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Mulching treatments favour the recovery of ecosystem multifunctionality after a large wildfire in Northwest Spain

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Abstract

Wildfires are a widespread phenomenon in forests across the Mediterranean Basin but have increased in risk and severity in recent decades. Post-fire treatments are measures that help recover burned vegetation and their functionality but to what extent they also help recover soil functionality is currently unknown. The main objective of this study was to assess the effect of post-fire treatments on ecosystem multifunctionality after a large wildfire in the Cabrera mountain range in 2017 (NW Spain) where close to 10000 Ha of forest were burnt. At the end of 2017 and during 2018, the administration applied different post-fire treatments in high fire severity affected areas: i) straw mulching, ii) woody debris and iii) subsoiling and iv) mechanical hole afforestation. In each treatment, we established ten 2 x 2 m plots and ten adjacent untreated burned plots and collected a composite soil sample from each plot four years after the fire (2021). We calculated regulating services as the standardized mean of total soil organic C (climate regulation), soil water repellence (water regulation) and soil aggregation (soil protection). Supporting services were measured as the standardized mean of mineral N-NH4+ and N-NO3- and available P (soil fertility), β-glucosidase, urease and acid phosphatase (nutrient cycling) and microbial biomass (soil quality). Ecosystem multifunctionality was measured as the standardized mean of all functions measured. Application of straw mulch and woody debris increased regulating ecosystem services in relation to burned control plots. Afforestation with holes had no impact but subsoiling decreased regulating ecosystem services in relation to burned control plots. Post-fire treatments did not have any effect on supporting services. Straw mulch, Woody debris and afforestation with holes improved ecosystem multifunctionality when compared with subsoiling methods. These results show that post-fire stabilisation treatments, in particular straw mulching have a significant positive impact on regulating services and are effective measures in restoring the ecosystem multifunctionality, helping develop effective management based-decisions for the recovery of ecosystem services and functioning after large wildfires.

1. Introduction

Wildfires are a very common phenomenon in the Mediterranean Basin and have increased in severity in recent decades, a rise that is likely to continue in the future (Wagenbrenner et al., 2021). This is not only because of increased temperatures and drought with climate change (IPCC 2021) that is exacerbating wildfire conditions, but also because of socio-economic factors such as land use change and urban expansion that are also considered main drivers of increased fire severity and surface (Pausas et al., 2008). Increase fire severity is not only affecting vegetation composition and growth but also lead to the appearance of serious impacts on forest soils such as loss of soil quality, increased runoff, flooding and/or erosion (Fernández-García et al., 2021). All these changes are associated with a loss of important ecosystems functions and services that not only have a negative impact on rural populations but also for society as a whole. These has resulted in both the scientific community and government administrations being increasingly worried in evaluating and implementing measures that help mitigate wildfire impacts. In recent years, effective post-fire measures have been developed focusing on stabilising the burnt area to prevent further additional damage to essential resources such as water supply systems or human infrastructures and critical habitats for protected species (e.g. straw mulching to prevent soil erosion). These measures need to be implemented as soon as possible after the fire to avoid potential damaging effects of rain events as their effectiveness in preventing soil erosion is high (Fernández and Vega, 2016). In other cases, post-fire treatments are implemented to assist and facilitate the recovery of the damaged ecosystem after the wildfire (e.g. vegetation afforestation). This type of treatments is usually applied in areas degraded by repeated fires that prevent the natural regeneration of vegetation (García-Matallana et al., 2022).

