Assessing vegetation recovery in different fire-severity conditions in central Portugal

Avaliação da recuperação de vegetação sob diferentes condições de severidade do fogo no centro de Portugal

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Abstract

Wildfire-induced landscape changes are a critical environmental issue in Southern Europe and are becoming increasingly relevant, especially in rural areas, where land use changes are leading to greater fuel availability, higher fire frequency, and wider affected areas. These factors are promoting scrubland-dominated landscapes and may contribute to biodiversity losses and impact vegetation dynamics. The aim of this study is to assess post-fire vegetation recovery in a mountainous region of central Portugal under different severity levels and environmental conditions, aiming to assess their influence on vegetation dynamics. Copernicus Sentinel-2 datasets were used to calculate different wildfire-relevant indices, such as the Normalized Difference Vegetation Index (NDVI), Normalized Burn Ratio (NBR) and delta Normalized Burn Ratio (dNBR) and coupled with floristic and vegetation data collected from 15 field plots (100m^2 each). Results indicated that, although no relationship could be established between fire severity and vegetation recovery, post-fire vegetation attributes were clearly influenced by abiotic conditions and floristic composition, particularly the presence of sprouters. After 5.5 years, most sample plots displayed expected regrowth rates, considering the potential dynamics, as the predominant shrub species are well adapted to fire disturbance. However, plots with greater cover and height (high shrub stratum) were dominated by the invasive tree species *Acacia dealbata*, presenting a distinct pattern compared to the prevalent vegetation recovery conditions in the study area.

Keywords: Vegetation recovery. Floristic composition. Abiotic conditions. DNBR. Mountain areas.

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Resumo

As mudanças na paisagem induzidas por incêndios florestais constituem um problema ambiental no sul da Europa e estão a tornar-se cada vez mais relevantes, especialmente em áreas rurais, onde as mudanças no uso do solo estão a promover uma maior disponibilidade de combustível e incêndios mais frequentes e extensos. Em simultâneo, estas mudanças estão a promover paisagens dominadas por matos, com perdas de biodiversidade e implicações na dinâmica da vegetação. O objetivo deste estudo é avaliar a recuperação da vegetação após incêndios, numa região montanhosa do centro de Portugal, sob diferentes níveis de severidade e condições abióticas, com o intuito de analisar a sua influência na dinâmica da vegetação. Produtos do Copernicus Sentinel-2 foram usados para calcular diferentes índices relevantes para incêndios florestais, como o *Normalized Difference Vegetation Index (NDVI)*, *Normalized Burn Ratio (NBR)* e o *delta Normalized Burn Ratio (dNBR)*, em conjugação com dados de cobertura e florísticos, recolhidos em 15 parcelas de campo (cada uma com 100 m^2). Os resultados mostraram que, apesar de não ser possível estabelecer uma relação entre a severidade do incêndio e a recuperação da vegetação, os seus atributos após o incêndio foram claramente influenciados pelas condições abióticas e pela composição florística pré-incêndio, particularmente pela presença de espécies com recuperação a partir de toiça. Cerca de 5 anos após o incêndio, a maioria das parcelas apresentou taxas de regeneração compatíveis com o esperado, tendo em conta a dinâmica potencial, dado que as espécies arbustivas predominantes estão bem-adaptadas à perturbação provocada pelo fogo. No entanto, as parcelas com maior cobertura e altura (estrato arbustivo alto) estavam dominadas pela espécie arbórea invasora *Acacia dealbata*, apresentando um padrão distinto em comparação com as condições de recuperação de vegetação predominantes na área de estudo.

Palavras-chave: Recuperação da vegetação. Composição florística. Condições abióticas. DNBR. Regiões de montanhosas.

1. Introdução

The long-lasting damages caused by wildfires in Mediterranean Europe are certainly one of the most relevant and growing topics in the present, not only due to the increasing recurrence and larger affected areas (Pausas & Muñoz, 2012), but also because of their deep impacts (Shakesby, 2011). In mountain landscapes these dynamics are accentuated by biophysical (Bergonse et al., 2022) and socioeconomic factors (Falcucci et al., 2006). In central Portugal, as in many other regions, land-use changes have contributed to wider affected areas (Salis et al., 2022) and higher fire recurrence at the landscape level. This trend is linked to increased fuel availability (Moreira et al., 2020) and the expansion of fire-prone or highly flammable vegetation communities (Catry et al., 2013; Maia et al., 2014; Silva et al., 2009; Xanthopoulos et al., 2012).

Fire is a natural element in most Mediterranean ecosystems (Pausas, 2009), and native plant species are adapted to it (Balao et al., 2018). In fact, the high presence of plant sprouters in the Mediterranean ecosystems might be an indicator of adaptation to disturbances, particularly to fire, as sprouters are favoured by frequent and severe disturbance regimes, namely in the case of fire-prone shrublands (Bond & Midgley, 2003). However, the increasing wildfire recurrence is challenging the native vegetation's regenerative capacity, and heavily compromising biodiversity (Fernandez-Manso et al., 2016; Taboada et al., 2017).

Vegetation recovery is not only determined by the composition and density of the plant community affected by fire (Taboada et al., 2018), or the prevalence of seeders/sprouters for instance, but it also depends on the environmental conditions of the site (Meneses, 2021; Rodríguez-García et al., 2022). Fire conditions, such as wildfire intensity and severity might contribute to shifts in vegetation response after the event, especially in the immediate post-fire (Catry et al., 2013; Marzano et al., 2012).

