Relationship between immediate fire severity and medium-term post-fire vegetation cover: A case study in NW Spain

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ABSTRACT

Assessing fire severity is crucial for planning post-fire management. However, few studies have examined the relationship between fire severity assessed immediately after wildfire and medium-term post-fire vegetation cover using field data. This study evaluated this relationship in 22 field plots located in shrublands (mainly *Cytisus striatus* and *Pterospartum tridentatum*) and Quercus pyrenaica stands affected by wildfires in NW Spain in 2020. Fire severity was assessed using dNBR, RdNBR and BNDVI, while vegetation cover was measured in the field four years after fire. RdNBR showed the strongest association with post-fire vegetation cover and was significantly correlated with total cover (rho = 0.68; $p = 0.0005$), shrub cover (rho = 0.45; $p = 0.04$) and tree cover (rho = 0.80; $p < 0.0001$). These results suggest that RdNBR may be a useful indicator of medium-term post-fire vegetation cover in these plant communities.

1. Introduction

Fire severity, defined as the magnitude of the fire's impact on vegetation and soil, is a key parameter for assessing ecological response and erosion risk (Keeley, 2009). Although most plant communities of the Mediterranean Basin have a high capacity to recover their composition and structure after wildfire due to their adaptive traits, i.e., resprouting capacity or serotiny (e.g. Keeley and Pausas, 2022), fire severity can significantly affect their post-fire recovery (Keeley et al., 2005; Vega et al., 2008). Vegetation fire severity and soil fire severity can affect the regenerative process through different ecological mechanisms. For example, in areas dominated by resprouters, it has been demonstrated that severe fires can damage belowground portions of shrubs or affect the bud bank limiting post-fire regeneration process (Enright et al., 2011) whereas, previous research in boreal forests has shown that soil burn severity positively affected seedling recruitment and post-fire vegetation recovery (Schimmel and Granström, 1996; Johnstone and Kasischke, 2005). In shrubland communities under oceanic climate, high vegetation severity does not hamper the capacity of regeneration at the medium-term although the role played by the soil burn severity on the regenerative process of these resprouting species has been little explored and the results are inconclusive (Fernández et al., 2019; Fernández, 2023).

Spectral indices are generally used to assess fire severity immediately after fire (e.g., van Wagtendonk et al. (2004); Lentile et al. (2006); Fernández-Manso et al. (2016); Navarro et al. (2017); van Gerrevink and Veraverbeke (2021); Sobrino et al. (2024)). The Normalized Burn Ratio (NBR) is the most commonly used index for post-wildfire severity mapping, and the differenced Normalized Burn Ratio (dNBR) is one of the most widely used vegetation indices to evaluate changes between pre-fire and post-fire conditions (e.g., Key and Benson (2006); Veraverbeke et al. (2010); Llorens et al. (2021)). The RdNBR (Miller and Thode, 2007) is also commonly used as it has been demonstrated its good performance in areas with high vegetation heterogeneity (e.g. Lydersen et al. (2016)). Recently, other indices such as the Blue Normalized Difference Vegetation Index (BNDVI) showed its performance for soil burn severity evaluation (Novo et al., 2024).

Post-fire vegetation recovery has been mostly evaluated through multi-temporal satellite observations, allowing the characterization of vegetation resilience and recovery trajectories across different ecosystems (e.g., Röder et al. (2008); van Leeuwen et al. (2010); Fernández-Manso et al. (2016); Viana-Soto et al. (2020); Pérez-Cabello et al. (2021); Anees et al. (2025). However, and despite the widespread application of remote sensing for fire severity assessment and post-fire monitoring, few studies have evaluated whether fire severity indices derived immediately after fire are significantly associated with field-measured post-fire vegetation cover several years later, particularly in shrublands dominated by resprouting species where vegetation resilience is typically high. Understanding how vegetation recovers after fire, and particularly, the quantitative relationship between post-fire vegetation cover and initial fire severity is crucial for restoration plans. Long-term measurements of post-fire vegetation recovery for differing forest types and fire severity levels can be useful to identify areas where post-fire intervention is necessary. The use of spectral indices could serve to provide a quantitative value of fire severity and determine whether the severity immediately after a fire is related to the regeneration of the assessed vegetation. Therefore, the aim of this study was to evaluate whether vegetation and soil fire severity, measured immediately after fire, influence vegetation cover at the medium-term.

