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REGULAR PAPER

# Early post-fire plant succession in slash-pile prescribed burns of a sub-Mediterranean managed forest

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**Background and aims** – This is the first report on early vegetation dynamics in prescribed slash-pile burns under a sub-Mediterranean climate. We studied a managed forest system of *Pinus sylvestris* plantations in the upper belt of *Quercus pyrenaica* forests in the Guadarrama Mountains (Spanish Central System). We investigated post-fire plant succession in order to assess how fire affects tree regeneration and species composition (vascular plants, bryophytes and fungi) in the first three years.
**Methods** – Species composition, species cover, number of pine seedlings and ecological data were recorded in twenty slash-pile burnt plots and twenty control plots the first and second year after fire. To identify ecological indicators and examine post-fire succession, we determined Indicator Analysis and Neighbour Joining Tree, respectively. Wilcoxon's signed-ranks test and Spearman's coefficient of rank correlation were used to study the effects of fire on pine seedlings survival and its changes overtime. Principal Components Analysis was performed to assess the relationships between environmental and structural variables in burnt plots.
**Key results** – The early plant community established after slash-pile prescribed burns was characterized by three pioneer species: *Funaria hygrometrica* (moss), *Coltricia perennis* and *Psathyrella pennata* (fungi). No taxonomical changes were detected in vascular plant families but there was an increased presence of therophytes and pine seedlings. Two early vegetation stages were identified relating to species richness and *Funaria hygrometrica* cover. Fire significantly increased pine seedlings density, which subsequently decreased overtime. Survival of one-year old pine seedlings was unrelated to the year of the burn.
**Conclusions** – We highlight the importance of bryophyte and fungi species in comparison to seeder species as indicators of recent prescribed slash-pile burns under a sub-Mediterranean climate; and also point out the impact of prescribed slash-pile burns on pine seedling recruitment after the first years post-fire. This recruitment decelerates over time in burnt sites, and it is more pronounced in control plots.

**Key words** – Anthropic fire, Iberian Peninsula, permanent plots, *Pinus sylvestris*, post-fire succession, *Quercus pyrenaica*.

## INTRODUCTION

Anthropogenic disturbance on Earth is substantial and growing (Niemelä et al. 2000, Zalasiewicz et al. 2011). Human activities such as farming, forestry, land-use change and urbanization create patchworks of modified landscape affecting the vegetation in many different ways and at various levels (Wardle et al. 2011). Among human activities, fire is a major disturbance factor in many of the world's ecosystems, particularly in regions under a Mediterranean climate with seasonally dry conditions (Ojeda et al. 1996). One of the common forest management systems in Mediterranean countries is doing slash-pile prescribed burns (Pérez & Moreno 1998), which consists of cutting and burning tree branches, in small circular stands, in order to reduce fire risk, increase establishment of understory vegetation, control tree and shrub growth and to eliminate branches affected by insect pests (Haskins & Gehring 2004). This management is much extended in Spanish Central System. The piles are composed by branches of the most common trees or shrubs in the area such as *Quercus pyrenaica* Willd., *Pinus sylvestris* L. and in less extent *Fraxinus angustifolia* Vahl. and *Prunus spinosa* L. Plots of one to two square metres are burnt each spring at different sites before the dry season. The Peñalara Nature

Reserve where the study area is located provides appropriate legislation for conducting prescribed burns when necessary, after obtaining the permits. As an example, in our 50-ha study area, 1708 slash-pile burns were carried out in the last ten years, representing 0.6% of the total area, with a large number of marks remaining from old burns.

Fire is a disturbance which provides a good opportunity to study plant succession (Rice 1993, Mutch & Parsons 1998). The investigation of the factors that affect plant succession is critical to an understanding of future fire regimes in managed areas (Pérez & Moreno 1998). Moreover, vegetation dynamics in the early stages after fire can determine the structure and composition of the community in the future (Keeley & Keeley 1981, Valbuena et al. 2000). In extensive wildfires, above-ground vegetation structures in the understorey are usually killed and the risk of wildfire is closely related to land cover (Bajocco & Ricotta 2008). Since the high fuel loads and long duration of intense heat, slash-pile burns produces alterations to abiotic and biotic site conditions (Creech et al. 2012). However, there is little information on vegetation responses to focalized fires such as those created by slash-pile burns in Mediterranean area, which are characterized by high-intensity.

