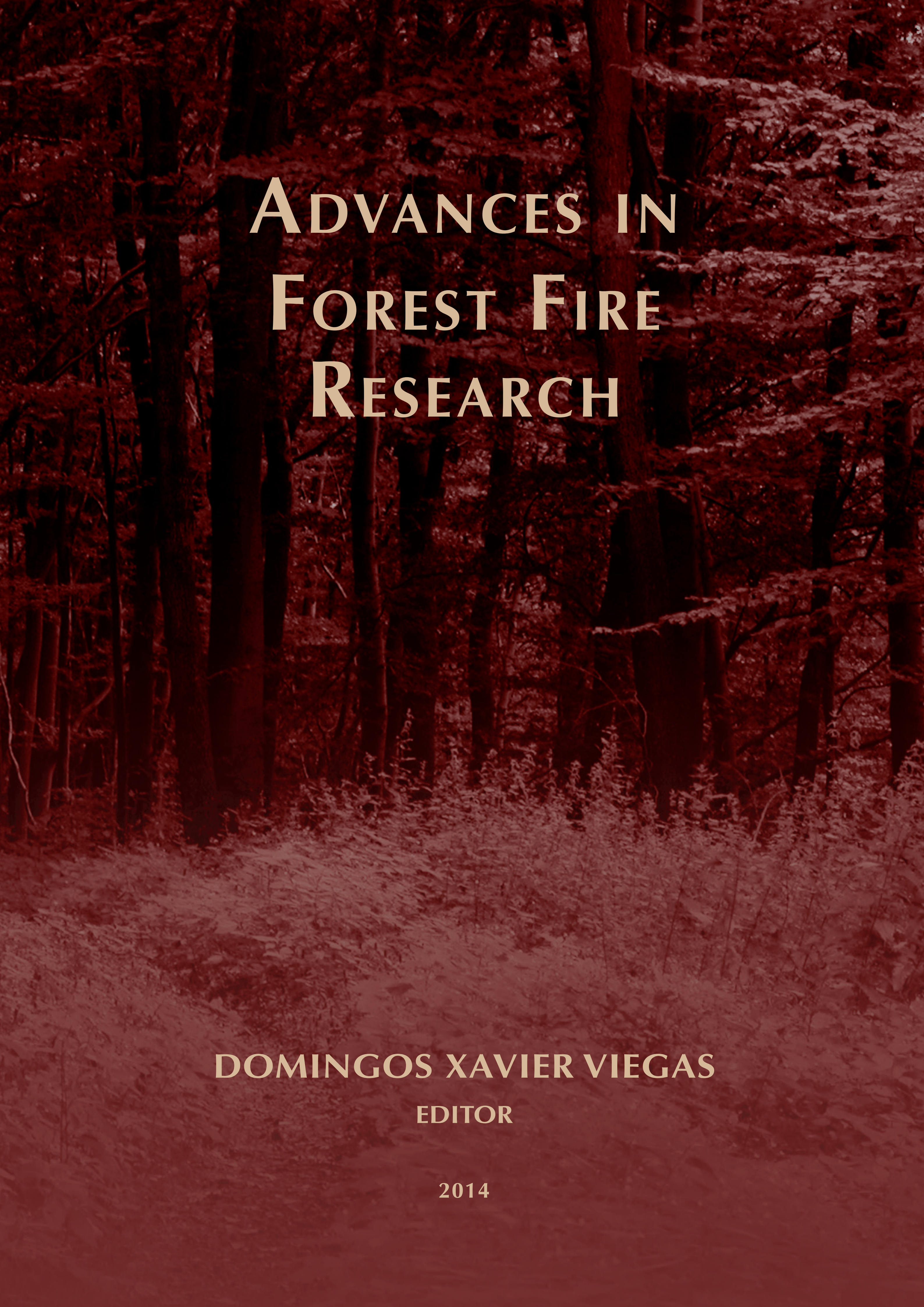

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Experimental prescribed burning in Turkey oak forest of Cilento and Vallo di Diano National Park (Southern Italy): effects on vegetation and soil

