Universidade de Aveiro
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IMPACTOS DO FOGO CONTROLADO NA VEGETAÇÃO E MACROFAUNA EDÁFICA DE UMA ÁREA FLORESTAL

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Ecologia aplicada, realizada sob a orientação científica do Doutor Paulo Silveira, Professor Auxiliar do Departamento de Biologia da Universidade de Aveiro e coorientação do Doutor Nelson Abrantes Investigador Auxiliar do CESAM.

Dedico este trabalho ao meu pai por ter juntamente com a minha mãe provido a minha educação e por todo o apoio que me têm dado, mesmo tão longe.

o júri

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palavras-chave Macrofauna do solo, Flora, Solos, conservação da natureza

resumo

O fogo controlado é geralmente usado como uma ferramenta de gestão de terra para melhorar e manter habitats e para mitigar riscos de incêndios florestais. No entanto, seu papel benéfico / prejudicial na estrutura da floresta e as consequências para a biota da floresta não são consensuais. Assim, este estudo teve como objetivo avaliar o impacto do fogo controlado na flora e nas comunidades edáficas e compreender sua evolução desde a ocorrência do fogo. Este estudo foi realizado no Baldio de Carvalhais, uma propriedade privada administrada pela associação Montis, dividida em quatro subáreas: três áreas geridas com fogo controlado (há 4 meses, 1 e 2 anos); e uma quarta que não foi queimada recentemente. Os dados coletados em cada subárea incluíram o pH do solo, a condutividade elétrica (CE) e a matéria orgânica (MO), assim como a composição e estrutura da flora e da macrofauna edáfica. Os resultados mostraram valores mais baixos de MO e valores de pH ligeiramente mais baixos nas subáreas que queimaram mais recentemente. A CE apresentou apenas valores mais baixos na subárea queimada recentemente. Em relação à vegetação, este estudo destaca o papel do fogo prescrito na promoção de sua diversidade, abundância, riqueza de espécies e uniformidade das plantas. Além disso, o uso da engenharia natural parece ter contribuído para um aumento na abundância e diversidade da flora em uma das subáreas. Em uma tendência oposta, a macrofauna edáfica diminui sua riqueza e uniformidade devido ao fogo. Este estudo também revelou que, com o tempo decorrido desde a ocorrência do incêndio, a flora e a macrofauna edáfica nas subáreas queimadas estão se recuperando e se aproximando da área não queimada. No entanto, mais estudos temporais e mais parâmetros do solo são necessários para uma melhor compreensão dos impactos do fogo controlado nas funções do ecossistema e em seus serviços.

keywords Soil macrofauna, flora, solis, nature conservation

abstract Prescribed fire is commonly used as a land management tool to enhance and maintain habitats and to mitigate wildfire risk. However, their beneficial/detrimental role in forest structure and the consequences for forest-dwelling biota is not consensual. Hence, this study aimed to assess the impact of prescribed fire in the flora and in the edaphic communities, and to understand their evolution since the fire occurrence. This study was conducted in Baldio de Carvalhais, a private land managed by the Montis association, which was divided in four sub-areas: three areas that were managed with prescribed fire (4 months, 1 and 2 years ago); and one fourth that was not burnt recently. The data collected in each sub-area included the soil pH, electrical conductivity (EC) and organic matter (OM), as well as the composition and structure of the flora and the edaphic macrofauna. The results showed lower OM values and slightly lower pH values in the sub-areas that burnt more recently. The EC only presented lower values in the sub-area burnt recently. Regarding the vegetation, this study highlights the role of prescribed fire in promoting their diversity, the abundance, species richness and evenness of the plants. Also, the use of natural engineering seems to have contributed to an increase in abundance and diversity of the flora in one of the sub-areas. In an opposite trend, the edaphic macrofauna decrease in their richness and evenness due to the fire. This study also revealed that with the time since the fire occurrence, the flora and edaphic macrofauna in the burnt sub-areas are recovering and approaching the unburned area. Nevertheless, more temporal studies and more soil parameters are required to better insight into the impacts of prescribed burning in the ecosystem functions and their services.

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INTRODUCTION

Forests are ecosystems that occur in several places with different ecological, climatic, geographical and socioeconomic conditions. They cover an area of 177 million hectares corresponding to 42% of the land area of Europe (Commision, 2016). In Portugal the forests comprise 5.69 million of hectares, that is, 64% of the Portuguese territory IFN (2005/06 in Dias et al., 2013). These ecosystems are part of different vegetation zones in EU and have a large value of species richness (Commision, 2016). The contrary of what happens with the forests of central and northern Europe the Mediterranean have more degree of endemism and biodiversity summing almost the half of the listed plant and animal species of the Habitats Directive. There are 100 plants species in the Mediterranean forests and this number is bigger than all the other European biogeographical regions together (Sundseth, 2010).

One of the most important structure to maintain the life on the planet is the soil, especially because a large part of the ecological interactions happens there. The differentiation between forest soils is really correlated with the plant cover above it, because they support a crucial influence on many processes of soil formation. Some of these processes are related to the growth of tree roots and its consequently breaking up of the bedrock and together with the fallen leaves help to increase the soil organic matter content, both can protect the soil from the erosion (Commision, 2016).

The joint study of the physicochemical and microbiological parameters are good soil quality indicators for the soils in Mediterranean forests (Andrés-Abellán *et al.*, 2019), because according with Bennett (2010) the soil community, plant diversity and the soil physicochemical parameters have a strong feedback loop that influence both diversities. Notwithstanding, there are some differences between all the types of soil in the diversity and abundance values caused by the variation in the soil physicochemical parameters (pH, organic matter and soil texture) and in the land management. It is possible to see these differences by groups in a temperate grassland soil in the table below (Commision, 2016).

Accordingly, with Leão *et al.* (2008) for the development of plants in a given ecosystem it is necessary to have soils with good concentration of nutrients and microbiological fauna activity. These ones are called as "ecosystem engineers" and are vital in the recovery of degraded areas improving the soil´s physicochemical parameters (Lavelle et al., 2006; Kampichler and Bruckner, 2009; Garcia-Palacios et al., 2013 in (Glecio *et al.*, 2016) (Filho, 2010).

Cantanozzi (2011) in a study about the importance of ecological aspects of the soil macrofauna, affirms that areas with high conservation had bigger values of taxonomic richness and densities of soil macrofauna. The comprehension of the role of the soil organisms in the soil is very important specially in ecosystems that are susceptible to constant fires (Abrantes, 2016).

Córdova, *et al.* (2014) concludes that it is impossible to separate the soil from its living organisms and its richness can be used as a good indicator of the quality of the ecosystem specially because they can act in many transformation process like in the organic matter. Their taxonomic richness can also be correlated with other parameters like the species richness, coverage, height and aboveground biomass of plants (Wu, *et al.*, 2015). Therefore, when analysing the biodiversity in the soil these indexes can reach even bigger levels (Commision, 2016).There are many strategies in the forest management to prevent the local ecosystem degradation that can be divided between forest planning, preventive forestry, prescribed fire (ex-ante strategies), mulching, ecosystem restoration, channel treatment, hillslope barriers and seedling (ex-post techniques). Currently, the forest wildfires are the most harmful traits in the Mediterranean zones (Ferreira *et al.*, 2015). Annually, around 50.000 fires clear 700.000 to 1 million hectares of Mediterranean forest (FAO, 2006).