Local biophysical characteristics, which include vegetation coverage, slope, humidity, and soil depth, among others (Bergonse et al., 2022), have a direct influence on fire conditions, such as fire intensity (physical process of energy release), fire duration and fuel properties (van Wagtendonk, 2006) Fire severity is measured by the magnitude of immediate fire impacts on vegetation and soil (Keeley, 2009) and constitutes an indicator for the magnitude of ecological change (Viana-Soto et al., 2017). In the post-fire, vegetation recovery is again determined by the local biophysical characteristics, which greatly influence the resources that a plant has at its disposal (Nioti et al., 2015; Spatola et al., 2023). In native ecosystems, floristic composition generally tends to remain unaltered (Capitanio & Carcaillet, 2008), and changes are often linked to the invasion of fast-growing non-native plants, which rapidly increase in cover and alter plant community composition. Changes that can modify fire regimes (Brooks et al., 2004; Marchante et al., 2003), due to the higher fire-proneness of such communities (Moreira et al., 2020). In fact, some invasive species benefit from increased fire recurrence (Vallejo et al., 2012) presenting rapid growth rates after massive germination, ultimately limiting the ability of native species to re-establish (Silva & Marchante, 2012).

Shifts on vegetation cover are mostly dependent on pre-fire plant community/structure and fire intensity (Marzano et al., 2012). While areas classified as transitional or permanent shrublands, generally are well adapted to fire, an thus capable of fast regeneration, due to large seed banks or good resprouting capabilities (Bastos et al., 2011); forested areas are reliant on their predominant species regeneration strategies. Forests dominated by sprouters, such as *Quercus* taxa, are considered to be more stable in terms of coverage, and capable of maintaining species richness (Lloret et al., 2003). In turn, forests that are constituted by seeder species, such as maritime pine, have a greater potential to alter their cover characteristics, and can take decades to regrow to their pre-fire heights (Viana-Soto et al., 2022).

Disturbance-caused land-use and vegetation cover changes can be assessed using multitemporal satellite imagery, calculating indexes that reflect physiognomic attributes; such as the Normalized Difference Vegetation Index (NDVI) associated to vegetation conditions; or the Normalized Burn Ratio (NBR) and difference Normalized Burn Ratio (dNBR) used to delimitate burnt areas and provide an estimate on burn severity (Lazzeri et al., 2021; Pádua et al., 2020). While remotely produced indexes enable the user to analyse vast areas in a time efficient manner, they do not reflect community composition nor recovery stage based on plant height; reinforcing the importance of incorporating field work into the study, not only to verify the data produced remotely (Smith-Ramírez et al., 2022).

According to the literature, burn severity (dNBR) can be a good indicator for a site's biophysical conditions, as it correlates with a variety of factors, such as vegetation attributes (Lentile et al., 2006), the associated humidity on a microclimatic level, the rate of combustion, the surface temperature, among other factors, such as susceptibility to erosion (Pereira et al., 2018). Consequently, fire severity could directly influence the ecosystem's response capacity in terms of vegetation regrowth (Fernández-Guisuraga et al., 2023). Higher burn severities are expected to correlate with bigger losses in terms of plant cover (González-De Vega et al., 2016), but shouldn't be used as an indicator to extract general conclusions about post-fire vegetation recovery (Keeley, 2009).

This study aims to evaluate whether burn severity is primarily determined by site conditions, without noticeable interfering with post-fire vegetation recovery, or if has long-term effects on plant recovery rates and cover density. Post-fire vegetation recovery in a mountainous area with a Mediterranean climate was assessed across different fire severity levels by integrating satellite imagery with field plot data. The analysis examined variations in vegetation recovery, considering both cover and floristic composition.

2. Materials and methods

2.1. Study area

The study area is located within the municipality of Arganil, in the mountainous region of Serra do Açor (Central Portugal). As a mountain area, it has high topographic complexity (Figure1), steep slopes, with an altitudinal gradient ranging from 240 to 1230m, and it is mainly dominated by schistose rocks. The climate presents a Mediterranean pattern, with hot and dry summers that contrast with mild winters. Precipitation is unevenly distributed throughout the year, with average annual values at higher altitudes around 900mm. In 2015, the predominant land use was forest, occupying two thirds of the territory (65%). These forested areas were constituted mainly by maritime pine stands, but also, in lower quantities, oaks, chestnuts, and eucalyptus. The other third of the area was occupied by shrublands, that could be found in approximately one quarter of the study area (27%); as well as agricultural or artificialized areas, representing around 7% of the study area. On the 15th of October 2017, the study area was affected almost in its entirety by a wildfire, severely altering the vegetative conditions of the site.

2.2. Methodology

To assess vegetation recovery, biophysical indices for the pre- and post-fire moments were calculated based on Sentinel-2 satellite multispectral imagery, accessible at the Copernicus Open Access Hub. To assess changes on vegetation, products with a spatial resolution of 20m and pre-processed at Level-2a with atmospherically corrected surface reflectance, were considered (Phiri et al., 2020) To enable fire