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Abstract

An experimental prescribed burn was conducted in February 2011 in a Quercus cerris forest in the Cilento e Vallo di Diano National Park (Southern Italy) to analyze fire effects on vegetation and soil.
Fuel fire behavior characteristics and were assessed to define the burning conditions that allowed a rate of fire spread between 0.10 and 0.22 m min-1, fireline intensity never below 50 kW m-1 and maximum flame temperatures in the litter of 600°C but the average residence time above 60°C and 300°C were 198 and 12 seconds, respectively. Litter fuel consumption ranged between 80% and 90%.
The effect of fire on vegetation was evaluated in terms of floristic composition and structure by means of phytosociological and dendrometric samplings randomly located in burned and unburned plots two years after fire. The effect of fire on soil was evaluated by determining soil chemical (pH, water content, total and extractable organic C content, total and mineral N) and microbial properties (microbial biomass, soil potential respiration) in the 0-5 cm soil at different time since fire (3 hours, 30, 94, 209 and 394 days). Moreover, water holding capacity and bulk density were measured in burned and unburned plots at first sampling.
Results on vegetation evidenced no significant differences in species richness and diversity, in both burned and unburned plots. No changes have been found in frequency and cover values of endemic species (Digitalis micrantha, Echinops ritro subsp. siculus, Lathyrus jordanii, Teucrium siculum). Woody species showed a great resilience with very low tree mortality. Sapling persistence by high sprouting rootstocks evidenced no significant difference in the abundance of some species (Quercus cerris, Acer campestre, Carpinus betulus, Crataegus monogyna) or an increase for few species (Ruscus aculeatus, Ilex aquifolium, Erica arborea, Fraxinus ornus, Sorbus torminalis, Carpinus orientalis) in burned plots.
Results on soil showed that prescribed burning did not affect soil chemical and microbial properties, so indirect effects on plants deriving on effect of fire on soil may be excluded. Our findings highlight the sustainability of prescribed burning in Quercus cerris forests and support its future use as a management tool of fire risk reduction without significant impact on vegetation and soil.

***Keywords**: Quercus cerris forest, prescribed burning, biodiversity, resilience*

1. Introduction

Fire has played an important role in shaping the distribution and composition of many biomes worldwide (Keeley *et al*. 2011), including temperate forests of the Northern Hemisphere (Abrams 1992; Bradshaw *et al*. 1997). In particular, natural and anthropogenic fire regimes have been one of the main drivers in determining life traits of oak species and the structure of oak forests in both North America (e.g., Cutter & Guyette 1994; Shumway *et al*. 2001) and Europe (Clark *et al*. 1989; Mason 2000; Robin & Nelle 2014).

Oaks have several fire related traits which enable them to survive on frequent fire. Mature oaks have thicker bark than most other hardwood species (Nicolai 1986). They are capable of living for decades after bole injury. Litter displays a relatively marked flammability (Kane *et al*. 2008). Regeneration from root and stump sprouts can be enhanced by fire (Hutchinson 2008). A synergistic interaction of fire and masting may result in burned sites having high oak seedling density following a mast year (Brose *et al*. 2006; Abrams & Johnson 2013). Fires may also kill acorn predators, which may result in increased acorn viability and germination (Johnson *et al*. 2002). Acorns germinate well below the soil surface where they are protected from the heat of a surface fire. The reduced shading and competition, and prepared seedbed that result from litter removal combine to provide favourable oak regeneration conditions (Wang *et al*. 2005).

For the above mentioned reasons, prescribed burning is broadly used to manage oak forests of North Eastern America with the objective to promote oak natural regeneration, reduce invasive species, restore biological diversity, and decrease hazardous fuel build-up (Peterson & Reich 2001; Burton *et al*. 2011; Cavender-Bares & Reich 2012; Brose *et al*. 2013). Such management goals are often achieved integrating prescribed burning with other sylvicultural treatments such as thinning and shelterwood cutting (Albrect & McCarthy 2006; Brose *et al*. 2006).

Several oak species of Northern America managed by prescribed burning (i.e. *Quercus alba*, *Q. ellipsoidalis*, *Q. macrocarpa*, *Q. marilandica*, *Q. rubra*, *Q. shumardii*, *Q. stellata*), are vicariant of main European oak species, e.g., *Q. alba* vs. *Q. petraea*, *Q. macrocarpa* vs. *Q. robur*, *Q. stellata* vs. *Q. cerris* (Box & Manthei 2005), with which share similar ecological traits and regeneration strategies. However, the use of prescribed burning for forest management goals has been relatively recent in Europe in comparison to North America (Fernandes *et al*. 2013).In particular, very little knowledge exists regarding prescribed fire behaviour and its ecological effects in deciduous oak forests of Europe. In order to assess the ecological sustainability of this management practice, investigations are needed to reduce undesirable fire effects on the ecosystem components, such as tree seedlings mortality, soil degradation and floristic impoverishment (Franklin *et al*. 2003; Hutchinson *et al*. 2005; Neary *et al*. 2010; Williams *et al*. 2012).