The climate in the Mediterranean basin is a determinant key to the forest fires. Long summers with high temperatures without rain are responsible to reduce the moisture content of the forest litter leading to a condition where anything (Cigarettes, lightning) can start a wildfire (FAO, 2006).

The factor that most influence the fire effect on the fauna is the regime of fire. It can be classified according with its speed of propagation, intensity, heterogeneity, by the season of occurrence, extension, frequency and shape, among others. Therefore, the frequency is one of the most important characteristics of a fire, because it can change the plant cover and consequently the fauna communities in a permanent way (Ferreira *et al.*, 2010). According with Abrantes (2016) there are two types of fire effects on the soil organisms, one more direct that causes the death or wounds and other indirect more related to changing in the habitat leading to shifting on the ecological processes such as the immigration, competition, starvation and predation, evolutionary variations may also occur on the adaptations of fire over time.

Also, the fire intensity affects decisively the structure of soil macrofauna communities and depending of the wildfire intensity, it can cleanse the soil surfaces (Commision, 2016). According with Abrantes (2016) intrinsic characteristics of each soil fauna group and abiotic parameters like the plant recovery, weather conditions, seasonality, fire regularity, fire austerity, uniformity and closeness to unburnt areas are preponderant factors to the after fire recovery.

In the case of the flora, the fire can act differently in different areas, or, within different fires. Although, a lot of characteristics will affect the response of the plants after a fire among them are: Plant characteristics (species, vegetative vigour, age), factors inherent to the fire (season, intensity, duration) and geographical characteristics (climate, soil, topography) (Ferreira *et al.*, 2010).

Corroborating with Ferreira et al., (2015), who conclude that the strategies and techniques of management have to be fast implemented, if possible, before the beginning of the rainfall season because many of the organic matter, ash and nutrients in the burned areas can be leached in first rainfall events. Elia *et al.* (2012) mentioned that the most important part after a fire is the management in the burnt area especially in the Mediterranean ecosystem, because these authors advocate that the plant cover indirectly influences the insects' community.

In the Mediterranean region many countries tried to reduce the fuel load through the use of prescribed fire. It can be used as a preventive tool because it can decrease the source of fire, but also to recover and to conserve the ecosystems (FAO, 2006). The main reason to the forest management is to conserve the integrity of the forests creating heterogenous habitat patches in areas with distinct ecological succession (Elia *et al.*, 2012). Even yet, they alter the environment and it is necessary to understand more about the effects on the vegetation, macrofauna and in the soil's physicochemical parameters of the areas managed with the prescribed fire (Commission, 2016).

Abrantes (2016) affirms that altough this theme have been studied in the last years, especially on the effects of specific faunal groups, there are gaps that have to be filled related to the consequences of the fire in these communities and in the ecosystem functions over the time. The prescribed fire has positive and negative effects, one of the positive effects of the prescribed fire is that some plants need it to regenerate. Therefore, the constant advance of the urban zones together with less information about its positive effects leads the population and the politicians to be aware and positioned against the prescribed fires (FAO, 2006).

Therefore, the aim of this work is to know more about the effects in the soil macro fauna's community, vegetation cover and in the physicochemical parameters of the soil of land management using controlled fire. We aimed with this study to (i) understand the impact of the fire in the flora composition and distribution, (ii) understand the impact of the fire on the biodiversity of the edaphic community (iii) and to know more the response of the flora and fauna in the middle time after-fire (10, 2, 1 years and 4 months after fire)

METODOLOGY

Study area

This study was conducted in Baldio de Carvalhais, one of the private lands managed by the Montis association for nature conservation (Figure 1). It is located in the South part of the Arada's hill in the União de Freguesias de Carvalhais e Candal, near the city of São Pedro do Sul, in Portugal (40º48'30,51''N; 8º07'29,15''O). The land occupies an area of 100 ha as is situated at an altitude between 620 to 720 m. The forest management in this area is based on the controlled fire technic applied during the wert season

Experimental design

The selected land was divided into five subareas (Figure 2): three areas delimited in red (B1, B2 and B3), which were managed with controlled fire; and one that was not burnt, used as reference (UP). The subareas managed by controlled fire were selected taking into account the year they burnt: three months ago (B1); one year ago (B2) and two years ago (B3) (Table 2).

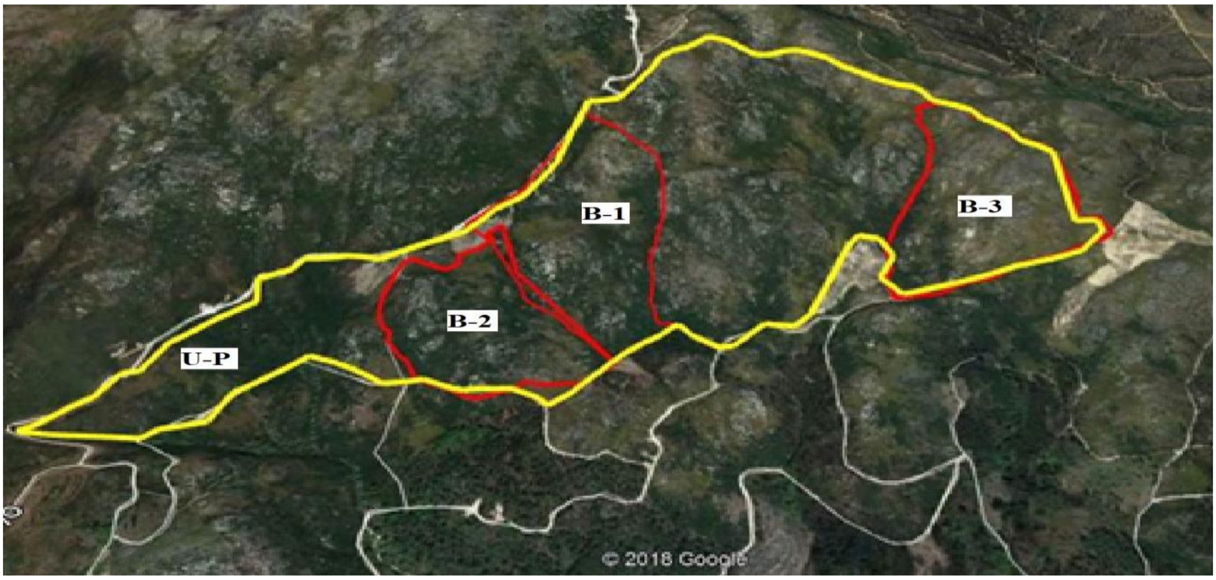

Figure 1*: Map of the study area in Baldio de Carvalhais. Yellow was used for the delimitation of the Montis area, and red for the areas managed with controlled fire B1 burnt 1 3 months ago, B2 burnt 1 year ago and B3 burnt 2 years ago. UP unburnt subarea.*

Table 1: Abbreviations of the different subareas managed with controlled fire and time since fire.

Time since fire	Abreviations
Burnt in March 2017	B3
Burnt in February 2018	B2
Burnt 1 January 2019	B1
Unburnt Pinus (summer of 2010)	UP

The areas and perimeters of the managed lands used in this study were measured with the help of Google Earth Pro and are resumed in table 3.

Table 2: Total perimeter and area of each of the subareas managed with controlled fire.