Many studies have evaluated the effectiveness of these practices on individual ecosystem properties in soil (erosion, runoff…) (Gómez-Rey et al., 2013; Prats et al., 2021) and vegetation (species richness, vegetation cover...) (Duniway et al., 2015; García-Matallana et al., 2022) but ecosystems provide multiple functions and services at the same time (ecosystem multifunctionality *sensu* Garland et al., 2020). Ecosystem multifunctionality could be considered as the ability of an ecosystem to supply multiple ecosystem functions and services increasing the benefits that societies can be obtain from an ecosystem (Hölting et al., 2019; Liu et al., 2021). However, the influence of these post-fire treatments on the provision of multiple ecosystem services and the recovery of the ecosystem multifunctionality (EMF) has not, to our knowledge, yet been analyzed (Taboada et al., 2021). As a soil contribute to a range of ecosystem services, in this study we focused on a set of ecosystem indicators that are relevant to a successful recovery and functioning of the ecosystem. Soil plays an important role as a carbon sink helping to favour infiltration and mitigate erosion and contributing to the development to microbial community. Therefore, our main objective was to evaluate the medium-term impact of four post-fire treatments (straw mulching, woody debris, afforestation with mechanical hole and afforestation with subsoiling) on ecosystem services and ecosystem multifunctionality after a large wildfire in Northwest Spain

2. Material and methods

The study area is located in the Cabrera mountain range, León province (NW Spain) where a large wildfire burned close to 10000 Ha of forests and scrub dominated areas in 2017 (Fig. 1). The burnt area was dominated by *Quercus pyrenaica* Willd forests and *Pinus sylvestris* L. afforestations (3480 Ha), different scrub formations dominated by *Genista hystrix* Lange, *Erica australis* L., and *Cytisus scoparius* (L.) Link (5440 Ha) and Mediterranean grasslands (580 Ha). The fire was intentionally set and the adverse weather conditions at the time, with maximum temperatures of 35ºC, a 35% relative humidity in combination with two months of drought prior to the fire increased its virulence and facilitated its spread. The climate in the area is Mediterranean with dry temperate summers with mean annual temperatures of 9ºC and mean annual precipitation of 700-800 mm (Iberian Climate Atlas, 2011) The orography is heterogeneous with altitudes ranging from 836 to 1938 m.a.s.l. Soils are acidic (pH ~5), with slates, sandstones, and quartzites from the Ordovician period as the predominant type of rocks (Huerta et al., 2020).

At the end of 2017 and during 2018, the regional government administration implemented a series of post-fire actions aimed at protecting the soil in the most affected and steeper areas and facilitate the recovery of vegetation. These included: (1) addition of straw mulching and (2) woody debris with the aim to protect soil and, (3) subsoiling and (4) mechanical hole afforestation in the steeper areas (Fig.1). In each treatment, ten 2 x 2 m plots and ten adjacent untreated burned plots were established during 2018. In summer 2021, we collected 4 randomly selected soil samples within the 2 x 2 m plots using an auger (7 cm diameter x 3 cm depth) that were pooled together in a composite sample for each plot. Half of the sample was air dried and sieved (<2 mm) to analyse chemical and physical properties and half frozen (-18ºC) to determine soil $N\text{-}NO^{-3}$ and $N\text{-}NH^{+4}$ and microbial biomass an activity. Total organic carbon (TOC) was determined following the combustion method (Dumas 1831), using a EuroVector EA3000 elemental analyser and available P was measured at 882 nm wavelength after digestion with HClO4 (Olsen et al. 1954). We measured weight diameter (MWD) to determine the average size of stable aggregates (Kemper and Rosenau 1986) and we used the water drop penetration test (WDPT) was used to determine soil water repellency (WR) (Doerr, 1998). Ammonium (N-NH4+) and nitrate (N-NO3-) were extracted with 2M KCl at a 1:10 soil-extractant ratio (Keeney and Nelson 1982) and measured by distillation with an automatic micro-Kjeldhal analyzer (Bremner 1965). β-glucosidase (β-D-glucoside glucohydrolase) and acid phosphatase (phosphate-monoester phosphohydrolase) activities were analysed following Tabatabai (1994) and urease (urea amidohydrolase) activity following Kandeler and Gerber (1988). Microbial biomass C was determined by the fumigation-extraction method (Vance et al., 1987).