With these aims, an experimental prescribed burning was carried out in 2011 in a *Quercus cerris* forest of the Cilento e Vallo di Diano National Park, Southern Italy (Ascoli *et al*. 2012). Since this forest is located in a Site of Community Importance (IT8050002 included in Annex I of the Directive 92/43/EEC), ecological monitoring was particularly important in order to evaluate the effects on biodiversity and to exclude possible negative impact to holly (*Ilex aquifolium*) and ruscus (*Ruscus aculeatus*), being both species protected by a regional law.

In particular the specific objectives of the present study are: i) to characterize fuels and fire behaviour observed during the experimental prescribed burning; ii) to assess short term effects of fire on understory plant species diversity, oak regeneration andprotected plant species ; iii) to analyse fire effects on soil chemical and microbial properties.

2. **Methods**

2.1. **Study area**

The study site (40°17’10’’N; 15°16’51’’E) is located in the National Park of Cilento, Vallo di Diano and Alburni, Sothern Italy (Figure 1), about 20 km apart from the sea in a hilly area. The site is 455 m a.s.l., with a SW aspect and an average of 40% slope. The climate is mesotemperate humid with mean annual temperature of 14.7°C (ranging from 6.3°C in January to 23.6°C in August) and annual precipitation of 825 mm with a dry period in summer with less than 100 mm. (Gioi meteorological station, 684 m a.s.l., 22 km apart from the study site).

Soil is Calcari-Vertic Cambisols and geologic substrate is Marls and Calcarenites of the Stream Trenico of the Chattian (FAO 1998; di Gennaro, 2002).

Vegetation is characterized by *Quercus cerris wood* 14-16 m high with an average cover of 80% and a low scattered presence of *Sorbus domestica*, *Ostrya carpinifolia* e *Fraxinus ornus*. The woody understorey is dominated by *Carpinus orientalis, Crataegus monogyna, Ilex aquifolium, Ruscus aculeatus* and *Erica arborea*, whereas the main representative herbs are *Festuca exaltata, Echinops ritro subsp. siculus, Digitalis micrantha.*

Figure 1. Study site location

2.2. Fuel and prescribed fire characterization

The prescribed burn was conducted in winter 2011 on an area of 0.7 ha. Fuel characteristics were assessed few days before burning. Dead fine (< 6 mm) surface fuels were constituted by *Q. cerris* litter, cured grasses and dead woody material. Live grasses and forbs, and elevated live woody fuels such as *Erica arborea*, were sparse. Dead surface fuels were harvested in six 1 m^2 quadrats and dried in the laboratory to determine the fuel load. Fuel bed depth and cover of dead fuels were also measured every 0.5 m along six linear transects (10 m).Dead fine fuel moisture was assessed at the time of the burn by collecting 5 litter samples. Fresh samples (50 g each) were weighed in the field by a portable scale, and then dried in laboratory.

Fire behaviour was assessed at a microplot scale (Fernandes *et al*. 2001) by measuring the arrival time of the fire front at the vertices of a triangle and computing the rate of spread according to the trigonometric method of Simard *et al*. (1984). Five equilateral triangles (2 m side) were visualized using 2 m rods placed at each triangle vertex. The time of arrival of the fire front was measured using K-Type thermocouples (0.4 mm) positioned at each triangle vertex within the litter fuel (5 cm from the soil surface), and connected to a data-logger buried one meter apart. Flame temperature was measured every second during all combustion phases. Flame height was assessed by two observers which used as a reference scale the increment markers(0.5 m)painted on each rod. Fireline intensity was calculated using the Byram (1959) formula applying a high heat content of 20000 kJ kg^{-1}. Air temperature and moisture, and wind speed and direction were assessed every time fire was spreading through a triangle using a portable weather stations positioned at midflame height at a distance of 5 m upwind the triangle. In total, 5 rate of spread observations and 15 time-temperature profiles were collected. Fuel consumption was assessed soon after the fire by harvesting remaining charred fuels in a 1 m^2 quadrat within the triangle.