Managed Land	Perimeter (m)	Area (ha)
B3	1974	18
B2	1290	8,75
B1	1707	14,6
UP	1955	12,4

In each of the four subareas, 3 experimental plots were selected, which totalizes 12 plots in the study area. The plot setup took place in March 22, 2019.The burnt plots consisted of quadrats with an area of 0.0025 ha, and the unburnt area, due to the presence of larger sized plants, namely pine trees, consisted of 0.01 ha. Plots were delimited with coloured ribbons to better identify the areas during sampling. All plots were georeferenced with the support of the View Ranger (Augmentra Ltd., Cambridge, UK) application as shown in the table 4.

Table 3: Geographical coordinates of the experimental plots in the four different subareas in Baldio de Carvalhais.

Plots	Coordinates
P1-3 A	29T 574381E 4517815N
P2-3 A	29T 574468E 4517806N
P3-3 A	29T 574384E 4517802N
P1-2 A	29T 573243E 4517515N
P2-2 A	29T 573443E 4517589N

P3-2 A	29T 573443E 4517588N
P1-1 A	29T 573443E 4517588N
P2-1 A	29T 573522E 4517681N
P3-1 A	29T 573555E 4517521N
P1-P	29T 573230E 4517282N
P2-P	29T 573261E 4517328N
P3-P	29T 573261E 4517288N

Characterization of habitat conditions

Biogeographically, the area is located in the Eurosiberian region more specifically in the Miniense Litoral superdistrict (Figure 2). The Eurosiberian region is characterized by zero or very mild summer aridity, never exceeding two dry months. The summer precipitation compensates the evapotranspiration avoiding the depletion of water reserves in general. The landscape is dominated by gorse and heath/gorse, which result from the degradation of the *Quercus robur* oak forests. In the Miniense Litoral superdistrict a correlation between the distribution of *Ulex europaeus* subsp. *latebracteatus* and of *Ulex micranthus* with the respective communities exists, that define this superdistrict. In the innermost part of the Superdistrict, except the most carved valleys, those two *Ulex* species are replaced by *Ulex europaeus* subsp. *europaeus* integrated in two associations with big areas of occupation: the *Ulici europaei-Ericetum cinereae* and the *Ulici europaei-Cytisetum striati* (Costa *et al.*, 1998).

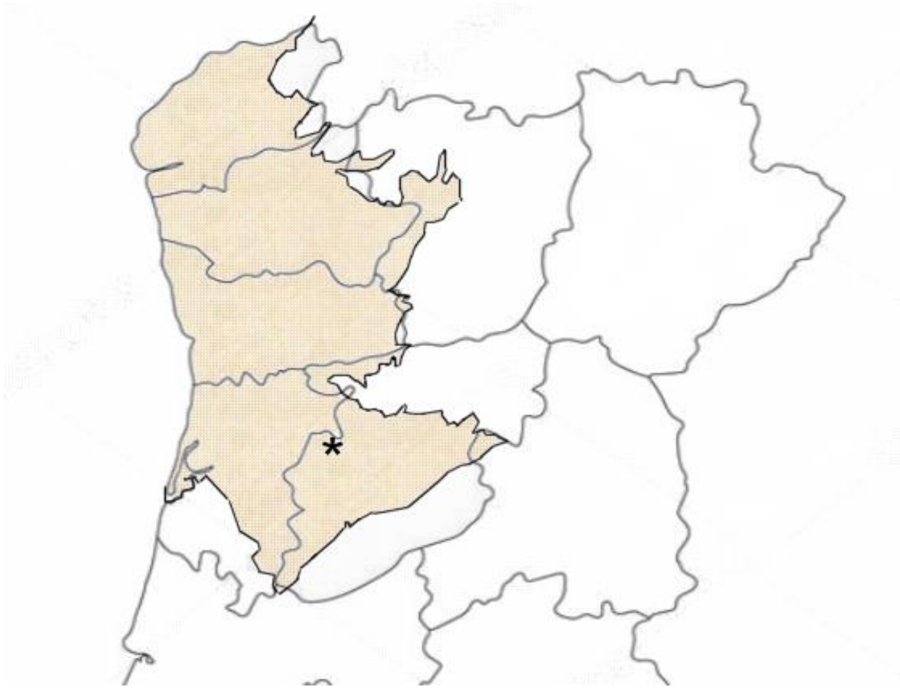

Figure 2: Localization of the Baldio de Carvalhais (*) in the biogeographic superdistrict Miniense litoral (shaded area) in Portugal.

The managed areas in this study were located in different habitat patches as illustrated in the figures 3 to 6. The unburnt area had a community of *Pinus pinaster* and the soil was covered almost completely by plants, with few incidences of stones (Figure 3). The B1 subarea, before the fire had a community of *Pterospartum tridentatum*, and it was the most recent area managed with controlled fire. Therefore, the soil was free of plant cover, being covered only by the stones and by dead plants (Figure 4). The B2 subarea, such as the B1 and B3 subarea had a community of *Pterospartum tridentatum.* In this case the plant cover was denser, although the soil continued to be bare and with occurrence of stones. This area had some particularities because in this locality another management technic, besides controlled fire, was applied, which was natural engineering. The natural engineering consisted in a contention with dead wood and stones to accumulate soil, sediments and to do waterlines inside the area (Figure 5). The B3 subarea was placed on the hillside in a stone ground where the soil had a good plant coverage (Figure 6).

Figure 3: Unburnt subarea UP.

Figure 4: Subarea recently burnt (B1).

Figure 5: Burnt subarea one year ago (B2).

Figure 6: Burnt subarea two years ago (B3).

Collection and taxonomic identification

Vegetation

The collection of vegetation data took place between April 03 to April 22, 2019. The information collected was plant identification, percent cover, frequency, height and diameter at the breast height (DBH). The percent cover was obtained visually and for each species seen in the plot. Whenever possible, the plants were identified directly in the field. When this was not possible, photos were taken (Figure 4) and one individual was collected and press-dried on a wood press for a better analysis at the University of Aveiro's herbarium.

Individuals were counted species by species, and frequency values were noted in a field notebook. A measuring tape was used for height and diameter at the breast height measurements. The height was measured from the ground base to the highest part of the plants. The diameter at breast height was measured at 1.5 m. These parameters were compiled into Microsoft Excel spreadsheets for subsequent calculations of Relative Coverage, Relative Height, Height Average, Relative Diameter, Mean Diameter, Absolute Density, Relative Density, absolute frequency, relative frequency, Importance Value (IV), Shanon-Wiener (H) and Pielou (J). Abbreviations of the collected plant and macrofauna can be seem in the table 4 and 5 below in the results.

Ground-dwelling arthropods

The soil macrofauna sampling was based on the pitfall technique, with 4 units per plot, totalizing 48 pitfalls in the entire study area (Figure 5). The traps consisted of 1.5 L commercial drinking water bottles with a diameter of 8.5 cm that were cut-open at a height of 12 cm. At the start of the sampling period, the traps were filled with a small portion of a 70% ethanol solution, to which a few drops of glycerine and a drop of detergent were added as preserving agents and for breaking the ionic tension at the top of the solution to ensure that trapped invertebrates would remain trapped. The solutions with the trapped invertebrates were collected, and stored temporarily in vials with a 70 % ethanol solution and some drops of glycerine until laboratory processing (Puga et al., 2017).