Sub-Mediterranean forests in Spanish siliceous mountains frequently consist of deciduous sub-Atlantic Pyrenean oak forests (*Quercus pyrenaica*) and evergreen sub-Mediterranean Scots pine forests (*Pinus sylvestris*) distributed along an altitudinal gradient. The change from one forest type to the other occurs from 1200 to 1400 m a.s.l. according to certain authors and is a controversial topic (Cañellas et al. 2000). Oak woods of *Quercus pyrenaica* are listed in the Habitat Directive (92/43/EEC), as a natural habitat type of European community interest for conservation (habitat code 9230). Regional representation of these forests consists of mostly young oak formations dedicated to pastures or mixed stands of planted Scots pines. *Pinus sylvestris* has been widely planted in the sub-Mediterranean areas in Spanish siliceous mountains due to its value for timber production, particularly in the upper altitudinal belt of the *Quercus pyrenaica* distribution. This management system is usually accompanied by slash-pile prescribed burns. Thus, these semi-natural forested areas offer a good scenario to study both the vegetation succession after prescribed burns and also the different early response to fire by the gymnosperm dominant tree species. Our hypotheses are that slash-pile prescribed burns influence vegetation dynamics and that in this management the obligate seeders are favoured (Abrahamson 1980). The main objective of this work is to investigate the relationships between past and current management regimes in the territory, where vegetation response is crucial to understanding the current plant landscape and the main environmental driving factors. This work aims to investigate early post-fire succession focusing on vascular plants, bryophytes and fungi, and on forest regeneration through tree recruitment.

## METHODS

The study area is located in Peñalara Natural Park (Rascafría, 1200 m a.s.l., 40°54'N 3°52'W, Madrid, central Spain). It corresponds to a semi-natural forest ecosystem of 50 ha in the foothills of the Sierra de Guadarrama (Spanish Central System), mainly consisting of patches of young *Quercus pyrenaica* mixed with stands of *Pinus sylvestris*. The area presents numerous burns as the consequence of slash-pile fires every year over the past decades. The area has a sub-Mediterranean climate with a summer drought period (Fernández-González 1991). Mean annual precipitation (P) is 1030 mm, and mean annual temperature (T) is 9.8ºC. Mean summer precipitation is 91 mm and mean summer temperature is 17.5ºC. Mean winter precipitation is 324 mm and mean winter temperature is 3.3ºC. In the study area, *Pinus sylvestris* trees reach an average height of 22 m and a dbh of 130 cm, whereas *Quercus pyrenaica* trees reach an average height of 7 m and a dbh of 23 cm (Castoldi & Molina 2012). Soils in the study area correspond to brown soils on silicate rocks (Guerra et al. 1966).

The following references were used for the nomenclature of species: Castroviejo et al. (1986–2002) and Tutin et al. (1964–1980) for tracheophytes; Casas et al. (2001) for moss; Bon (1988) for fungi; and Pignatti (1982) for Raunkiaer's life-forms.

Floristic composition and species cover were recorded in forty randomly located one-square-meter plots (fig. 1). In order to study plant succession in the first and second year after fire, twenty burnt plots (ten burnt in spring 2008 and ten burnt in spring 2009) were sampled and the percent cover was assigned for each species found in June 2010 and 2011, the most phenologically favourable period. With regard to the real time elapsed since the last fire, plots burned in 2008 were sampled two and three years after the burn, and plots burned in 2009 were sampled one and two year after. Twenty non-burnt plots close to the burnt ones were taken as a control and sampled to interpret the impact of the fire on the initial conditions. We recorded some environmental variables related to forest structure such as canopy cover, closest pine tree diameter at breast height (dbh), number of pine trees in a 15 m radius, distance from principal pine tree, number of pine cones and oak litter cover. In burnt plots we also recorded the burnt remains of plant matter, namely here charcoal, as a surrogate of fuel amount and burning duration. Species richness was determined as the number of species per plot. *Pinus* seedlings were counted in 2010 in order to monitor their survival in the first three years after the fire.

