Bulgarian Academy of Sciences. Space Research and Technology Institute.
Aerospace Research in Bulgaria. 36, 2024, Sofia

DOI: https://doi.org/10.3897/arb.v36.e08

COMPARATIVE ANALYSES OF SECONDARY ECOLOGICAL SUCCESSION FOLLOWING WILDFIRES IN THREE DISTINCT FOREST TYPES. A STUDY CASE FROM MOGUER, SPAIN

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Keywords: *Wildfires, post-fire recovery, Remote sensing, Vegetation indices, Ecological succession.*

Abstract

Wildfires have become increasingly prevalent and destructive in forest ecosystems worldwide, necessitating a comprehensive understanding of post-fire recovery dynamics for effective conservation and management. Remote sensing technology, coupled with vegetation indices such as Normalized Burn Ratio (NBR), Normalized Difference Vegetation Index (NDVI), Green Red Vegetation Index (GRVI), and Red Vegetation Index (RVI), offers a powerful means to investigate these processes. In this study, we utilize remote sensing techniques to conduct a comparative analysis of secondary ecological succession following wildfires in three distinct forest types (Coniferous, Sclerophyll, and Mixed) of a forest affected by fire near Moguer, Spain. Through the acquisition and analysis of multispectral satellite imagery, we monitored changes in vegetation health and recovery across the region of interest. The NBR index allowed us to assess the severity and extent of wildfire damage, while NDVI quantified vegetation greenness and regrowth. GRVI and RVI provided insights into subtle variations in vegetation composition and health. We identified distinct temporal and spatial patterns in post-fire recovery among the different forest types by applying these indices for the period between 2017 and 2021. Our findings underscore the significance of understanding the diverse responses of these ecosystems to wildfires. While common recovery patterns emerged, such as an initial decrease in NDVI followed by regeneration, variations were observed in the timing and magnitude of recovery. These distinctions are attributed to differences in species composition, fire adaptations, and ecological processes specific to each forest type. In conclusion, the utilization of NBR, NDVI, GRVI, and RVI indices allows for a more nuanced evaluation of post-fire recovery dynamics.

Introduction

Wildfires have become an increasingly prevalent and destructive force in forest ecosystems worldwide. These events have grown in both frequency and intensity [1]. To effectively address these challenges, it is essential to gain a comprehensive understanding of the dynamics of post-fire recovery. In this context, remote sensing technology has emerged as an invaluable tool, allowing us to observe and analyze these events from a broader perspective. Remote sensing techniques enable us to acquire data through multispectral satellite imagery, facilitating a more detailed examination of post-fire recovery processes [2].

In this study, we aim to employ remote sensing technology and vegetation indices to conduct a comparative analysis of secondary ecological succession following wildfires in *coniferous, sclerophyllous,* and mixed forest types. By utilizing the Normalized Burn Ratio (NBR)[3], Normalized Difference Vegetation Index (NDVI)[4], Green Red Vegetation Index (GRVI)[5], and Red Vegetation Index (RVI)[6], we can assess the severity of wildfire damage and measure vegetation greenness and regrowth, providing critical insights into the impact and recovery of these ecosystems.

Normalized Burn Ratio (NBR) is commonly used to assess the severity of burn scars and monitor post-fire vegetation recovery [7].

Normalized Difference Vegetation Index (NDVI) is widely utilized to evaluate and monitor vegetation health and density, aiding in the assessment of ecosystem dynamics [8].

Green-Red Vegetation Index (GRVI) is specifically designed to emphasize the presence of green vegetation and is valuable in distinguishing plant vigor and stress levels [6].

Ratio Vegetation Index (RVI) is often employed to measure the density and vigor of vegetation cover, particularly in agricultural plots [6].

In this research, we are utilizing these indices to analyze the impact of a recent wildfire on a local forest ecosystem's vegetation cover and health. By integrating these indices, we can gain a comprehensive understanding of the post-fire recovery process, the changes in vegetation density, and the overall ecosystem resilience. The combination of these indices enables us to capture a holistic picture of the complex vegetation dynamics, ensuring a more accurate assessment of the recovery progress and facilitating informed management decisions for ecological restoration.

The relevance and importance of this study are underscored by the urgent need to comprehend how different forest types respond to contemporary wildfires. Each forest type may exhibit unique patterns of post-fire recovery, influenced by species composition, fire adaptations, and ecological processes specific to their environment. This knowledge is critical for developing tailored strategies to conserve and manage these ecosystems effectively.

Study area

The study area is situated close to Moguer town, in the province of Huelva, within the autonomous community of Andalucia (Fig. 1). The fire was declared on June 24, 2017, in Mazagón, within the area corresponding to the municipal district of Moguer, Huelva. It lasted a total of 10 days, and it was extinguished on July 4th. It covers an area of 203.5 km² (20,350 ha) and is positioned at an elevation of 49 meters above sea level. Due to its location along the Huelva coastal area, the study area experiences a Mediterranean climate with influences from the Atlantic, resulting in a maritime climate pattern. The annual average temperature is 19.2°C (Moguer climate station). During summer, the average air temperature is 26°C and the maximum values reach up to 30°C.

Moguer has dry periods in June, July, and August. On average, December is the wettest month with 72 mm of precipitation. On average, July is the driest month with 1 mm of precipitation. The average amount of annual precipitation is 251 mm (https://www.eltiempo.es/moguer.html).