2.3. **Vegetation sampling**

The effects of prescribed burning were assessed in summer 2013 to analyze the following parameters: floristic and structural composition, plant community sintaxonomy, species richness, species density, demography and regeneration of structural species. Plant community was sampled by the phytosociological method (Braun-Blanquet, 1964) on sampling area of 100 m^2 for sintaxonomical characterization. Moreover the phytosociological method was applied on 1 m^2 sampling plots along randomly located transects to analyze the effects of burning application on plant biodiversity. In total, 40 plots were surveyed in both burned and control sites. Thesurvey was carried outin accordance with theBraun-Blanquet scale and then converted in Van der Maarel (1979) scale in the data matrix.

The data matrix (60 species x 80 relevés) was analyzed by Principal Component Analysis (PCA) with algorithm Euclidean distance contained in SYN-TAX package (Podani, 2001) to test the degree of floristical similarity between burned and control plots. The software EstimateS (Colwell, 2013) was used to calculate rarefaction curve of richness estimators and biodiversity for sample based data (40 burned plots and 40 control plots). The nomenclature of species follows Pignatti (1982), Med Check list (Greuter *et al*., 1989), and Conti *et al*. (2005, 2007).

Stand structure (tree species density, basal area, height, and status: alive, dead, fallen, fire scar) was also assessed. Trees with a diameter at breast height >5 cmwere measured in a circular plot of 20 m in diameter. Tree regeneration with a diameter <5 cm and a height >30 cm was assessed in a circular plot of 8 m in diameter. Regeneration with a height <30 cm was assessed in the same plot used for phytosociological relevés. Regeneration was characterized by stem density, height and status (live/dead; seedling, sapling, post-fire sprout). For each plot, environmental data such as slope, litter cover and depth, bare soil, rocks, herb and shrub cover and height) were also recorded to evaluate their potential effects. A total of 40 plots were surveyed in both burn and control sites. Statistical analysis was performed to evaluate significant differences of individual number (test Chi^2) and average height (test U-Mann-Whitney) between burned and control plots.

2.4. **Soil collection and analysis**

To evaluate the effect of prescribed burning on soil properties that could affect oak, soil samples were collected at 0-5 cm depth in 6 randomly selected sub-plots (40 x 40 cm) of burned and unburned plots at different times since burn (3 hours, 30, 94, 209 and 394 days).

In the first sampling, in both control and burned plots, soil water holding capacity and bulk density were determined by gravimetric method (USDA, 2004). At each sampling time sieved soil samples (2-mm mesh) were analysed for chemical (water content, pH, total organic C, extractable organic C, total N, ammoniacal N and nitric N) and microbial properties (microbial C and soil potential respiration).

Water content was measured by gravimetric method (Allen, 1989). Soil pH was determined by potentiometric method on air dried soil:water suspension with a 1:2.5 ratio using a calibrated electrode (Hanna Instruments mod. HI1230). Total organic carbon content was measured on air dried soil by humid oxidation method (Springer and Klee, 1954). Extractable and microbial C were determined on fresh soil by chloroform-fumigation extraction method (Vance *et al*., 1987). Total N was determined with NCS Elemental Analyser (ThermoFlash EA 1112). The ammonium and nitrate contents were determined by potentiometric method (Beck, 1993) on fresh soil stored at 4 °C until measurement, by using specific potentiometric electrode for ammonia (ORION, Mod. 9512BNWP) and one specific for nitrate (ORION, Mod. 290A) after Castaldi and Aragosa (2002). Soil potential respiration, indicating microbial activity, was determined measuring, by gas chromatography, CO_2 evolved from samples incubated in standard conditions (25 °C, 55 % of water holding capacity, in the dark) for one hour (Kieft *et al*., 1998).

3. Results

3.1. Fuel characteristics and prescribed fire behaviour

Pre-fire fuel cover was 100%.Mean fuel bed depth was 8 cm. Dead fine fuel load ranged between 3.4 and 5.7 t ha^{-1}. During the burn, mean fine dead fuel moisture content (dry weight basis) was 38% (Table 1).Weather conditions are reported in Table 1.

Table 1– Mean weather, fuels and fire behavior characteristics observed during an experimental prescribed burning in Quercus cerris litter fuels. Photos shows prescribed fire behavior and fuel consumption.