Indicator species analysis (Dufrêne & Legendre 1997) was used to identify species as ecological indicators of environmental changes; in this case to calculate plant species fidelity to burnt locations (PC-ORD 4 software, McCune & Mefford 1999.). Neighbour joining tree was determined on the squared Euclidean distance computed between the quadrats to examine floristic post-fire succession (Syntax 2000 software, Podani 2001). Squared Euclidean Distance is a dissimilarity index strongly sensitive to dominant species (van Tongeren 1995). A completely empty quadrat corresponding to the precolonization stage (i.e. no plant cover) was used as outgroup to root the tree diagram. The sample plots were investigated synchronically in 2010 in order to study the presence of taxa in twenty burnt plots for two consecutive years (2008, 2009) and in twenty unburnt plots, thus yielding a total of forty objects. Additive trees have been successfully used to investigate post-fire successional processes in *Pinus*


**Figure 1** – Examples of the slash-pile prescribed burns studied in mixed *Quercus pyrenaica* patches and *Pinus sylvestris* stands of Central Spain: A, canopy layer; B, recently burnt; C, burnt and control plot samples; D, grid used in sampling plots.

plantations (Podani et al. 2000). Wilcoxon's signed-ranks test and Spearman's coefficient of rank correlation were used to estimate the effects of fire on pine seedlings survival and their changes during the first three years after fire (SAS 9.2, SAS Institute Inc. 2008). Since our design consisted of paired plots (one burnt plot and one control plot) we performed our statistical analyses taking into account samples nested in site (ten sites per year). Environmental and structural affinities of burnt plots were assessed by proximity in a multivariate space defined by components extracted from a principal components analysis (species-centred PCA, CANOCO software, ter Braak & Šmilauer 2002).

## RESULTS

### Species indicators

Sixty-seven taxa were identified in the plots. Forty-one species occurred in both burnt and unburnt situations. Fifteen species were exclusively found in burnt plots and eleven in control plots. Most of the species sampled in unburnt plots correspond to herbaceous perennial plants, including characteristic species of meadows (*Arrhenatherum elatius* subsp. *bulbosum* and *Ranunculus bulbosus* subsp. *aleae*), grasslands (*Jasione montana* and *Luzula campestris*), wood fringes (*Filipendula vulgaris*) and understorey deciduous forests of Querco-Fagetea (*Hedera helix* and *Stachys officinalis*). It was also worth noting the occurrence of certain nanophanerophytes such as *Crataegus monogyna*, *Rosa canina* and *Rubus* sp. Fifteen species were found only in burnt sites, of which two are fungi (*Coltricia perennis* and *Psathyrella pennata*) and one is moss (*Funaria hygrometrica*). The rest correspond to vascular species characteristic of wood fringes (*Galium aparine* and *Vicia tenuifolia*), grasslands (e.g. *Senecio jacobaea*, *Trifolium repens* and *Trifolium campestre*), and weeds (*Veronica arvensis*). Indicator species analysis identified one bryophyte and two fungi as characteristic species of post-fire situations: *Funaria hygrometrica*, *Psathyrella pennata* and *Coltricia perennis* (table 1).

**Table 1** – **Indicator species analysis results.**
Relative frequency (%) and Indicator values of the three pioneer species of post-fire slash-pile burnt and unbrunt plots conditions in a Submediterranean forest ecosystem. Values are referred to ten plots established in each treatment. Indicator values of taxa identified by indicator species analysis as being significant indicator species are shown in the last column. * $p < 0.05$; *** $p < 0.001$.

| Species | Burn plots | | Unburnt plots | Indicator Values |
|---|---|---|---|---|
| | 2008 | 2009 | | |
| *Coltricia perennis* | 27 | 78*** | - | 58.2*** |
| *Funaria hygrometrica* | 91*** | 78 | - | 49.0*** |
| *Psathyrella pennata* | 36* | 11 | - | 28.7* |

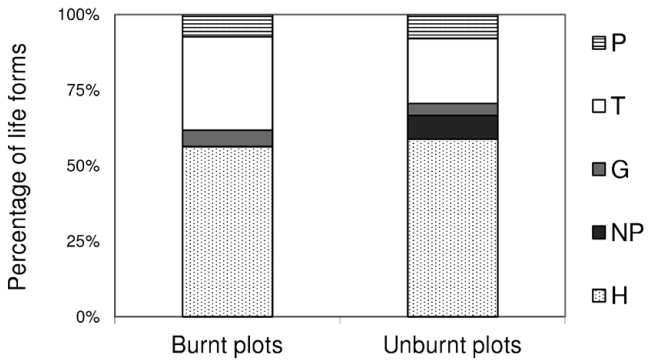


**Figure 2** – Raunkiaer's life-forms spectra in burnt and control plots. H, Hemicryptophytes; NP, Nanophanerophytes; G, Geophytes; T, Therophytes; P, Phanerophytes.