Figure 7: Pitfalls in the field with rocks to protect against the rain and soil input.

They were implanted on May 3, 2019 and were removed 10 days later on May 13, 2019. Each pitfall content was transferred to 50ml plastic vessels with 70% alcohol. At the laboratory, specimens were identified under a stereoscopic magnifier to the taxonomic rank of family, using standard taxonomic keys (Harde & Severa, 1984; Goulet & Huber, 1993; Roberts, 1995; Barrientos, 1998; Czechowski et al., 2002; Puga *et al.*, 2017).

Physicochemical parameters

Soil was collected on the same day as the pitfalls were removed (13/05/2019). The top soil (0-20 cm) was collected in the same place where the pitfalls were placed. Therefore, four soil samples were collected from each plot and then mixed to obtain a composed sample of 500 g. At laboratory, the soil samples were dried at room temperature and sieved using a 2 mm sieve. Parameters such as pH, Electrical Conductivity and Organic Matter content were determined in each composed sample, following the guidelines: ISO 10390:2005, ISO 11265:1994 and A5TM D 2974-87, respectively.

Data analysis

Regarding the vegetation, the average richness and average abundance were determined per each sub-area. Relative values of percent cover and height were calculated to get the importance value index (IVI= Relative percent cover + Relative height) for each specie in the subareas without the presence of *Pinus pinaster* Aiton, in the subareas with its presence was used the DBH (IVI= Relative percent cover + Relative height + Relative DBH) only to this specie. Based on the IVI, the Shannon-Wiener´s (H´=- Σpi.ln (*pisi*=1), where pi is the IVI) diversity and Pielou (J=H´/Hmax, where Hmax=ln(total of species)) evenness indexes were calculated. Abundance values were calculated through the ratio of the number of individuals in each quadrat per the plot area (nºind./ha) and the species richness was obtained by the ratio of the number of species per 0.01 ha (nºsp./0.01ha). Concerning the edaphic macrofauna, the average richness and average abundance were calculated per each subarea. The relative density was also measured and used in the calculation of the Shannon´s diversity and in the Pielou evenness indexes.

One-way ANOVA was used to check for significant differences between four subareas: B1, B2, B3 and UP for all parameters measured. Normality and homoscedasticity were tested. When normality and homoscedasticity were not achieved, Kruskal-Wallis One-way ANOVA on ranks were used instead. One-way ANOVA and Kruskal-Wallis One-way ANOVA on ranks were followed by Tukey tests or Dunn's tests, respectively. These statistical analysis were performed using Sigma-Plot 14.0 (Systat Software, Inc, San Jose, California, USA).

RESULTS

SOIL PHYSICO-CHEMICAL PARAMETERS

Regarding the OM%, the highest values were found in subarea B3 , followed by UP, B1 and B2 (Figure 8), therefore, the subareas with the highest content of organic matter were those two with more time since the fire. However, significant differences (table 5) were only found only between B3 and B2 (Table 5 and figure 8).

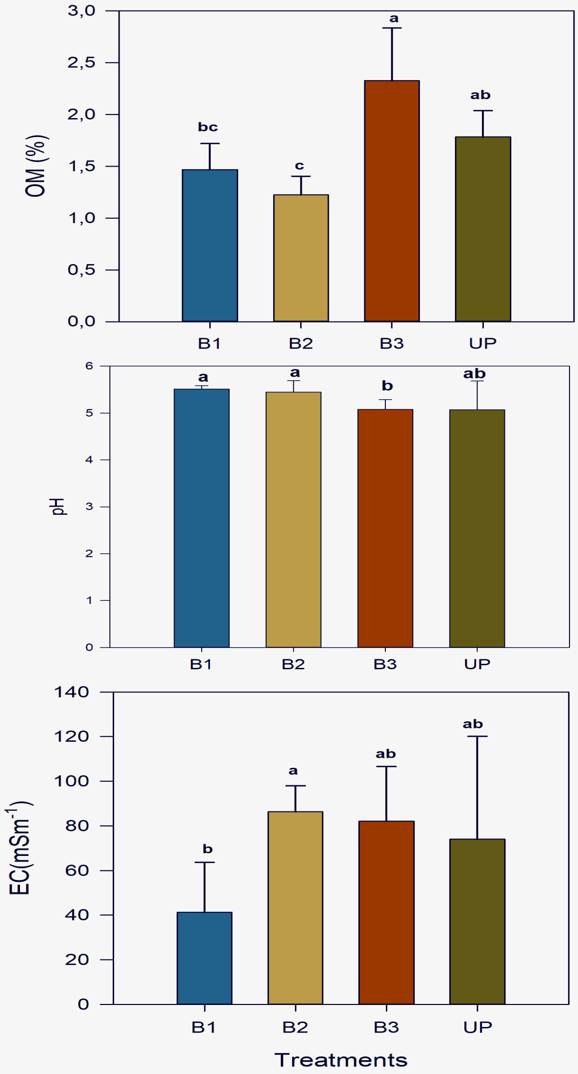

Figure 8: Organic matter (OM) (a), Soil Acidity (pH) (b) and Electric Conductivity (EC) (c) in the four subareas. B1 – burnt three months ago; B2 – burnt one year ago; B3 – burnt two years ago; UP –unburnt.

Table 4: Summary of the one-way ANOVA performed in the several parameters to test the statistical differences between the four sub-areas. the distinct parameters of the soil, flora and macrofauna.

Evaluated parameters	d.F	Statistical test	P
OM	3	H=25.378	0.001
pH	3	H=14.266	0.003
EC	3	H=9.684	0.021
Flora abundance	3	F(3, 8)=10.262	0.004
Flora species richness	3	F(3, 8)=11.710	0.003
Flora H´	3	F(3, 8)=4.442	0.041
Flora J	3	F(3, 8)=6,366	0.016
Macrofauna abundance	3	H=12.875	0.005
Macrofauna order richness	3	F(3, 41)=3.901	0.015
Macrofauna H´	3	F(3, 41)=4.567	0.008
Macrofauna J	3	F(3, 41)=0.999	0.403

On the contrary, the subareas with high pH values were those with less time since the fire occurrence, i.e. B1 and B2, with, statistically significant differences found between B3 and both B1 and B2 (Table 5 and Figure 8).

The subareas B2, UP and B3 showed the highest values of EC and did not differ statistically among them (Table 5 and Figure 8). In opposite, the subarea with the lowest value -B1- was significantly different from the other three areas.

VEGETATION COMPOSITION AND DISTRIBUTION

The abundance of the flora in the distinct subareas can be seen in the figures 10 a) to 10 d). The total number of individuals reached 4.552, from which the most abundant were *Cisturs psilosepalus* (1518), *Pteridum aquilinum* subsp. *aquilinum* (611) and *Pterospartum tridentatum* (506) (Table 6). Regarding each subarea, *C. psilosepalus* was the dominant species in the burnt plots, especially in B1, while *P. pinaster* was the species more abundant in the unburnt - UP Statistically significant differences were found in the abundance of the distinct subareas (Table 5), being B2 the sub-area with the highest abundance value (556.33), followed by B3 (315.67). The treatments with the lowest abundance were B1 (169.67) and UP (118.92), which differed statistically from B2, but not from B3 (Fig. 10 a).

Table 5: Scientific names and abbreviations of the plant taxa detected in the study area.