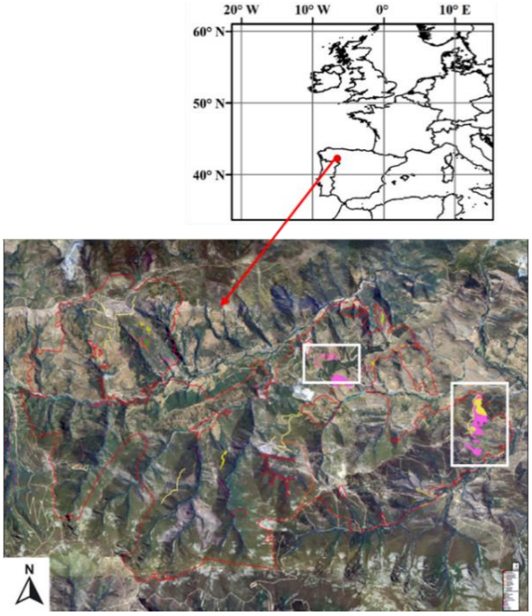

Figure 1- Post-fire treatments (yellow and pink) within the perimeter (red) of Cabrera wildfire which occurred in 2017.

Each of these variables was assigned to a regulating or supporting ecosystem service following Gardlan et al (2020). Regulating ecosystem services indicators were TOC for climate regulation, soil water repellence for water regulation and MWD for erosion protection. Supporting ecosystem services indicators were $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ for soil fertility, β-glucosidase, urease and acid phosphatase for nutrient cycling and microbial C biomass for soil quality. We then calculated a standardized value of regulating and supporting services as the average value of the standardized (between 0-1) corresponding variables. Similarly, ecosystem multifunctionality was calculated as the average standardized values of regulating and supporting ecosystem services.

In order to test differences in provisioning of regulating and supporting ecosystem services between post-fire treatments and unburned controls we used one-way analysis of variance (ANOVA) or nonparametric Kruskal-Wallis test when assumptions for ANOVA were not met. One-way ANOVA was used to compare differences in the recovering of ecosystem multifunctionality between post-fire treatments. Analyses were performed with PAST 4.01 (Hammer et al., 2001).

3. Results and discussion

Post-fire treatments aimed at protecting soil (straw mulch and woody debris) improved the ability of the soil to provision regulating ecosystem services (Fig 2). After a high severity fire, high temperatures in the soil reduced soil organic matter content affecting other related properties such as soil aggregate stability (Fernández-García et al., 2019) and water repellence (Marcos et al., 2018). In our study, both straw mulching and addition of woody debris increased TOC and improved the soil structure by increasing the size of the aggregates in the mid-term whereas soil water repellence was only improved where woody debris was added. Short-term studies found no effect of similar stabilisation treatments on soil quality after 16 weeks (Díaz-Raviña et al. 2012) but our results indicate that they can have an impact in the mid-long term. On the other hand, subsoiling afforestation did not have this beneficial effect in regulating ecosystem services although, individually, it reduced soil water repellence. When afforestation was done mechanically with a hole, the impact in regulating ecosystem services was negative because it did not improve any of the indicators analysed. Similar results were found by Mongil Manso and Bengoa Martínez de Mandojana (1997) that found 20% greater soil moisture in plots that were subsoiled than in plots that had been hollowed, as subsoiling favours soil physical properties related with hydrological processes (Fig. 2).