Mean species richness is higher in control sites (11 ± 2.8 SD) than in burnt sites (8 ± 3.3 SD). No taxonomic changes were found between burnt and control plots for the best represented families of vascular species, namely Fabaceae and Poaceae in both cases. However, a marked decrease in species was found for Rosaceae in burnt plots (electronic appendix). The results also showed that burnt sites included a higher proportion of therophytes and lack of nanophanerophytes in comparison with unburnt sites (fig. 2). Nevertheless, hemicryptophytes were the dominant growth forms in both situations.

**Post-fire succession**

Our results show that in the first year after fire, mean (± SD) species richness is 6.9 ± 2.3 and in the second year increases to 8.8 ± 2.8. Neighbour joining tree shows a close-to-origin cluster corresponding to a first stage post-fire condition, mainly including first-year post-fire plots with lower species richness and a lower occurrence of the moss *Funaria hygrometrica* (fig. 3). A second stage post-fire condition (Group A) can be distinguished by both first- and second-year post-fire plots with intermediate species richness and the constant presence of *Funaria hygrometrica*. This group A is close to the cluster containing most control plots (Group B) which in its turn has the higher species richness (*t*-test mean A = 8.8, mean B = 6.9, $p = 0.0125$). Electronic appendix shows frequency and mean absolute cover of the 65 most frequent species in burnt and control plots.

Fire significantly increases pine seedlings density ($p < 0.0001$, table 2). A significant positive correlation was noted between the closest pine tree dbh and the number of cones in burnt plots (Spearman's rho = 0.73, $p < 0.05$). Additionally, a significant decrease was also observed in pine seedling density over time ($p < 0.0001$, table 2), and this reduction was greater in control plots than in burnt situations ($p < 0.005$, table 2). PCA shows that the year of the burnt is unrelated to the one-year survival percentage of pine seedlings. The year of the burnt it is positively related to soil charcoal content and negatively related to oak litter. Pine seedling density is positively related to oak litter and negatively to charcoal (fig. 4).