Weather	
Air temperature (°C)	16
Air moisture (%)	43
Wind speed (km h^{-1})	6
Days since rain (days)	5
Fuel load	
Litter fuels(t ha^{-1})	4,24 ± 0,34
Cured grasses + fine dead woody(t ha^{-1})	2,44 ± 0,46
Fuel moisture	
Litter (%)	38 ± 5
Duff (%)	132 ± 19
Fire behaviour	
Ignition pattern	Backfire
Rate of spread (m min^{-1})	0,17 ± 0,04
Flame height (m)	0.1-0.3
Fireline intensity (kW m^{-1})	25 ± 5,7

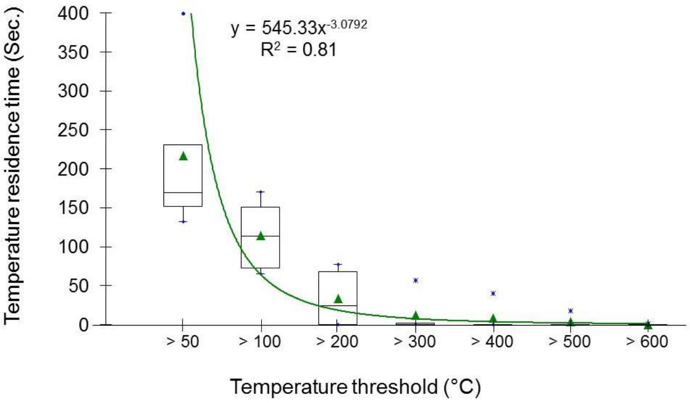

Figure 2. Flame temperature residence time above threshold temperatures measured at the soil surface during a prescribed burning in Q. cerris litter fuels.Boxes show the first and third quartiles; the black line is the median.Green triangles are the mean.Negative exponential function, its equation and R2 are also displayed.

Fire rate of spread varied between 0.10 and 0.22 m min^{-1}. Fuel consumption ranged between 80 and 90% of the pre-fire mean fuel load (see figure in Table 1). Maximum flame temperature ranged between 159°C and 601°C. Average residence time above 60°C and 300°C were 198 and 12 seconds, respectively. Figure 2 shows the flame temperature residence time above threshold temperatures measured at the soil surface. The temperature decay displayed a negative exponential function.

3.2. Vegetation

On the basis of phytosociological relevés the studied forest formations can be classified as part of mesotemperate *Quercus cerris* wood, referring to the association *Lathyro digitati quercetum cerridis* Bonin and Gamisans 1976 and subassociation *festucetosum exaltata* (Rosati *et al*.2005). These forestsare distributed in the clay-marl and sandstone areas of hilly and mountain between 400 and 850 m a.s.l. and are referred to suballiance *Ptilostemo-Quercenion cerridis* (*Teucrio siculi-Quercion cerridis*). Burned and control area show a great homogeneity in the floristic composition especially highlighted by the high number of species frequency V (at least 80% of the relevès). In the phytosociological relevés all the species characteristic of association (*Lathyrus jordanii*, *Carpinus orientalis*, *Ptilostemon* *strictus* and *Melittis melissophyllum*), were found while between the characteristics of sub-association *Erica arborea* and *Drymochloa drymeja* are very common.