2. Experimental design and field sampling

The study was carried out in two contiguous areas affected by wildfire in NW Spain (Figure 1). The wildfires burned over 2000 ha of shrublands and forest stands in July 2020. Just after fire, 22 field plots were distributed in the burned areas trying to reflect the variability in fire severity.

2.1. Field sampling

The surveyed vegetation types were immature Quercus pyrenaica Willd. stands regenerated from previous fires and shrublands dominated by Cytisus striatus (Hill) Rothm. or Pterospartum tridentatum (L.) Willk. as they were the most common vegetation communities in the burned areas. For each site, the plot center was geolocated using a Global Navigation Satellite System (GNSS), from which two 40 m transects were established coinciding with the plot center. Field data collection was conducted as soon as possible after fire extinction. The procedure, adapted from Fernández et al. (2021) was based on a visual assessment of post-fire vegetation structure. Vegetation burn severity (VBS) was classified in two levels (moderate and high) depending on biomass consumption: moderate when vegetation foliage was charred and high when it was totally consumed. In each plot, we also assessed soil burn severity with the aid of a 20 cm × 20 cm quadrat, which was placed at 80 systematically selected points along the transects. The soil in each quadrat

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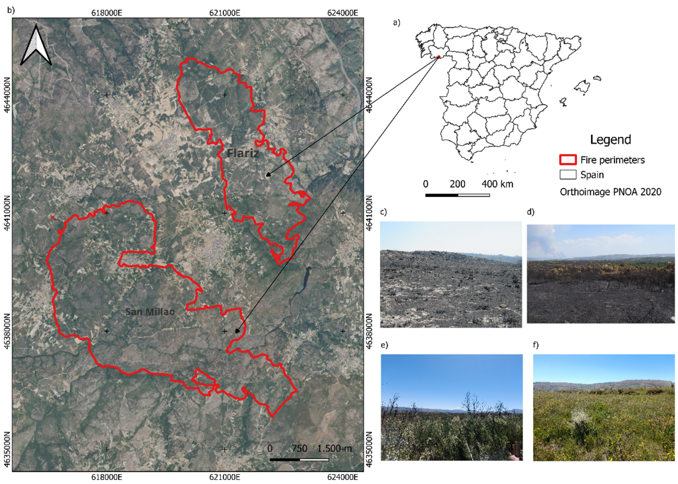

Figure 1: a) Location of the study sites in NW Spain; b) Fire perimeters of the San Millao and Flariz wildfires; (c-f) representative field of post-fire conditions (year 2020); and (e-f) post-fire vegetation conditions at the time of field sampling (year 2024). The map coordination system is ETRS89/UTM zone 29N (EPSG:25829).

was classified following Fernández and Vega (2016). The main characteristics of the field plots are compiled in Table 1.

Table 1
Mean fire severity in the field plots.

Vegetation type	Vegetation burn severity	Soil burn severity
Quercus pyrenaica (10 plots)	Moderate to High	Low to High
Shrubland (12 plots)	High	Low to High

In the spring of 2024, vegetation characteristics were measured in the same plots where the fire severity evaluation was carried out. Cover by all species present was measured for each transect using the line intercept method (Canfield, 1941). Trees, shrubs, and grass cover and also total vegetation cover were calculated for each plot. Total cover was determined by adding up the covers of all species so the final value may exceed 100%.

2.2. Spectral indices

We calculated the spectral indices using data from Sentinel-2 satellite provided by the European Space Agency (ESA). Sentinel-2 is a constellation of two satellites providing high-resolution multispectral optical imagery. All study images used were downloaded from the ESA website (Copernicus Open Access Hub, https://scihub.copernicus.eu/dhus/#/home) and were Level 2A (bottom of atmosphere) reflectance images, which are atmospherically corrected.

To assess the spectral indices, Sentinel-2 Level-2A data were downloaded from the Copernicus browser platform (https://browser.dataspace.copernicus.eu/). Images were acquired as close as possible to the date of the field fire severity assessment, and were selected to ensure limited cloud cover ($< 5\%$) over the study areas. Prefire and postfire image acquisition dates were T29TPG_20200708T112121 and T29TPG_20200906T112121, respectively.