Taxa	**Abbreviations**
Pterospartum tridentatum (L.) Wilk.	Ptr
Pteridum aquilinum (L.) Kuhn subsp. *aquilinum*	Paq
Erica arborea L.	Ear
Cistus psilosepalus Sweet	Cps
Digitalis purpurea L. subsp. *purpurea*	Dpu
Senecio sylvaticus L.	Ssi
Teesdalia nudicaulis (L.) Br.	Tnu
Agrostis curtisii Kerguélen	Gra
Filago pyramidata L.	Fpi
Scilla monophyllos Link	Smo
Lithodora prostrata (Loisel.) Griseb.	Lpr
Erica australis L. subsp. *australis*	Eau
Halimium lasianthum (Lam.) Greuter	Hla
Lotus sp.	Lsp
Thapsia minor Hoffmanns. & Link	Tmh
Ulex minor Roth	Umi
Ulex europaeus (Mariz) Rothm.	Ueu
Quercus robur L.	Qro
Linaria triornithorphora (L.) Wild.	Ltr
Pinus pinaster Aiton	Ppi
Senecio jacobaea L.	Jvu
Asteraceae	Ast
Erica umbellata Loefl. ex L.	Eum
Anarrhinum bellidilifolium (L.) Wild.	Abe
Cystisus striatus (Hill) Rothm.	Cst
Andriala integrifolia L.	Ain
Quercus suber L.	Qsu

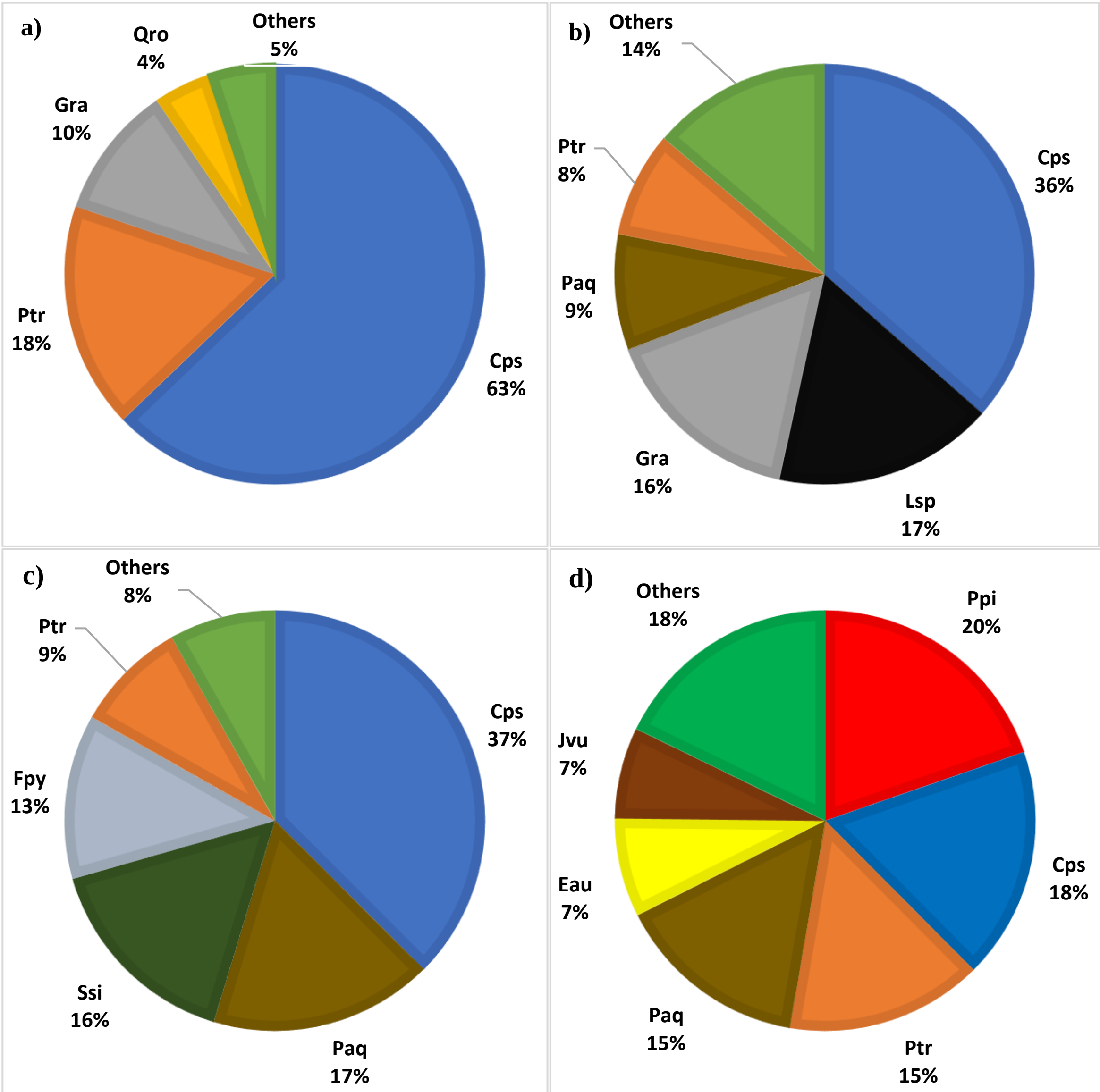

Figure 9: Relative abundance of the main taxa of the vegetation in each subarea: a) B1 subarea, b) B2 subarea, c) B3 subarea and d) UP subarea. Taxa with less than 4% abundance were summed up and included in "others" in the figure 10 a) to d).

The total number of plant taxa listed in this work was 27 (table 6), belonging to 13 families, including three species of trees, 15 species of shrubs and nine herbaceous species. Similarly, to what happened in the abundance, the highest species richness value was found in the B2 (10.67) treatment, followed by B3, B1 and UP. Statistically significant differences (Table 5) were detected between the subareas, since UP (3.33) statistically differed from B2 and B3, and B1 from B2. However, B2 did not differ when compared with B3 (8.00) and this did not differ when compared with B1 (5.33) (Fig. 11, b).

The subarea B2 presented the highest Shannon-Wiener index value, followed by UP, B3 and B1. However, statistically significant differences were found only between B2 and B1 (Fig. 10, c). There were also statistically significant differences (Table 5) between the treatments in the Pielou (J) evenness index. The subarea with the higher value was B2 (0.92), which was significantly different from UP (0.71), but not from B1 (0.87) and neither B3 (0.82) (Fig. 11).