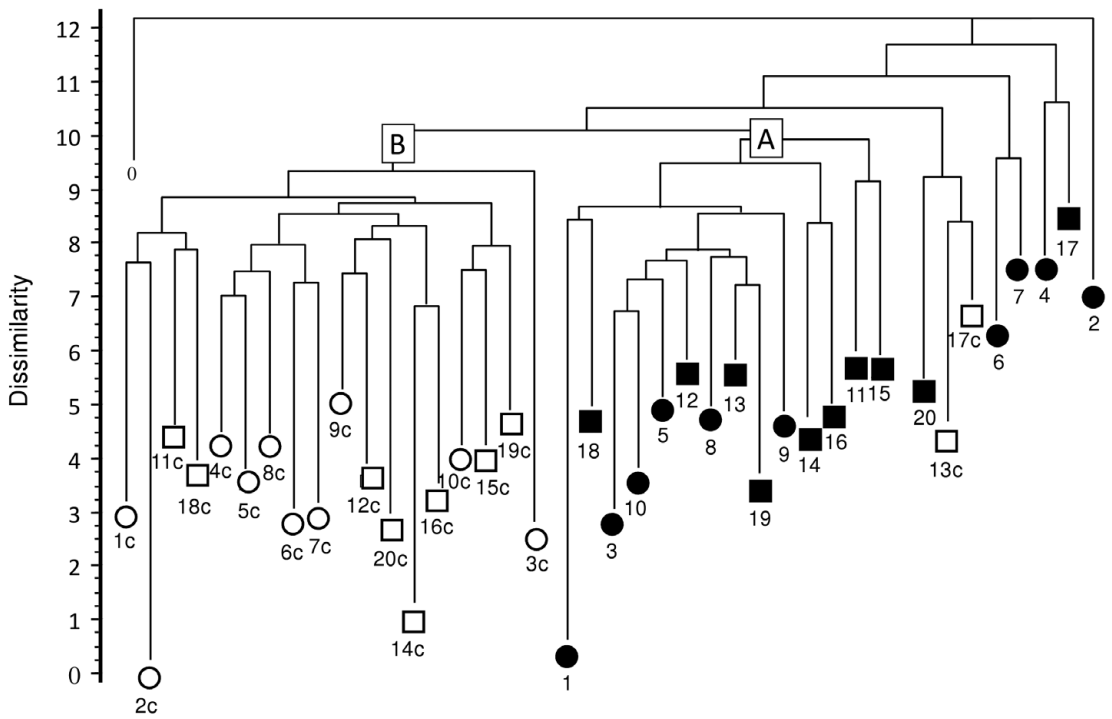


**Figure 3** – Neighbour joining tree for the post-fire succession data. Sites consist of twenty burnt and twenty unburnt (control) plots, the latter follow by C. Dark circles represent plots sampled 2 years post-fire, and dark squares are plots sampled 1 year post-fire. Empty symbols are control plots. 0 is the outgroup without vegetation used to root the tree.

**Table 2** – **Comparison between burnt and unburnt sites**.
The plots were compared taking into account pine seedlings, pine cones, oak cover litter and pine seedling establishment over time. Plots were sampled in 2010 (10) and 2011 (11). * $p < 0.005$; ** $p < 0.0001$.

| | N | Mean | Standard deviation | Minimum | Median | Maximum |
|---|---|---|---|---|---|---|
| Burnt plots | | | | | | |
| Pine seedlings 10 | 20 | 149.40 | 67.50 | 60.00 | 124.00 | 298.00 |
| Pine cones 10 | 20 | 7.20 | 12.19 | 0.00 | 2.00 | 48.00 |
| Oak litter cover 10 | 20 | 4.90 | 2.17 | 2.00 | 5.00 | 9.00 |
| Pine seedlings 11 | 20 | 93.10 | 49.11 | 33.00 | 81.00 | 201.00 |
| percentage change of pine seedlings 10-11 | 20 | -35.90** | 22.15 | -65.83 | -36.72 | 0.00 |
| Unburnt plots | | | | | | |
| Pine seedlings 10 | 20 | 38.05 | 33.93 | 0.00 | 31.00 | 149.00 |
| Pine cones 10 | 20 | 17.50 | 31.22 | 0.00 | 1.00 | 118.00 |
| Oak litter cover 10 | 20 | 7.00 | 2.55 | 0.00 | 8.00 | 9.00 |
| Pine seedlings 11 | 20 | 14.70 | 17.24 | 0.00 | 10.00 | 67.00 |
| percentage change of pine seedlings 10-11 | 19 | -64.63* | 31.73 | -100.0 | -73.24 | 25.00 |
| Comparison of the percentage change of pine seedlings 10-11 between unburnt and burnt plots | 19 | 27.72 | 30.81 | -43.10 | 34.81 | 82.03 |

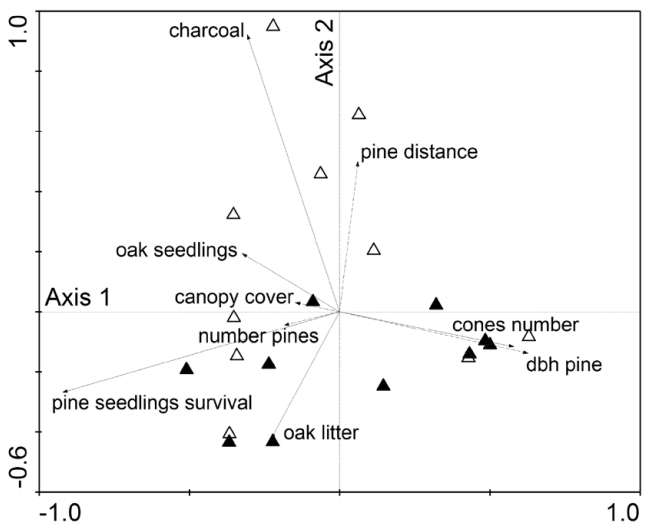


**Figure 4** – Principal Components Analysis (PCA) plot of the variables studied. First and second principal components (PC1 and PC2) explain 47.1% and 24.3% of the total variance respectively. Vector variables abbreviations correspond as follows: charcoal (burnt remains of plant matter), cones number (number of pine cones), dbh pine (dbh of the nearest pine), distance pine (distance from principal pine tree), number pines (number of pine trees in a 15 m radius), pine seedlings survival (one-year survival percentage of pine seedlings), oak litter (oak litter cover). Empty triangles represent plots burnt in 2008, and dark triangles are plots burnt in 2009. Structural variables are represented with a continuous line and environmental variables with dashed line in the biplot.