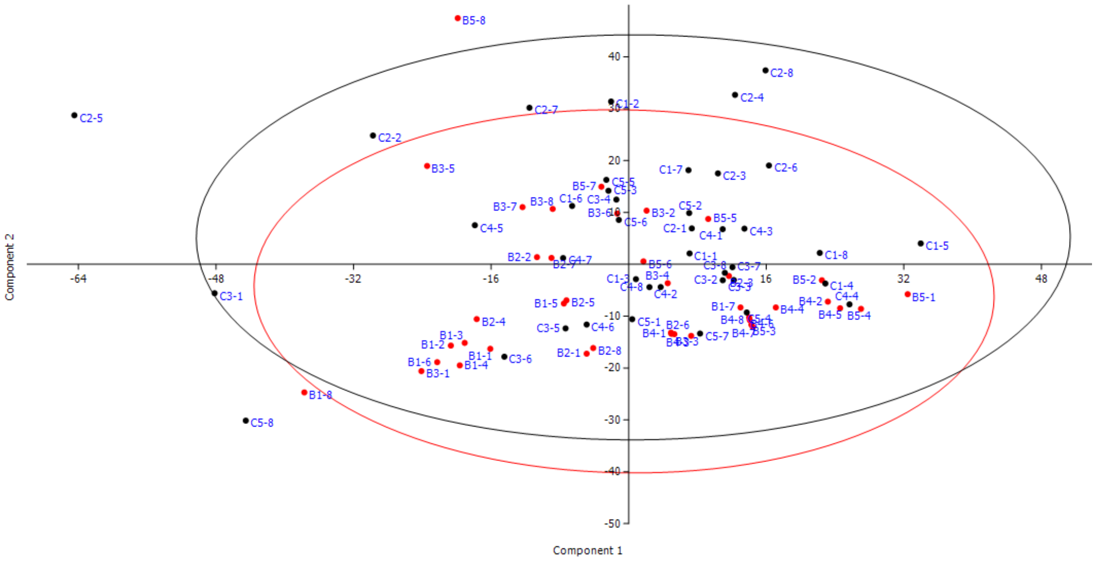

Figure 3. Principal Component Analysis of sampled 80 plots in burned (red) and control (black)area.

The prescribed burning did not affect the understory floristic composition as showed in the Figure 3. The PCA obtained by the analysis of a data matrix (60 species x 80 relevès) does not show a clear separation of burned and control plots along the axis 1 and 2 (explaining35%of the total variability). The ellipses enclose 95% of the variability and are strongly overlapping.

Prescribed burning did not affect the understory plant biodiversity. The rarefaction curve of richness estimators and biodiversity for sample based data (40 burned plots and 40 control plots) showed a similar pattern of variation with a not significant distance. In fact, considering the 95% confidence limits, the curves are superimposed (Figure 4A). No changes were found also in species density as reported in Figure 4B that evidence the same values in the average species number in both treatments.

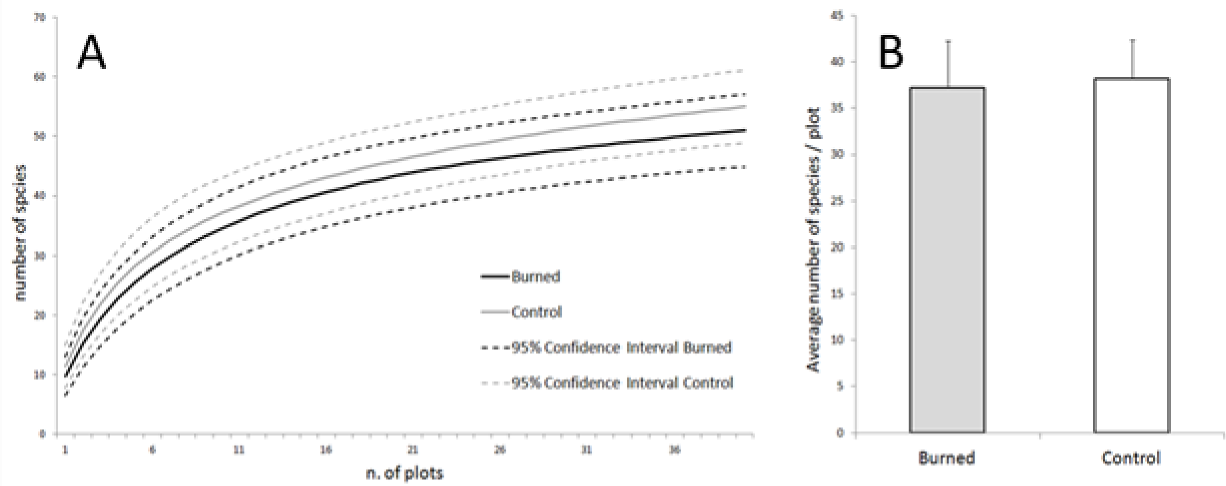

Figure 4. Rarefaction curve of species richness (A) and Average number of species/plot in burned and control area (B).

The analysis of the regeneration was carried out on all tree species present in both seedling and the sapling state. As showed in Table 2 the burning treatment produced a different effect in relation to life trait of species. In particular, *Erica arborea*, *Fraxinus ornus*, *Ilex aquifolium*, and *Sorbus torminalis* evidenced a significant increase of individual number in burned area while *S. domestica* show a decrease.