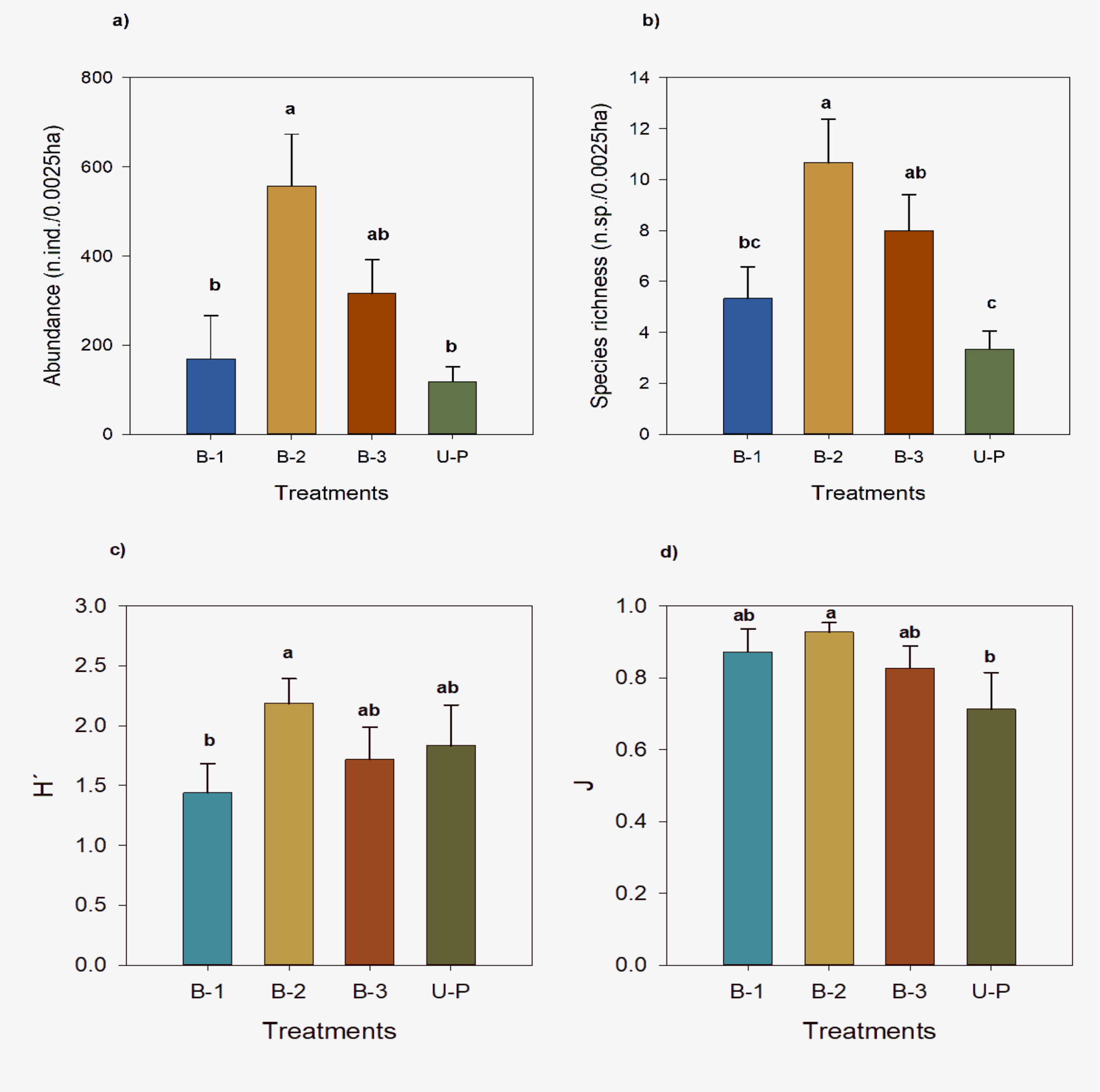

Figure 10: Abundance (a), Species richness (b), Shannon-Wiener H' (c) and Pielou -J (d)) determined for the vegetation in the study area. Distinct lower-case letters were used to point-out the statistical differences between the four subareas (p<0.05).

SOIL EDAPHIC MACROFAUNA

The total number of listed individuals was 2.513, corresponding to 19 orders (Table 7), from which Hym (1.158) and Col (607) were the most abundant orders. Regarding each-sub area, Hym was the dominant taxa in the burnt lands (B1, B2 and B3), while Col was the main dominant taxa in the unburnt – UP (Figure 11). Overall, these orders were dominants in all the subareas only changing the position in the abundance values. Albeit, other orders with minor abundances, like Ort, Dpa, Hem, Amp, Iso, Sym, Opi, Mic, Asc, Tys, Pse, Dec and Der, were summed up and included in "others" in the graph. Regarding the abundance per subarea, UP and B3 were the ones with the highest average abundance (Figure 12 a). Statistical differences were only found between UP and B2 (Table 5, Figure 11a).

Table 6: Orders and their respective abbreviations of the macrofauna in the study area.

Orders	Abbreviations
Hymenoptera	Hym
Coleoptera	Col
Zygentoma	Zyg
Orthoptera	Ort
Araneae	Ara
Protura	Pro
Pseudoscorpiones	Pse
Thysanoptera	Tys
Opiliones	Opi
Decapoda	Dec
Diplopoda	Dpa
Hemiptera	Hem
Microcoryphia	Mic
Ascídeo	Asc
Amphipoda	Amp
Isopoda	Iso
Chilopoda	Chi
Symphila	Sym
Dermaptera	Der

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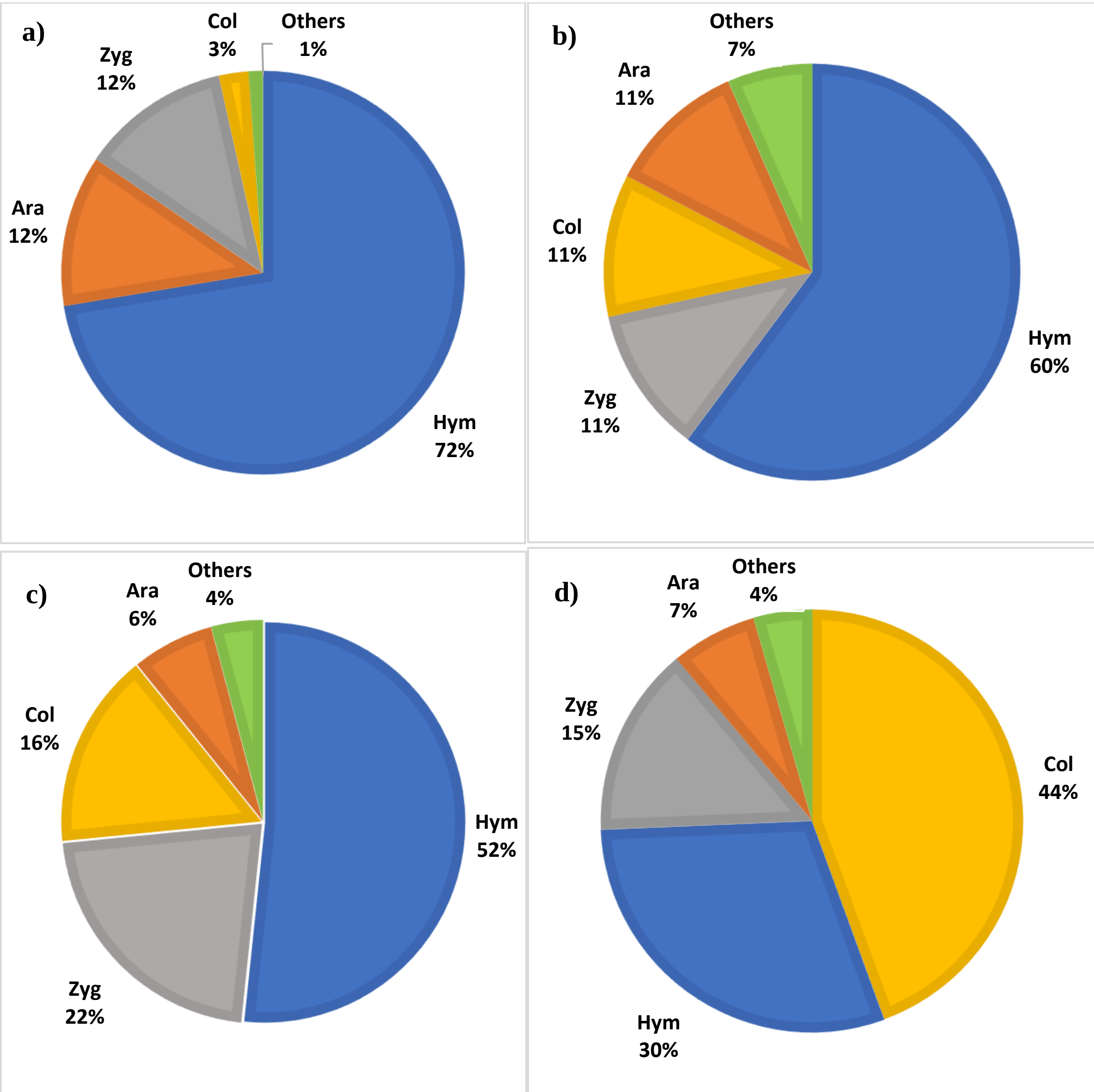