## DISCUSSION

Our results point out the importance of spore species in comparison to seeder species as indicators of recent slash-pile prescribed burns under a sub-Mediterranean climate. The three taxa revealed here as characteristic species, *Funaria hygrometrica*, *Psathyrella pennata* and *Coltricia perennis*, are known as colonizers of post-fire soils under different extra-tropical climates (Visser 1995, Baar 1996). In post-fire situations, mosses can act as the first colonizers, soon forming a dense layer which locally favours the establishment of new species (Bradbury 2006). Specifically, the moss *Funaria hygrometrica* is related to temporally unstable sites, particularly charred surfaces (Delasheras et al. 1994, Esposito et al. 2009), and prepares the ground for a subsequent colonization of vascular plants, as well as counteracting erosion in the early post-fire stages. However post-fire vascular species content closely resembles the initial floristic composition (Purdie & Slatyer 1976) which in the case of our study mainly consists of plants from the surrounding vegetation such as grasslands and wood fringes.

Germination response after fire is not randomly distributed across life-forms, and the type of germination behaviour is related to certain growth forms (Keeley & Bond 1997). In post-fire conditions, annual species are predominantly triggered by chemicals from smoke and/or charred wood (Keeley et al. 2005). This fact explains why therophytes can be an important component in the early stages of post-fire succession, playing an important role in preventing loss of nutrients from the soil (Kazanis & Arianoutsou 1996, Pérez &

Moreno 1998, Guo 2001). However, fire relatively influences the diversity patterns of growth forms (Lloret & Vilà 2003). Our results show that although therophytes are favoured after prescribed burns, hemicryptophytes remain dominant; these are also the dominant growth forms in the surrounding plant landscape.

The results found for changes in species richness after fire over time vary according to different authors. Some report an increase in substrate stability and species richness as a result of the gradual development of the vascular plant cover (Foster 1985, Podani et al. 2000). Others indicate a decrease after fire, which can be attributed to the increased cover of matrix species resulting from enhanced productivity (De Grandpré et al. 1993). It is worth noting that the diversity peak in the immediate post-fire year (or two) appears to be driven by factors different from those in subsequent diversity peaks (Keeley et al. 2005). In slash-pile prescribed burns, we found two plant-succession steps throughout the two first years post-fire. They are characterized by an increase in species richness, and specifically an increase in the cover of two characteristic species, *Funaria hygrometrica* and *Coltricia perennis*. Further investigations into these patterns are required in order to determine how long these characteristic species remain.

The contrasting growth of *Pinus sylvestris* and *Quercus pyrenaica* seedlings can be explained by the fact that cone pines have orthodox seeds which can survive after a desiccation period, while acorns have recalcitrant seeds (Pammentera & Berjaka 1999). High germination of pines after fire has also been attributed to the opening of pinecones and the preparation of an appropriate seedbed (Trabaud 1987, Núñez & Calvo 2000). Our results indicate the importance of slash-pile prescribed burns in pine seedling recruitment after the first years post-fire. However, the expectation of pine seedling establishment decelerates over time in burnt sites, although to a lesser extent than under the unburnt understory. The fact that the year of the burn it is positively related to soil charcoal content and negatively related to oak litter is probably fortuitous. The pine seedlings are positively related to oak litter and negatively to charcoal.

Thus, the current management of *Quercus pyrenaica* forests including plantations of *Pinus sylvestris* and slash-pile prescribed burns implies ecological niches where plant succession can be studied. A massive germination of sexual pine diaspores is followed by a later decline in pine seedling establishment over time. This declining it also occurs but is more pronounced in control plots.

## SUPPLEMENTARY DATA

Supplementary data are available in pdf format at *Plant Ecology and Evolution*, Supplementary Data Site (http://www.ingentaconnect.com/content/botbel/plecevo/supp-data), and consist of a table with the frequency (Frq) and mean absolute cover (Mean) of the 65 most frequent species in burnt and control (unburnt) plots.

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