Table 3. Total number of individuals and average height of woody species in burned and control area. *For each species significant differences between burned and unburned are reported (n.s.= not significant; *= p<0,05; **= p<0,01; ***= p<0,001).*

	Number of individuals			Average height (±STD)		
Species	**Burned**	**Control**	**test X^2**	**Burned**	**Control**	**U test**
Acer campestre	17	13	n.s.	0.39 (±0.09)	0.65 (±0.34)	n.s.
Carpinus betulus	20	32	n.s.	0.99 (±0.29)	0.81 (±0.32)	n.s.
Carpinus orientalis	37	49	n.s.	0.51 (±0.23)	0.85 (±0.39)	***
Crataegus monogyna	25	27	n.s.	0.63 (±0.33)	0.56 (±0.23)	n.s.
Erica arborea	194	45	n.s.	0.62 (±0.22)	0.90 (±0.34)	***
Fraxinus ornus	304	169	***	0.46 (±0.16)	0.63 (±0.30)	***
Ilex aquifolium	65	20	***	0.58 (±0.26)	0.58 (±0.31)	n.s.
Quercus cerris	177	202	n.s.	0.43 (±0.24)	0.40 (±0.10)	**
Sorbus domestica	6	15	*	0.50 (±0.00)	0.47 (±0.12)	n.s.
Sorbus torminalis	27	7	***	0.51 (±0.16)	0.55 (±0.17)	n.s.

The ability to survive burning treatment with vegetative regrowth was found particularly interesting both in the structural species *Quercus cerris* but especially in some species of conservation interest as *Ruscus aculeatus* and *Ilex aquifolium*. These species responded to burning by resprouting from both the stem and the rhizome (Figure 5).

Figure 5. Regrowth after prescribed burning in Quercus cerris seedlings (right) and Ilex aquifolium (left).

3.3. Effects on soil

Results show that soil samples collected in control and burned plots did not affect soil water holding capacity or bulk density (Table 4).

Soil chemical and microbial properties determined at different times in burned and unburned plots showed that sampling time is the main factor affecting properties of soil compared to fire (Table 5, Figure 6). In fact, all parameters were significantly ($P<0.05$; two-way ANOVA) affected by sampling time, except for soil pH and total N, probably because of temporal variation of climatic conditions. By contrast, only nitric N appeared significantly ($P<0.05$; two-way ANOVA) affected by fire. It has to be underlined that accidental changes of some parameters (pH, water content and nitric N), observed only much time after prescribed fire (Table 5), did not appear due to fire treatment. It is not surprising that no effect on soil was found because litter surface temperature was higher than 100°C only for 114 seconds. Similarly, Tecimen and Sevgi (2011) found no effect on C or N fractions if soil from *Quercus* forests (*Q. petrea*, *Q. robur, Q. frainetto* and *Q. cerris*) was heated until to 100 °Cfor 1-4 h, whereas a loss of C content and an increase in ammoniacal N were observed at higher temperature.

Table 4. Mean values (±standard deviations) of water holding capacity and bulk density of soil determined in the first sampling (February 2011) in burned and unburned plots of Q. cerris stand.

Treatment	Water holding Capacity(%)	Bulk density (kg m^{-3})
Control	41.5 (±11.0)	0.94 (±0.2)
Burned	45.7 (±16.0)	0.95 (±0.2)

Table 5. Mean values (± standard deviations) of soil pH, water content, total N (N_{tot}), ammoniacal N (NH_4^+-N) and nitric N (NO_3^--N) in burned and unburned plots of Q. cerris stand at different sampling times. For each sampling date significant differences (one-way ANOVA) between burned and unburned are reported (* P<0.05: ** P<0.01).

Sampling date (times after fire) Treatment	**pH**	**Water content (% d.w.)**	**N_{tot} (µg g^{-1})**	**NH_4^+-N (µg g^{-1})**	**NO_3^--N (µg g^{-1})**
8/2/2011 (3 h)					
Control	5.5 (±0.5)	63.0 (±19.1)	6.1 (±1.8)	74.1 (±35.6)	2.1 (±1.2)
Burned	5.6 (±1.0)	63.5 (±9.4)	7.0 (±2.2)	68.1 (±30.8)	7.7 (±8.3)
10/3/2011 (30 d)					
Control	5.4 (±0.5)	73.5 (±18.8)	7.7 (±2.0)	52.0 (±34.8)	1.9 (±0.6)
Burned	5.6 (±0.6)	62.1 (±13.9)	5.7 (±1.7)	45.3 (±9.4)	2.6 (±1.4)
13/5/2011 (94 d)					
Control	5.7 (±0.5)	50.4 (±4.8)	5.7 (±1.0)	44.8 (±17.2)	1.8 (±1.9)
Burned	6.5 (±0.4)*	42.7 (±2.7)**	6.6 (±0.6)	45.1 (±13.0)	7.8 (±5.2)*
16/9/2011 (209 d)					
Control	6.1 (±0.9)	25.2 (±3.1)	6.7(±1.5)	8.1 (± 2.3)	0.2 (±0.2)
Burned	5.4 (±0.6)	27.3 (±8.0)	6.1 (±0.9)	9.0 (±3.5)	0.1 (±0.1)
8/03/2012 (394 d)					
Control	5.0 (±0.4)	59.1 (±9.1)	6.3 (±1.3)	21.1 (±8.5)	0
Burned	4.7 (±0.6)	44.9 (±11.0)**	4.7 (±1.4)	13.6 (±7.0)	0