Four spectral indices were selected due to their demonstrated robustness and generalization ability to assess fire severity in different scenarios. Indices were computed at 20 m of spatial resolution. For each sampling point, a 40 × 40 m area was analyzed, and the mean pixel value was calculated for each index.

The dNBR and its relativised form, the RdNBR, both derived from the NBR proposed by Key and Benson (2006) where computed as follows:

$$\mathrm{NBR} = \frac{\mathrm{NIR} - \mathrm{SWIR}}{\mathrm{NIR} + \mathrm{SWIR}} \tag{1}$$

$$\mathrm{dNBR} = (\mathrm{NBR}_{\mathrm{pre}} - \mathrm{NBR}_{\mathrm{post}}) \tag{2}$$

Where NIR (Eq. 1) correspond to band 8 and SWIR (Eq. 1) to band 12 of Sentinel-2 satellite.

The RdNBR, introduced by Miller and Thode (2007), adjusts dNBR by the magnitude of pre-fire NBR values and, were calculated following Eq. 3.

$$\mathrm{RdNBR} = \frac{\mathrm{dNBR}}{\sqrt{|\mathrm{NBR}_{\mathrm{pre}}|}} \tag{3}$$

The BNDVI proposed by Wang et al. (2007) is defined as Eq. 4.

$$\mathrm{BNDVI} = \frac{\mathrm{NIR} - \mathrm{BLUE}}{\mathrm{NIR} + \mathrm{BLUE}} \tag{4}$$

The mean value of each index was obtained for each field plot.

2.3. Statistical analyses

Spearman's rank correlation was used to evaluate the strength and direction of the association between multispectral indices and vegetation variables. The R statistical package (Version 4.4.1.) was used to conduct the statistical analyses.

3. Results

The evaluation of fire severity immediately after fire (July 2020) showed that RdNBR and BNDVI were the best indices to indicate vegetation burn severity and soil burn severity, respectively (Table 2).

Table 2
Spearman rank correlation coefficients between spectral and field fire severity indices

	dNBR	RdNBR	BNDVI
Vegetation burn severity	0.521 ($p = 0.01$)	0.624 ($p = 0.002$)	−0.470 ($p = 0.03$)
Soil burn severity	0.368 ($p = 0.09$)	0.585 ($p = 0.004$)	−0.737 ($p < 0.0001$)

The vegetation parameters obtained in the surveys performed in the fourth spring after fire are summarized in Table 3. The shrubs were the vegetative group showing the highest post-fire cover.

Table 3
Mean and range of variation of the vegetation parameters measured in April 2024

	Total vegetation cover (%)	Shrub cover (%)	Tree cover (%)	Grass cover (%)
Mean	161.4	105.2	2.7	53.6
Range of variation	73.0-284.6	50.0-210.7	0.0-11.5	0.0-170.0

No significant correlations were found between dNBR or BNDVI and the vegetation parameters.

RdNBR showed the strongest association with post-fire vegetation cover four years after fire (Figure 2). The index was significantly correlated with total cover (rho = 0.68; $p = 0.0005$), shrub cover (rho = 0.45; $p = 0.04$) (Figure 3) and tree cover (rho = 0.80; $p < 0.0001$) (Figure 4).

According to Figure 3, vegetation cover increases with RdNBR, with lower values when RdNBR was less than 0.84 and maximum when it when it exceeded 1.14. The RdNBR thresholds of 0.84 and 1.14 were selected based on visual inspection of the relationship between RdNBR and post-fire vegetation cover. Consequently, we reclassified the RdNBR in the two study sites (Figure 5), showing the differences in vegetation cover. This provides a different perspective compared to the fire severity assessment following the levels proposed by Miller and Thode (2007) that is shown in Figure 6.

4. Discussion

The level of post-fire vegetation cover observed in the field plots were similar to those observed after wildfire in shrubland communities in NW Spain (Fernández, 2021). The high post-fire vegetation cover observed may be related to the high resprouting capacity of Atlantic shrubland communities, where post-fire regeneration is primarily driven by vegetative resprouting rather than seed recruitment (Keeley and Pausas, 2022). Interestingly, tree