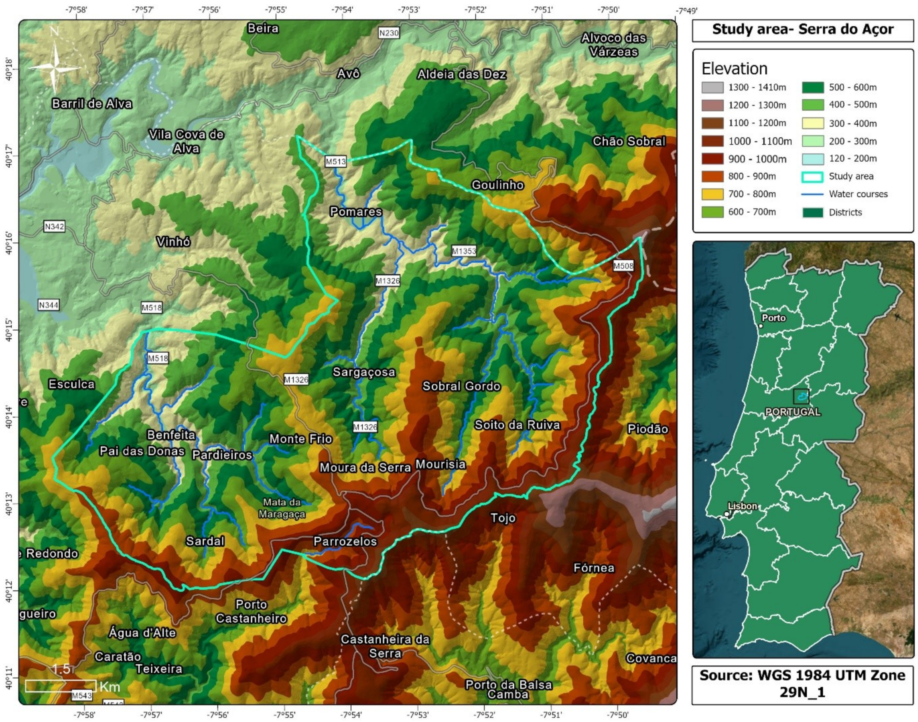

Figure 1. Location of the study area in mainland Portugal (right) and topographic conditions (left).

severity derivation, images for the pre-fire (2nd October) and immediate post-fire (22nd October) were selected. Relying on the near infrared and short wave infrared spectral bands, Normalized Burn Ratios (NBR) were calculated, allowing precise burnt area delimitation. Fire severity levels were calculated based on the Differenced Normalized Burn Ratio (dNBR), obtained by subtracting the post-fire NBR from the pre-fire NBR (1). The classification of the dNBR output was performed based on the parameters proposed by Key & Benson (2006) (Table 1).

$$\mathbf{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}} \quad \mathbf{NBR} = \frac{\mathrm{NIR} - \mathrm{SWIR}}{\mathrm{NIR} + \mathrm{SWIR}} \quad \mathbf{dNBR} = \mathrm{NBR}_{\text{pre-fire}} - \mathrm{NBR}_{\text{post-fire}} \tag{1}$$

Stratified sampling plots were assigned based on the spatial representativeness of each severity class within the study area (Table 1), and a total of 15 100m^2 sampling plots (Figure 2) were randomly distributed across the study area, ranging from low to high severity conditions. The "enhanced regrowth" classes and the "unburned" class were not considered in this case due to the lack of scientific interest for the study. As the post-fire dataset was captured on the 22nd of October, only 7 days after the fire, vegetation regrowth would be practically non-existent in burned areas, supporting the exclusion of these classes. Unburned areas occupied only around 4,4% of the study area, mainly within or in the proximity of settlements and agricultural areas. To assess the influence of fire severity on vegetation recovery, namely cover density and greenness, the Normalized Difference Vegetation Index (NDVI) was calculated

Table 1. dNBR classification parameters and sampling design.

Severity level	dNBR range	Area (%)	Sample plots (n)
Enhanced Regrowth, High	-0.500 to -0.251	1.5	0
Enhanced Regrowth, Low	-0.250 to -0.101	0.1	0
Unburned	-0.100 to 0.099	4.4	0
Low severity	0.100 to 0.269	6.7	1
Moderate-low severity	0.270 to 0.439	10.5	2
Moderate-high severity	0.440 to 0.659	20.3	3
High severity	0.660 to 1.300	56.6	9

for the pre-fire (2nd October 2017) and current conditions (19th May 2023), with the values being classified considering the thresholds proposed by Atun et al. (2020). In addition, topographical variables (altitude, slope, aspect) were also considered to assess their contribution in explaining current vegetation features. Regarding the influence of pre-fire vegetation conditions for recovery, land use data (COS 2015) and photointerpretation of high-resolution imagery from Google Earth Pro's historical imagery function (August 2017) were used.

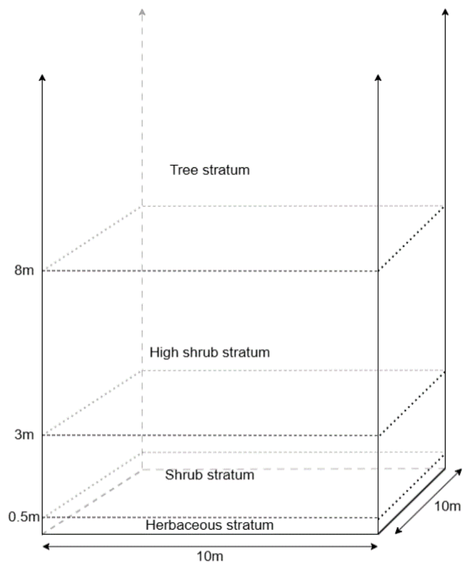

Figure 2. Sample plot design.

During the field survey, conducted in May 2023, floristic composition and cover (%) were recorded within each sample plot (100 m2) considering different vegetation layers (Figure 2). This assessment aimed to detect shifts in vegetation dynamics relative to the expected composition of local vegetation communities. Taxa identification followed Castroviejo (2015), and invader status was determined according to Marchante et al. (2014). Species identification was carried out exclusively for woody taxa, while for herbaceous taxa, only total cover values were considered. The vegetation data collected from the sample plots were subsequently used to assess similarities in vegetation regrowth and composition through cluster analysis.