Figure 11: Relative abundance of the main taxa of the edaphic macrofauna in each sub-area: a) B1 subarea, b) B2 subarea, c) B3 subarea and d) UP subarea. Taxa with less than 4% abundance were summed up and included in "others" in the figure 11 a) to d).

Nineteen orders were identified and the subarea with the highest richness value was B2 with 11 taxa (Figure 12b). In terms of significant differences just UP and B1 were different (Table 5, Figure 12b).

Regarding the Shannon-Wiener's (H´) index of diversity, the subarea with the higher value was UP, that like in the richness differs significantly from B1 (Table 5, Figure 12c). Finally, the Pielou (J) values were similar between the four sub-areas, without significant differences (Table 5, Figure 12 d).

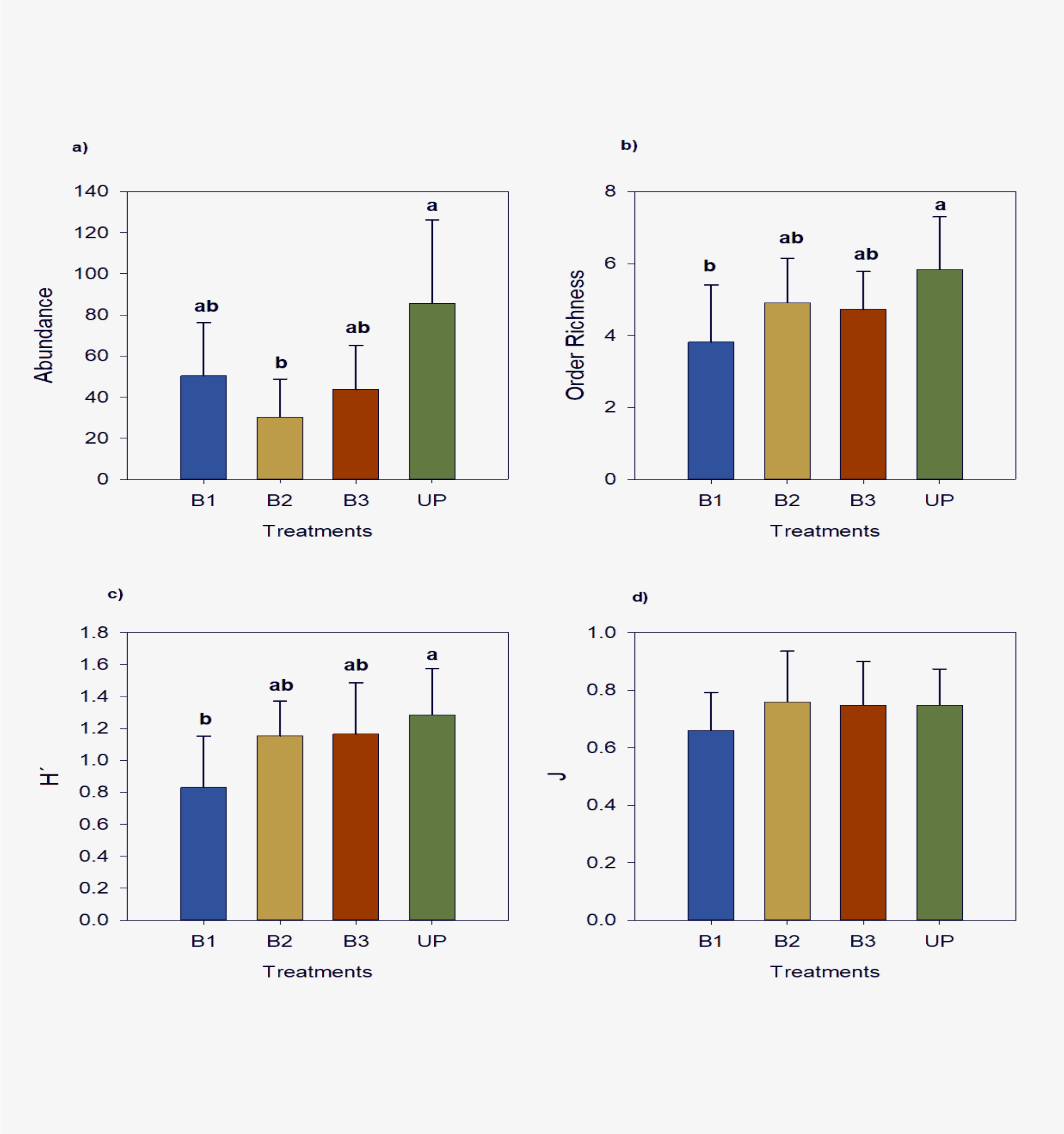

Figure 12 Abundance (a), Species richness (b), Shannon-Wiener H' (c) and Pielou -J (d) determined for the vegetation in the study area. Distinct lower-case letters were used to point-out the statistical differences between the four subareas ($p<0.05$).

DISCUSSION

The subareas with higher OM content were those with more time without the use of fire in their management (B3 and UP), which is in agreement with another studies were it was concluded that the soil organic matter content decreases after a fire, but the values recover over the years (Fonseca *et al.*, 2017) (Franco *et al.*, 2016). Nevertheless, this is not consensual, since Nogueira, (2014) found no significant differences in organic matter content between subareas in 3 soil horizons until 3 years of the use of controlled fire. Additionally, the subarea with less OM content was the B2 and this could be because this area had suffered another type of management, called natural engineering, and had water lines crossing it.

Wu *et al.* (2015) detected variations, among the habitats, in some soil physicochemical parameters, especially in the organic matter which presented their lowest contents in the places with higher degradation. This happens all over the world and is a result of the habitat loss caused by the conversion of forest to agricultural areas with unsustainable management practices that also leads to climate change. The reduction of this soil parameters is generally correlated with a decrease in the abundance and diversity of soil organisms (Commision, 2016).

The excrements and remains of the organisms, more often of the plants, origin the soil organic matter and it can be used in many ways by the soil organisms, for example in the structure of their bodies and source of energy (Of, 2010). Right after a fire in the soil the nutrients change their form to dissolved salts mainly because of the mineralisation of the organic matter. However, in the condition of a degraded habitat the nutrients don't stay long time in the soil and are easily superficially drained by the water (Ferreira *et al.*, 2010).