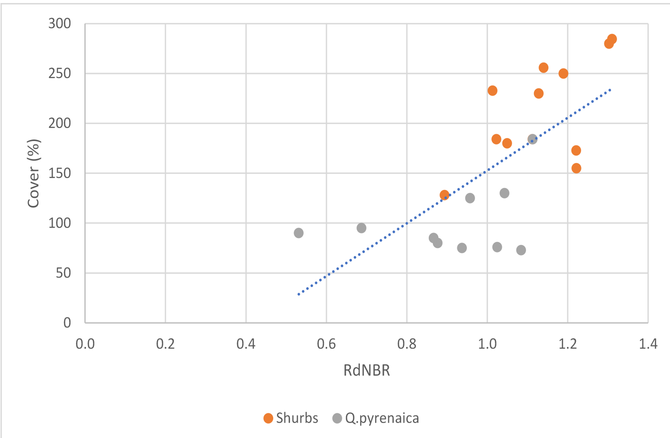

Figure 2: Relationship between the RdNBR index and total cover percentage. The lines represent the fitted relationship.

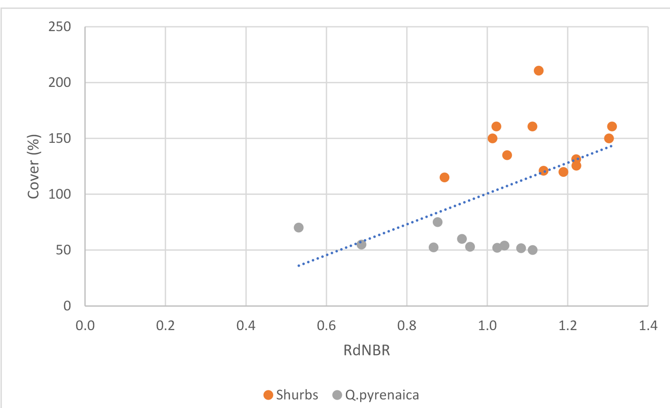

Figure 3: Relationship between the RdNBR index and the shrub cover percentage. The lines represent the fitted relationship.

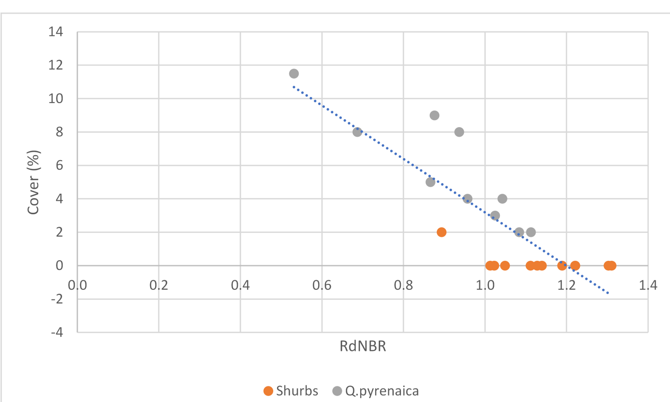

Figure 4: Relationship between the RdNBR index and the tree cover percentage. The lines represent the fitted relationship.

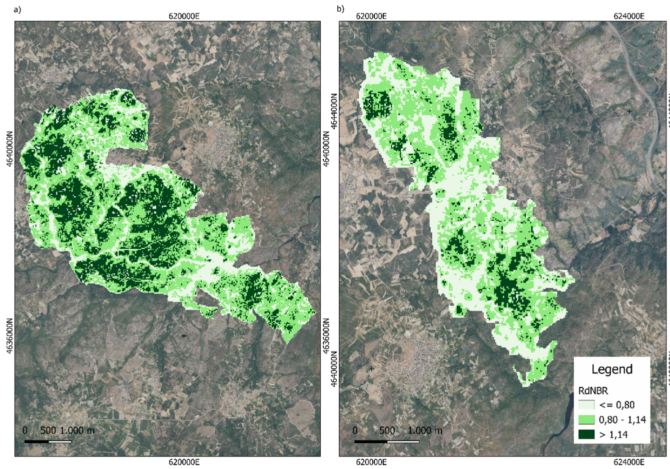

Figure 5: Spatial distribution of the RdNBR in the (a) San Millao and (b) Flariz wildfire perimeters reclassified following vegetation cover in 2024.