3. Results

During the three decades before the 2017´s wildfire, the study area was recurrently affected by wildfires, as seen in Figure 3. Most of the area burnt once (49%) or twice (34%), attributed mainly to the occurrences of 1987 and 2005, affecting 86% and 28% of the study area, respectively. During this 30-year period, only around 13% of the area remained completely unaffected by wildfires. Despite the fire recurrence for the last 30 years being quite high, only a fraction of the study area (2%) recorded occurrences between 2005 and 2016.

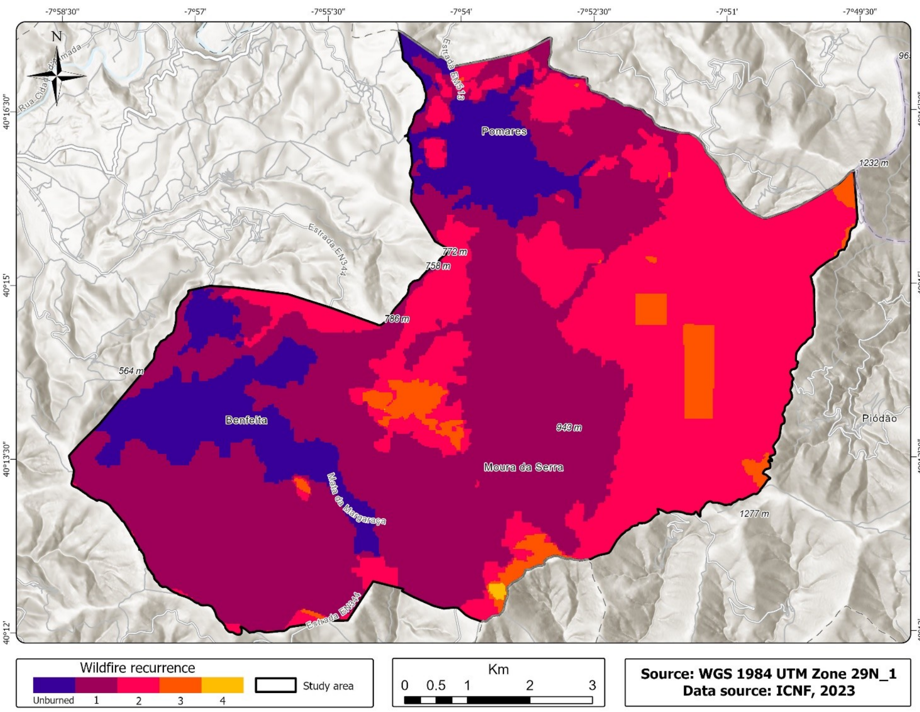

Figure 3. Fire recurrence between 1986 and 2016 in the study area.

Considering current vegetation conditions, recovery clearly differs across the study area even 6 years after the wildfire event. In the pre-fire stage, 82% of the study area was covered by dense vegetation, and 13% by moderately dense vegetation, indicating that about 95% of the study area had a well-developed vegetation cover. Only 5% were associated to sparse vegetation, related primarily to cultivated or deforested areas, as well as terrain ridges (Figure 4).

In the current timeframe (May 2023) (Figure 4), dense vegetation covers approximately 18% of the study area, although only 5% of these areas correspond to

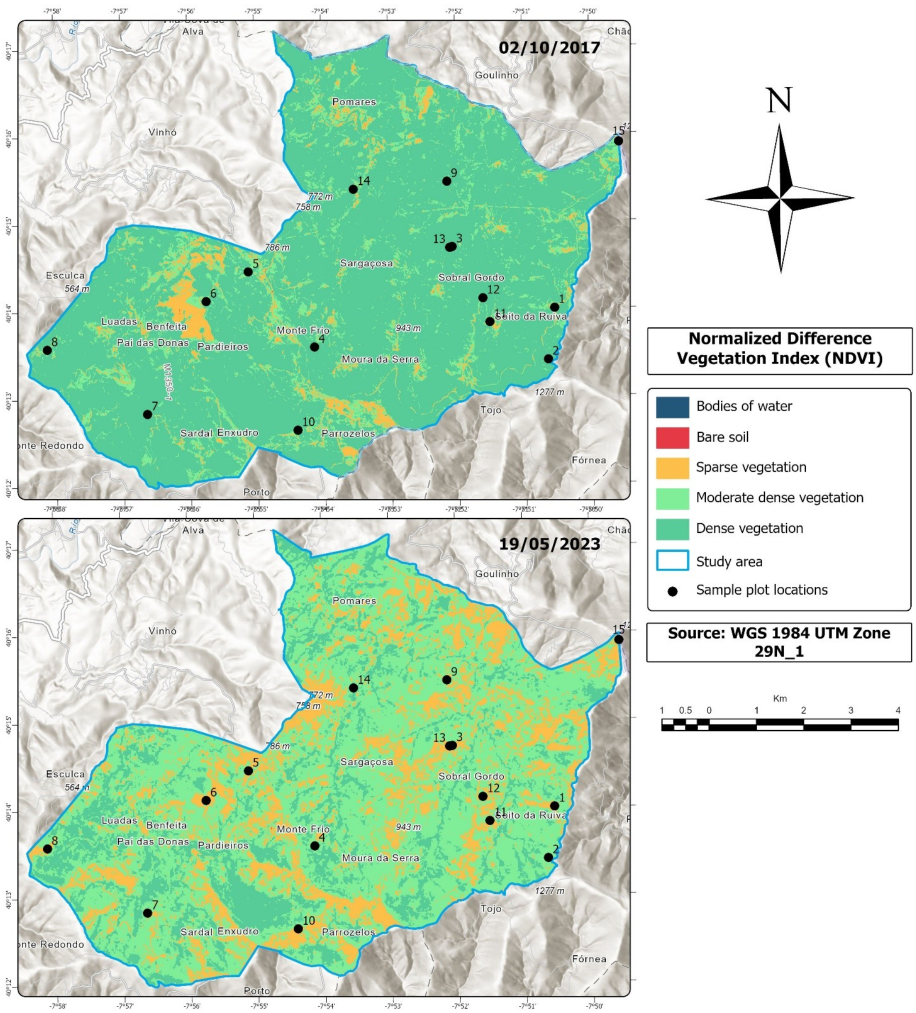

Figure 4. Pre- and Post-Fire NDVI classifications.