After a fire, in general, the incorporation of the ashes into the soil promotes and increase in pH and electrical conductivity. For example, Ferreira *et al.* (2010) found an alkaline pH of 8.5 in their study, and Wu *et al.*(2015) also detected in increase of pH after fire. Our results seem to agree with this, since in the case of the pH, B1 and B2, presented the highest averages, although remaining acid (Nogueira (2014), differing statistically from B3 and UP, which presented the lowest values.

According with Nogueira, (2014), three years after the prescribed fire the pH values are the same of those observed in an unburnt area, that is, three years is a good time lapse to consider as sufficient for the recovery of the physicochemical properties of the soil. In the present study, the pH of the subarea burned two years ago, already presented a similar value to the UP subarea, which was burned c. 9 years ago.

Over a broad scale, the structure of the soil microorganisms is shaped mainly by the soil pH, and the changes in this value can explain a large part of the variation of these communities between the different habitats (Of, 2010).

The EC do not completely follow the pattern exhibited by pH, since although B2 presented the highest value, B1 presented the lowest, which is more difficult to interpret.

Nevertheless, the EC values decrease from the B2 subarea to B3 and UP, which generally agrees whit what was described by Nogueira (2014) and can be interpreted as resulting from leaching and uptake of minerals by the growing vegetation Mataix-Solera, 1999 in Nogueira, (2014).

The EC variation can cause a lot of impacts over the soil organisms, especially when an increase on this value is verified, causing stress and consequently evolving to a fast desiccation of these organisms (Of, 2010).

Bunning *et al.*, (2011) informs that the plant growth can be affected by the soil salinity through the increase on the osmotic tension what leads to a more difficult water absorption from the soil. Also, when even the plants can absorb the soil water with high salinity this can cause direct toxic effects on them.

Regarding the vegetation, although relevant differences were detected between the subareas, we should highlight that the Baldio de Carvalhais area is part of the same plant association called *Erico umbellatae-Pterospartetum tridentati.* This plant association is a moor/heath community, characterized by the domination of *Ulex minor* Roth, *Erica umbellata, Pterospartum tridentatum* (L.) Wilk (Capelo & Almeida, 2008).

The rise in plant abundance and species richness from B1 to B2 may be explained by the relatively short time from fire in B1, which might have been insufficient for recovery of the vegetation. Contrarily, the reduction in abundance and species richness from B2 to B3 might have been caused by the natural engineering management used in B2, but not in B3, and by the effects of trees over the shrub layer in the case of B3 to UP. Regarding the latter, several authors (Bergstedt and Milberg, 2001; Légaré *et al.*, 2001; Légaré *et al.*, 2002) state that trees influence shrub diversity and abundance via changes in the soil properties and shading, which could, at least, explain the reduced abundance and diversity in UP subarea, that were dominated by pine trees, *versus* the other subarea, that had only shrubs. Additionally, both effects are in agreement with Wu *et al.*, (2015), that concluded that the plant abundance and species richness in a severely degraded habitat were significantly smaller than those in nondegraded habitats, and that the same variables were higher in moderately degraded habitats than in nondegraded habitats.

Hence, Davies (2013) affirms that after individual fires the changes on the vegetation can be remarkable, but the environment has an amount of resilience, that is, over the time it will come back to the a structure very close to the original.

The analysis and comparison of diversity indexes are of great importance to know if there is dominance of some species, because the lower the value of the Shannon index, the higher dominance can one particular species have on the studied community and this can be seem also in the J index (Magurran, 2004). As above mentioned, the reduced time since the prescribed fire in B1 subarea also explains its lower H' value. On the contrary, the higher value obtained for B2 seems to be a consequence of its higher species richness. Regarding the J index, the higher value was observed in the B2 subarea, and the lower value was presented by the UP subarea, which is probably due to the higher species richness of B2 and the presence of several dominant species and a higher proportion of low abundance taxa in UP. This emphasises the role of fire in resetting the communities and controlling understory vegetation (FAO, 2006).

Although, the management used in the areas influences litter decomposition both directly and indirectly, the direct effects are mainly changes in the vegetation cover. The indirect effects are a result of the changes in plant cover, combined with the land use, and this together can cause shifts in the parameters of the soil macrofauna (Peña-Peña and Irmler, 2016).

In what concerns the edaphic macrofauna, the UP was the subarea with higher values in all the evaluated diversity indexes, with exception of J'. In opposite, B2 was the subarea with the lowest soil macrofauna abundance, differing statistically from the others. This lowest value found in B2 was in concordance with the OM% value in this subarea. In fact, Tavares *et al.*, (2015) conclude that the macroinvertebrates can be used like good bioindicators of the soil quality, mainly because of their influence in the organic matter and nutrient cycle.

Sayad *et al.* (2012) affirm that the soil macrofauna richness is greatly influenced by the presence of tree species. By the same, Antunes *et al.* (2008) recorded the highest number of macro-arthropods in the sampling areas with higher plant cover, which promoted the abundance and diversity of litter macro-arthropods, as was the case of the UP .

Additionally, Wu *et al.,* (2015) in their study, observed that the soil macrofauna richness was significantly correlated with the aboveground biomass, coverage, vegetation height and plant richness. However, in the present study the subarea with the highest values of diversity (UP) were not the place where we found high plant diversity – B2.

By comparing the diversity indexes determined in each subarea it is clear the role of fire as a disturbance factor in the macroinvertebrate community. Also, by comparing the subareas it is also evident the fast recovery of the community over time, with close values between the B2, B3 and the UP.

The results of this study also revealed an high dominance of the order Hymmenoptera in the burnt subareas (B1, B2 and B3) and of the Coleoptera in the UP. According to Wu, *et al.,* (2015), the abundance of the coleoptera order is significantly influenced by the plant coverage and species richness. The Hymenoptera order was dominant in the disturbed areas and based on Graham *et al.* (2009) this order, specially the ants, are used as indicators of environmental change in disturbed landscapes, explaining why this order was more common in the burnt areas. This also could be a suggestion that the macrofauna abundance of some groups varied among different land management (Franco *et al.*, 2016).

CONCLUSION

Overall, the results of this study brought new knowledge on the effects of prescribed burning in the forest structure and their consequences for forest-dwelling biota.

Some changes on physicochemical soil parameters were observed due to the fire, namely a reduction in OM and a slight increase in pH in the subareas that burnt more recently. Also, the EC was lower in the subarea that burnt recently.

In terms of effects in flora, the results of this study point-out the role of prescribed fire in enhance their diversity, abundance, species richness and evenness. Additionally, the use of natural engineering seems to have contributed to an increase in abundance and diversity of the flora in one of the subareas that combined these two types of management.

Conversely, the fire has resulted in a decrease in richness and evenness of the edaphic macrofauna. Also, it was observed the dominance of the order Hymenoptera, which is an indicator of disturbed sites.

Regarding the progress of the communities over the time since fire, it was observed that both flora and edaphic macrofauna are recovering and approaching the unburned area.

However, more temporal studies and more soil parameters are required to better understand the advantages/disadvantages of prescribed burning in the ecosystem functioning and how it can impact the provision of services.

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