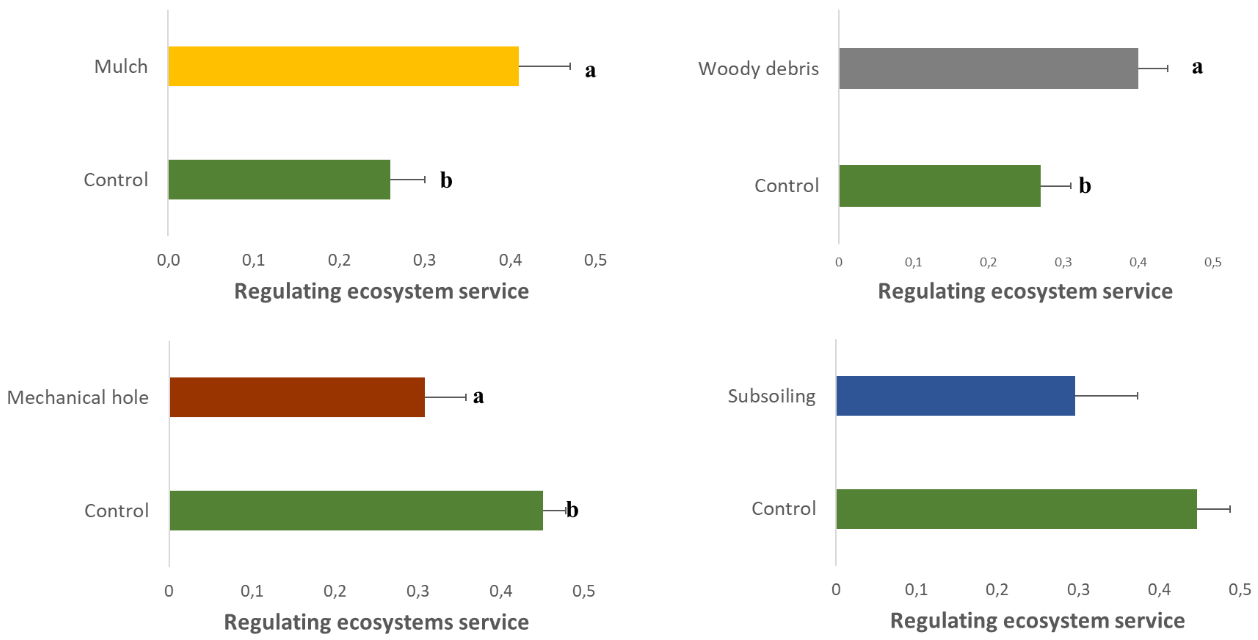

Figure 2. Regulating ecosystem services (Mean and standard error) for post-fire treatments (mulch, woody debris, mechanical hole and subsoiling) and their respective burned controls. Different letters show significant differences at $p < 0.05$.

Supporting ecosystem services were not significantly affected by post-fire treatments and only a slight tendency to improve this service was observed when straw mulching was applied (0.38 in treated plots vs. 0.29 in control plots). Straw mulching tends to improve soil nutrient concentrations (P and N), microbial C biomass and increased enzymatic activities, while in the other post-fire treatments results were not as consistent (e.g. enzyme activities were increased with addition of woody debris and soil microbial C biomass was increased under mechanical hole and subsoiling afforestation treatments). If we compare all treatments together, we observed that those aimed at protecting soil in the short-term were the most effective in facilitating the recovery of the multifunctionality of ecosystems in the mid-term (Fig.3).

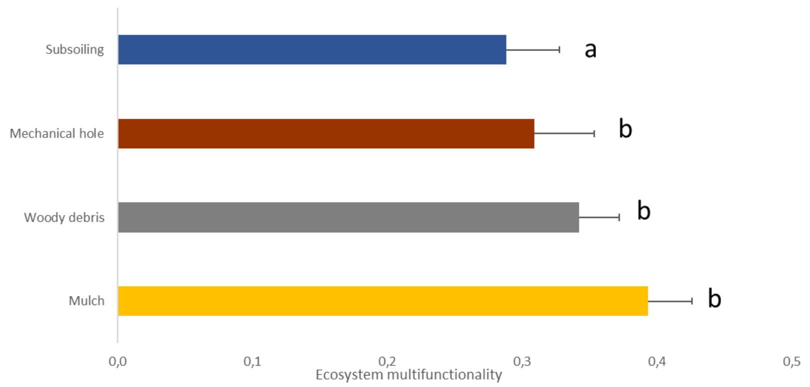

Figure 3. Average value and standard error of ecosystem multifunctionality for each post-fire treatment: mulch, woody debris, mechanical hole and subsoiling. Different letters show the presence of significant differences ($p < 0.05$) among post-fire treatments.

4. Conclusions

This study shows that post-fire stabilisation treatments, and in particular straw mulching, are effective in restoring ecosystem multifunctionality (EMF). These treatments had a significant positive impact on regulating services which may help reduce local and global impacts after a wildfire. However, afforestation with subsoiling or mechanical hole had a negative effect on the recovery of ecosystems functions so these measures are not recommended with we aim at recovering ecosystem functionality. This type of studies is essential in order to make decisions focused on the recovery of functions and services that are strongly impacted by large wildfires.

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