unburned conditions. The distribution of the other 95% includes a set of diverse conditions, being frequently associated to valley bottoms (43%), and lower slopes (24%). The vegetation density is generally dependent on the topographic position, but there are exceptions where unfavourable conditions show high vegetation densities. In these cases, it is expected that the species composition plays a key role, namely the predominance of fast-growing shrubs (heathers, brooms, etc.) or the invasion by even faster growing non-native species, such as silver wattle (*Acacia dealbata*). The predominant coverage in May 2023 is moderate dense vegetation, which represents around 61% of the study area. Sparse vegetation covers around 21% of the study area, in most cases replacing previously dense vegetation cover (61%) mainly near the summits (ridges - 33%; upper slopes - 27%; middle slopes - 22%). Considering NDVI data for the sampled plots, only 3 plots attained the same level of vegetation cover registered in the pre-fire stage, once 11 plots exhibit lower levels of vegetation cover and one plot registers higher vegetation cover on current conditions (Table 2). Those sampled plots that register similar values of vegetation cover are associated to invasion by the exotic tree *Acacia dealbata*.

When contextualizing the different variables that were calculated remotely, seen in Table 2, with the data acquired through field work, some of it seen in Figure 5 and Figure 6; it becomes evident that the environmental conditions play a big role in the pre- and post-fire vegetation dynamics. Conditions, such as elevation, soil depth, water availability, etc. determine which species will be able to colonize the areas and have a huge influence in the amount of produced/accumulated biomass and fuel. In fact, pre-fire vegetation density and composition heavily influence fire severity, as confirmed in Table 2, where every sample plot with dense vegetation cover in the pre-fire stage exhibits high severity levels (dNBR values). In the post-fire stage, the combination of these 3 factors will determine vegetation regrowth. Here, although vegetation density has decreased overall, most of the sample plots show good recovery progress, when considering pre-fire coverage.

Table 2. Sample plots biotic and abiotic features. dNBR severity classes: 4 = Low severity; 5 = Moderate-low severity; 6 = Moderate-high severity; 7 = High severity.

	Pre-fire stage			Post-fire stage						
Plot	COS2017	NDVI 02/10/2017	dNBR	COS2022	NDVI 19/05/2022	Cover	Altitude	Recurrence	Aspect	Slope
1	Shrublands	Dense vegetation	7	Shrublands	Mod. Dense Vegetation	95%	931	2	West	48%
2	Shrublands	Dense vegetation	7	Shrublands	Mod. Dense Vegetation	85%	1099	3	Northwest	37%
3	Shrublands	Dense vegetation	7	Shrublands	Mod. Dense Vegetation	90%	650	2	East	21%
4	Shrublands	Dense vegetation	7	Shrublands	Dense vegetation	130%	719	2	East	47%
5	Maritime pine stands	Dense vegetation	7	Shrublands	Sparse vegetation	85%	706	1	Southwest	25%
6	Maritime pine stands	Dense vegetation	6	Without vegetation	Sparse vegetation	40%	630	1	East	10%
7	Broadleaved stands	Mod. Dense Vegetation	5	Shrublands	Sparse vegetation	65%	617	1	West	55%
8	Shrublands	Mod. Dense Vegetation	6	Without vegetation	Sparse vegetation	25%	643	1	Southeast	38%
9	Broadleaved stands	Dense vegetation	7	Broadleaved stands	Mod. Dense Vegetation	100%	599	1	Northwest	43%
10	Shrublands	Mod. Dense Vegetation	6	Herbaceous vegetation	Sparse vegetation	60%	953	1	South	26%
11	Shrublands	Sparse vegetation	4	Shrublands	Mod. Dense Vegetation	90%	740	2	Northeast	33%
12	Shrublands	Dense vegetation	7	Shrublands	Mod. Dense Vegetation	80%	763	2	North	23%
13	Shrublands	Dense vegetation	7	Herbaceous vegetation	Sparse vegetation	70%	664	2	Northeast	26%
14	Invasive stands	Dense vegetation	7	Broadleaved stands	Dense vegetation	90%	384	1	South	71%
15	Shrublands	Mod. Dense Vegetation	5	Herbaceous vegetation	Sparse vegetation	70%	1208	3	Southwest	22%

Based on their similarities in terms of environmental features and species composition, plots can be joined into 3 groups (Figure 5).