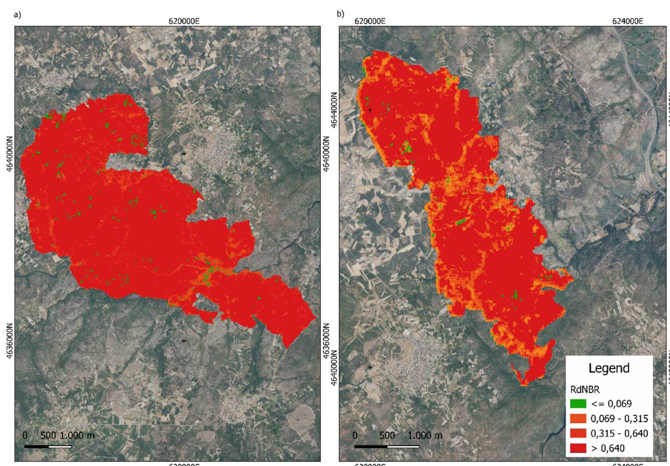

Figure 6: Spatial distribution of the RdNBR in the (a) San Millao and (b) Flariz wildfire perimeters with the fire severity levels proposed by Miller and Thode (2007).

cover four years after fire was positively associated with RdNBR (rho = 0.80; $p < 0.0001$), indicating greater tree cover at higher initial fire severity, in contrast to previous observations in NW Spain (Vega et al., 2005; Fernández, 2022). This positive relationship may reflect the high resprouting capacity of *Q. pyrenaica*, suggesting that higher initial fire severity did not constrain tree cover four years after fire.Fire severity assessment using multispectral indices showed that the performance of the indices is different depending on whether fire severity is evaluated in the vegetation or in the soil and regarding soil burn severity, BNDVI seems to be the best option as previously observed by Novo et al. (2024). Our results showed that the RdNBR is a more effective index for vegetation burn severity mapping as previously found in different ecosystems (Miller and Thode, 2007; De Santis et al., 2010; Quintano et al., 2018; Dos Santos et al., 2020). For instance, Miller and Thode (2007) demonstrated that classifications of the RdNBR can produce higher accuracies for the high severity category than the dNBR, as in the present case of study. In the present study, the underrepresentation of the moderate severity class precludes us to provide vegetation severity thresholds, but the highest severity level was established above 1.0, clearly higher than the 0.640 and 0.732 values proposed by Miller and Thode (2007) or Lydersen et al. (2016). These differences likely reflect the contrasting vegetation structure compared with the conifer forests where those thresholds were originally developed. Given the limited number of field plots, the thresholds identified in this study should be considered exploratory and site-specific and should not be extrapolated to other areas without further validation.

Although several studies have subsequently used burn severity maps derived from RdNBR or dNBR to analyse vegetation recovery (Díaz-Delgado et al., 2003; Meng et al., 2018; Dos Santos et al., 2020; Kim et al., 2021; Zahabnazouri et al., 2025), vegetation trajectories have been generally quantified using remotely sensed vegetation indices such as NDVI, SAVI, NIRv or EVI instead of field data. By contrast, this study relates RdNBR measured immediately after wildfire to vegetation cover measured directly in the field four years later. Until now, most of the immediate fire severity evaluation carried out in NW Spain was related to the assessment of the impact of wildfire for post-fire soil stabilization planning (e.g. Sobrino et al. (2019); Novo et al. (2024)). No information was available on how fire severity is related to post-fire vegetation cover in the medium-term. The results obtained in the present study show how RdNBR may be a useful indicator of not only the immediate impact of the fire but also medium-term post-fire vegetation cover in these communities.

The influence of BNDVI, as a surrogate of soil burn severity, on the regenerative process seems less significant. This is consistent with the results obtained by Fernández et al. (2019) and Fernández (2021) who stated that the vegetative recovery was not influenced by soil burn severity in communities dominated by resprouters.

5. Conclusions

Although the relatively small dataset used in this study prevents us from drawing broad conclusions, the results obtained in this study seem to indicate that RdNBR computed immediately after fire was significantly associated with medium-term post-fire vegetation cover, although further studies with larger datasets are needed to assess the genrality of this relationship. Future studies including a wider range of fire severities, vegetation communities and environmental conditions would help validate the robustness and transferability of this relationship.

Author Contributions

Cristina Fernández: Funding acquisition, Project administration, Resources, Supervision, Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing– Original Draft , Writing- Review & Editing. **Ana Novo:** Methodology, Software, Validation, Formal analysis, Investigation, Data Curation, Writing– Original Draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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