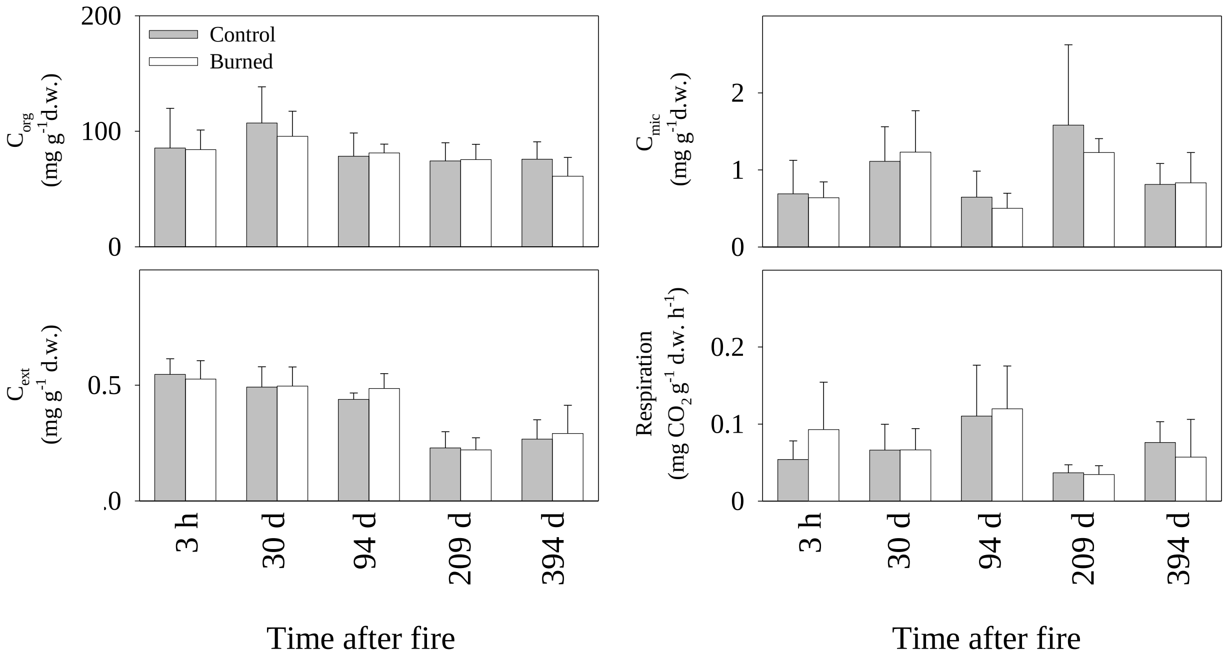

Figure 6. Mean values (+ standard deviations) of soil total organic C (C_{org}), extractable organic C (C_{ext}), microbial C (C_{mic}) and respirationin burned and unburned (control) plots.

4. **Conclusion**

In the studied Quercus cerris forest (*Lathyro digitati quercetum cerridis-subassociation festucetosum exaltata*) the prescribed burning application did not affect vegetation and soil during the two year after treatment. No significant changes occurred in floristic composition, species richness and density. The structural species Quercus cerris and some interesting protected taxa (*Ruscus aculeatus and Ilex aquifolium*) evidenced a high regeneration ability by regrowth of killed stem through resprouting new young shoot.
Moreover changes in soil chemical and microbial parameters due to fire were generally not significant and smaller than those occurring during the year, suggesting that fire-induced changes do not overcome the natural temporal variability of these parameters.
Our first results highlight the sustainability of prescribed burning in *Quercus cerris* forests as a management tool both in fire risk reduction and quercus cerris regeneration. Further monitoring activities should be continued to know the impact on all ecosystem components in the medium and long term and to evaluate the most appropriate burning prescriptions and time of frequency application.

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