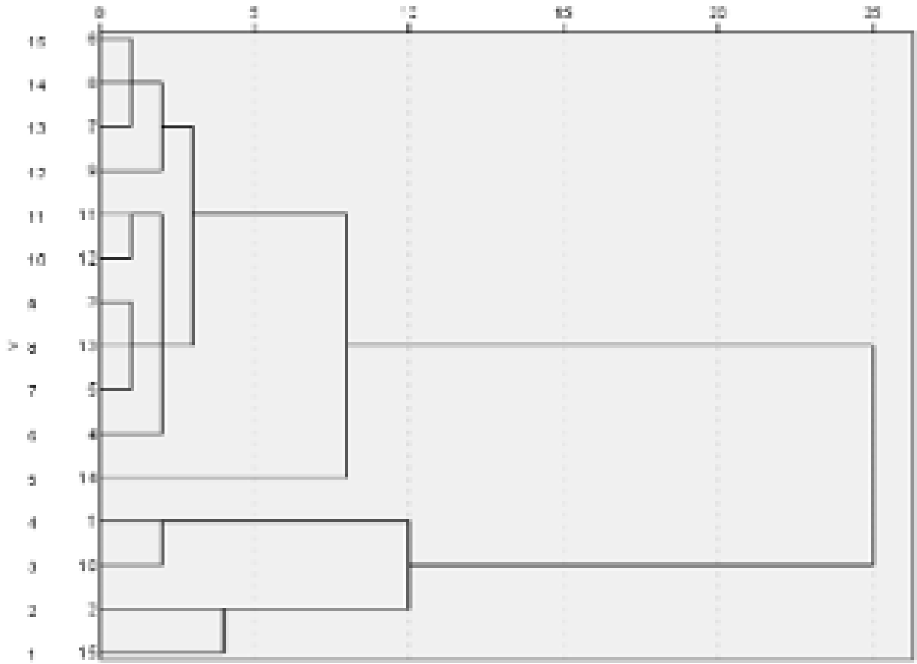

Figure 5. Dendrogram based on the attributes of the sampling sites using between-groups linkage (Rescaled Distance Cluster Combine).

Group A includes sample plots 1, 2, 10 and 15; and corresponds to plots located at the summits, at higher altitudes (above 900m), where vegetation is mostly associated to open shrubby communities installed on shallow and poor soils with lower water availability. Group B, containing sample plots 6, 7, and 8, displays similar but even poorer soil conditions, with high percentages of rocky outcrop, and consequently the overall lowest vegetation cover (Figure 6). In contrast to group A, these plots are located on lower altitudes (617-642m) and are dominated by dense communities that include sparse maritime pine (*Pinus pinaster*).

Group C (plots 3, 5, 11, 12 and 13) includes sample plots that display moderately dense shrubby coverage, associated to more favourable soil conditions and located at heights between 650-763m. Although differences on vegetation cover, these plots are quite similar in terms of species composition, featuring maritime pine (*Pinus pinaster*), heathers (*Erica sp.*) and gorse (*Pterospartum tridentatum*). More specifically sample plots 3, 5 and 13 represent recovering maritime pine communities (*Pinus pinaster*), in different regrowth stages; while sample plots 11 and 12 are recovering shrublands dominated by heathers (*Erica sp.* and *Calluna vulgaris*) and brooms (*Cytisus striatus*), and sparse individuals of maritime pine (*Pinus pinaster*). In this context, sample plot 4 shows similar vegetation recovery rates, but presents different floristic composition, as it is densely occupied by exotic and invasive species, such as eucalyptus (*Eucalyptus globulus*) and silver wattle (*Acacia dealbata*), but also sparse individuals of chestnut (*Castanea sativa*). The presence of silver wattle, implying usually higher vegetation cover, supports also the differentiation of plot 9 within group B, where higher species diversity and cover density (Fig. 6) are coincident with deeper soils. Attributes that support the isolation of plot 14, dominated by the exotic tree but installed on steep slopes (71%).

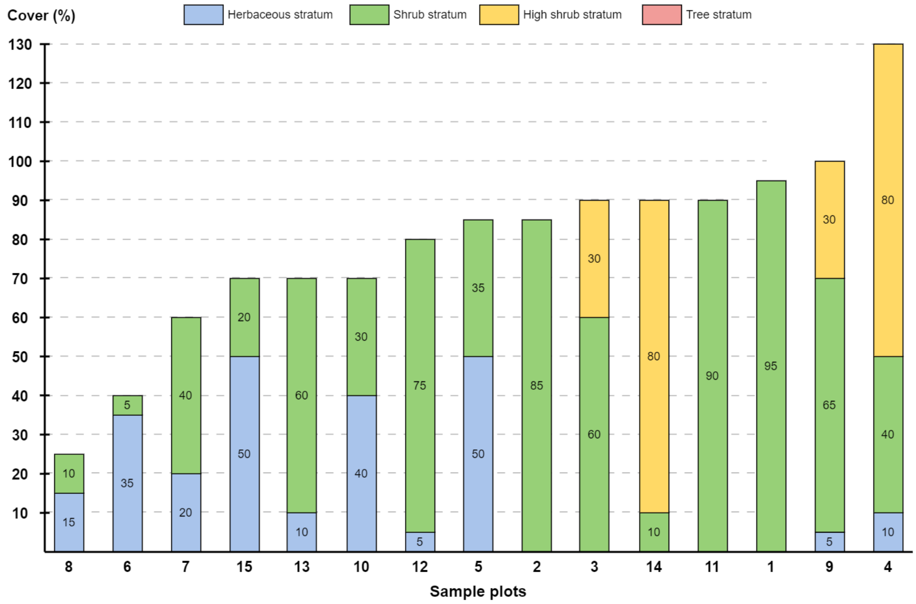

Figure 6. Vegetation cover by stratum for the sample plots.

4. Discussion

While fire severity is generally associated with the magnitude of direct and immediate impact, the fire intensity describes the physical process of combustion and release of energy (Keeley, 2009). In other words, the intensity of a fire influences its severity, but it is not the only factor that does so. Considering the dNBR, the wildfire that occurred on October 15, 2017, reached high severity levels in most of the study area, with 56,6% burning at high severity, and 20,3% with moderate-high severity. In this case, fire severity showed no spatial correlation (r^2=0,02) with terrain physical variables, such as slope or aspect (Figure 7).

Correlation analysis regarding fire severity and determinant factors is highly complex, as it is influenced by countless factors. Looking at Figure 8, which relates the NDVI values calculated for October 2nd, 2017 (pre-fire), with the dNBR values, it is possible to establish a positive correlation between pre-fire vegetation cover density and the degree of fire severity. It is less considerable in the lower severity classes, but clearly identifiable in the red and pink areas on the graphs x axis, which correspond to the "moderate-high" and "high" severity classes; with this discrepancy being the probable cause for the relatively low value of the determination coefficient (r^2).

Considering NDVI results, the existence of large areas with sparse vegetation 6 years after fire, covered by dense vegetation in a pre-fire stage, might indicate

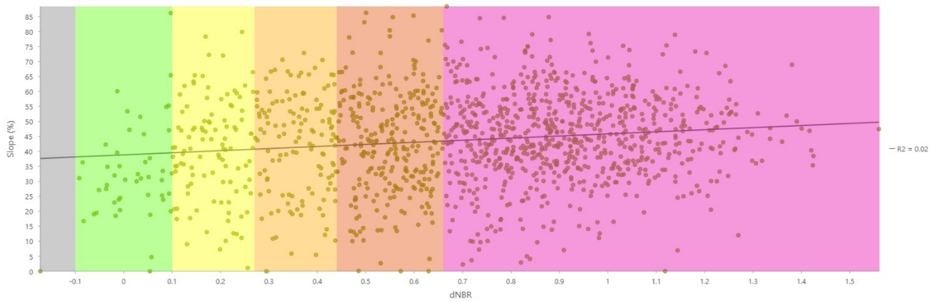

Figure 7. Relationship between dNBR severity levels and slope (based on ca. 1100 sample points). Coefficient of determination (r^2) = 0.02.

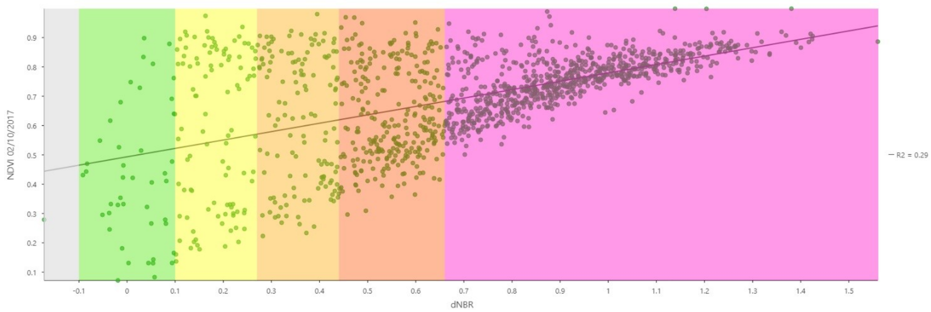

Figure 8. Relationship between dNBR severity levels and slope (based on ca. 1100 sample points). Coefficient of determination (r^2) = 0.02.

impacts from fire severity, once 41% of such areas are associated with high severity, although 66% of the area currently occupied with moderately dense vegetation and 47% of the area with dense vegetation also registered high severity levels.

Since it was possible to establish a correlation between the pre-fire vegetation density and fire severity (dNBR), it was verified whether the dNBR values would have some type of relationship with the vegetation cover density in May 2023, creating the result shown in Figure 9. According to the results, there is no relationship between these two variables, corresponding to the field data presented previously in Table 2 and Figure 7, in which the degree of severity also does not appear to be related to the density of the existing coverage in May 2023.

Due to the circumstances in which the fire of October 15th, 2017, arose and developed, it will certainly be difficult to identify generalized spatial patterns regarding its development. The year 2017 was particularly dry, establishing combustion favourable conditions throughout the summer months, and promoting exceptional fire weather conditions (Ramos et al., 2023). However, the scaled result of the intersection between pre-fire land use and the dNBR severity values, highlights three types of land uses as particularly severe burning. Out of 10Ha that are classified as forests constituted by invasive stands (0.2% of the study area), 82% burnt with high severity, and 14% with moderate-high severity. Out of 1800 ha classified as shrublands, being the second largest overall land use type, 67% burned with high severity, and 21% with moderate-high severity. Finally, out of 3020Ha occupied by maritime pine forests, that before the fire would be the most common land use, 63% burnt with high severity and 20% with moderate-high severity.

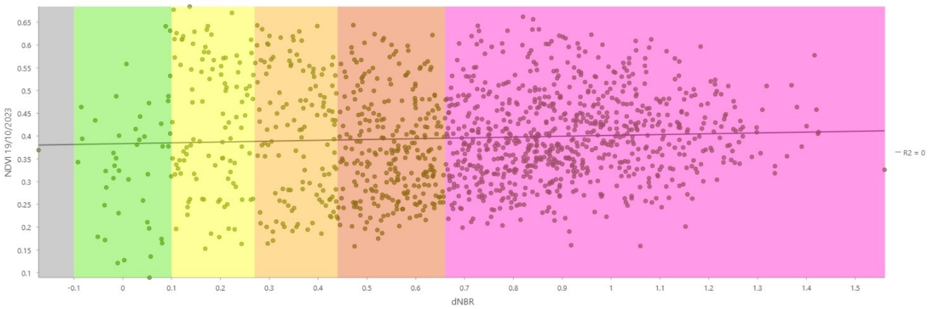

Figure 9. Relationship between dNBR severity levels and plant density 5.5 years after the fire (18/10/2023) (based on approximately 1100 sample points). Coefficient of determination $(r^2) = 0.0$.

These results could be expected due to the inflammable characteristics of the species constituting these types of land-use, such as the Maritime pine (*Pinus pinaster*), a resinous species and highly flammable (Xanthopoulos et al., 2012), and the invasive silver wattle (*Acacia dealbata*), adapted to fast recurring fire regimes (Cueva, 2014). Land use classified as shrubland, in this region, is constituted by species such as heathers, brooms and gorses (ex.: *Calluna vulgaris*, *Pterospartum tridentatum*, *Cytisus striatus*, *Ulex minor*, *Erica sp.*) which are considered native and pioneer species in mediterranean ecosystems, also adapted to fire, with fast recovery.

As for the analysed sample plots, the fire severity doesn't seems to affect the vegetations recovery, conclusions already drawn by Smith-Ramírez et al. (2022) and Spatola et al. (2023). Some of the sample plots that registered high severity levels currently exhibit higher vegetation cover than others that burned with low severity levels, for example. This dynamic can be explained by two factors: soil conditions, namely depth and composition of the soil, as well as its nutritional characteristics; and local species composition, which determines post-fire response. Both of these factors, in turn, are highly related to the physical characteristics of the territory, mostly confirming the conclusions presented by Nioti et al. (2015).

In terms of NDVI (Table 2), out of the 15 sampling plots analysed, the only two that managed to regrow to their pre-fire (dense) vegetation density, although high severity levels registered, are also the plots that show the greatest percentages of exotic and invasive plant species (*Eucalyptus globulus*, *Acacia dealbata*) (plot 4 & 14). However, Table 2 relies heavily on NDVI values, which can sometimes produce misleading results, and thus should only be used to get a rough outline of current vegetation conditions.

Looking at field data (Figure 6), the plots 4 and 9 showed the highest cover, and are located near ephemeral streams or areas with deeper soil, providing higher availability of soil water. While plot 4 is dominated by the alien invasive silver wattle (*Acacia dealbata*), a fast-growing plant that establishes in a wide variety of ecological conditions (Cueva, 2014; Dessì et al., 2021), plot 9 shows a more diverse cover, with species such as the chestnut (*Castanea sativa*), strawberry tree (*Arbutus unedo*), and grey willow (*Salix atrocinerea*), with lower invasive cover. The case of higher values of recovery (with large "high shrub" strata) far from streams is only identified in conditions where invasive *Acacia dealbata* is dominant, such as in the case of plot 14, representing an advanced stage of invasion by *Acacia dealbata*, being the plot with the highest cover and the lowest plant diversity.

In contrast, plots 6, 7 and 8, being located in areas with thin and poor soils, probably caused by deforestation and subsequent erosion, burnt with low and moderate low-severity, and currently present the lowest vegetation cover.

The vegetation recovery of the remaining sample plots was as expected. Plots 1, 2, 10 and 15 have not yet managed to fully recover, with respectively lower NDVI values (Table 2). The predominant native shrub-type species in this region, being fire-adapted, are capable of rapidly regenerating during the post-fire period, due to their shallow roots and large seed production, or good resprouting capabilities (Bastos et al., 2011). Based on land use maps from the years 1995, 2005 and 2017, such plots keep the shrubland physiognomy during multiple decades, a condition greatly determined by the poor soils and recurrence of fire.

In group C, plots 3, 5 and 13, occupied by maritime pine communities (*Pinus pinaster*) in the pre-fire stage, registered high fire severity levels and present similar vegetation regrowth. The presence of *Pinus pinaster* is the attribute that justifies the similarities with plots 11 and 12. Maia et al. (2012) state that fire severity played a significant role in the spatial variability in pine recruitment. These authors founded that pine recruitment was significantly higher following lower than higher fire severity. Vega et al. (2008) estimated the level of fire severity by the degree of crown damage and also highlighted the important role in the post-fire seed rain rate Vega et al. (2008). As an example, founded that scorched trees released the stored seeds more rapidly and to a higher degree than in trees with unaffected crown. Vega et al. (2011) also confirm that the probability of *Pinus pinaster* mortality increased with increasing crown damage. However, post-fire tree mortality is the result of complex processes in which many factors are involved (Vega et al., 2011). In this context, maritime pine landscapes, which consist of compositionally and structurally complex communities with high intraclass heterogeneity, varying stand densities, and frequent mixed stands, need to be addressed in a more detailed analyses, before and after the fire.

5. Conclusions

The results suggest that wildfire severity is not a determinant or a good indicator for expected vegetation recovery. The "magnitude of ecological change" stated by different authors, is conditioned by the biomass/fuel that a plant community produces, which on the other hand is dependent on its species composition. Most of the species associated to shrubby communities in mediterranean regions, like the one assessed in this study, are easily combustible and are mostly sprouters and well adapted to fire. Thus, it is unsurprising that high severity levels were reached in most of the areas. The observed changes are expected for secondary ecological succession process and should by reference pre-fire land-use and dominant species. Post-fire plant regrowth depends on recovery strategies adapted by the predominant species in each community, and the environmental/physical characteristics of the corresponding territory. Such physical variables are not only responsible for the density of a plant cover, or the severity level, but they also determine species composition. The dominance of shrubby communities in the landscape is supported by their rapid recover, because of prevalence of sprouters, and by fire recurrence, which hinder the chance for the recovery of forests, mainly dominated by maritime pine in the pre-fire stage. It is clear that vegetation recovery at higher topographic positions was mostly influenced by species composition, as confirmed by the majority of the sampling plots, and follows the expected dynamics. Unexpected changes occurred mainly on areas where exotic invasive species established (*A. dealbata, A. melanoxylon*), a trend that can expand in the future in the study area, as these species are fast growing, inflammable, and quite adapted to a variety of terrains (Brooks et al., 2004).

To further strengthen the results, future work should include other variables (e.g. and adjust sampling design, collecting data for more plots and include other ecological conditions (bottom valleys) and pre-fire land-uses (broadleaved native forests), aiming to explore correlation between dNBR and vegetation recovery in broader ecological conditions.

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