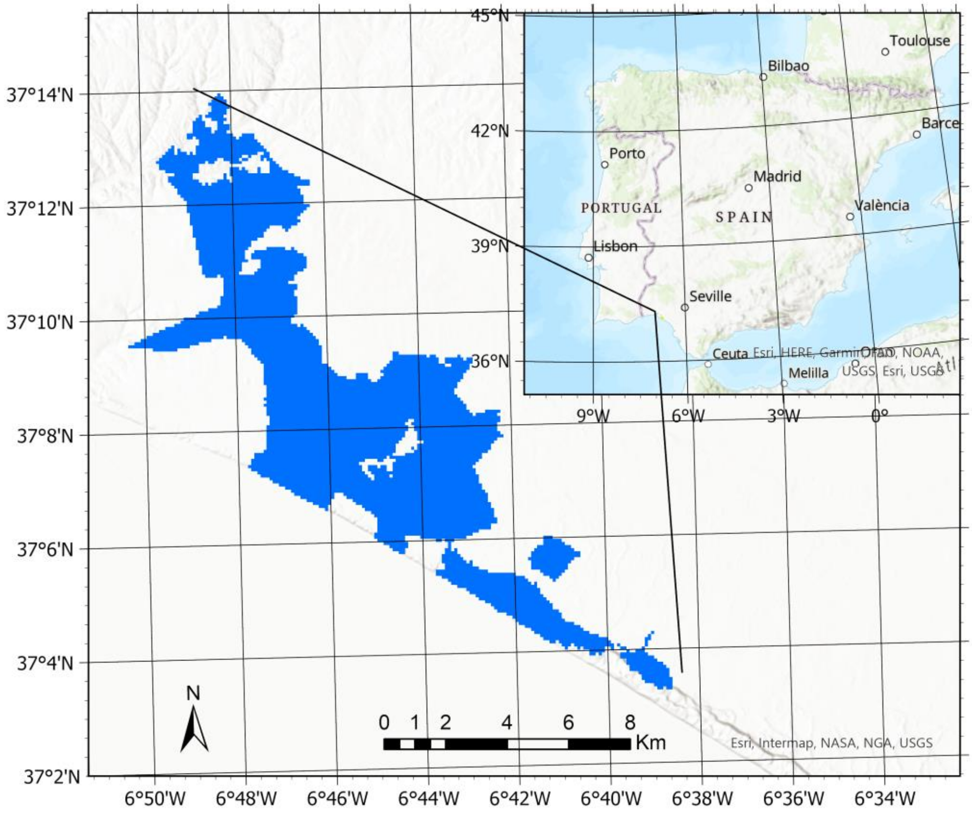

Fig. 1. Map depicting the study area affected by the fire declared on June 24, 2017, in Mazagón

Data and Methods

<u>Data and data processing</u>

A series of multispectral satellite images were acquired from the Landsat 8 satellite for post-wildfire dates, with a spatial resolution of 60 meters. The satellite image pre-processing steps include georeferencing, layer stacking, subseting, etc.

Input data processing

After the pre-processing, spectral vegetation indices were calculated (Table 1). They were used to assess the post-fire vegetation dynamics and to analyze the secondary ecological succession in individual forest types.

Table 1. Formulas for calculating the spectral vegetation indices, used in the present study

Spectral index	Abbreviation	Formula	References
Normalized Difference Vegetation Index	NDVI	$NDVI = \frac{NIR - RED}{NIR + RED}$	[4]
Differenced Normalized Difference Vegetation Index	dNDVI	$NDVI_{post-\text{fire}} - NDVI_{pre-\text{fire}}$	[9]
Normalized Burn Ratio	NBR	$NBR = \frac{NIR - SWIR}{NIR + SWIR}$	[3]
Differenced Normalized Burn Ratio	dNBR	$NBR_{pre-\text{fire}} - NBR_{post-\text{fire}}$	[9]
Green-Red Vegetation Index	GRVI	$GRVI = \frac{GREEN - RED}{GREEN + RED}$	[5]
Differenced Green-Red Vegetation Index	dGRVI	$GRVI_{post-\text{fire}} - GRVI_{pre-\text{fire}}$	-
Ratio Vegetation Index	RVI	$RVI = \frac{RED}{NIR}$	[6]
Differenced Ratio Vegetation Index	dRVI	$RVI_{post-\text{fire}} - RVI_{pre-\text{fire}}$	-

Where NIR represents near-infrared reflectance, SWIR is shortwave infrared reflectance, Red is red band reflectance, and Green denotes green band reflectance.

Analysis of Ecological Succession

Temporal trend analysis was conducted to examine the changes in vegetation over time using the computed dNBR, dNDVI, dGRVI, and dRVI indices. Spatial pattern recognition techniques, including GIS-based analysis, were employed to identify the spatial distribution of different successional stages in the post-fire forest ecosystem.

Software and Tools

Data processing and analysis were carried out using the ERDAS IMAGINE software 2014 (https://hexagon.com/products/erdas-imagine) for image preprocessing and the ArcGIS Pro platform [10] for spatial analysis and visualization.

This research adhered to the ethical guidelines outlined by the International Society for Photogrammetry and Remote Sensing (ISPRS). The limitations of this study include the reliance on satellite data with a 60-meter resolution, which may not capture fine-scale changes in vegetation.

Results

The results are structured to provide a comprehensive understanding of the recovery dynamics, utilizing data from a four-year period (2018-2022) and differential indices, including NBR, NDVI, GRVI, and RVI. The results are organized according to each forest type (*coniferous*, *sclerophyllous*, and mixed forests), highlighting the respective recovery rates, spatial and temporal variations on the regeneration process.

When examining the distribution of dNDVI, dNBR, dGRVI, and dRVI values across *coniferous*, *sclerophyll*, and mixed forests over multiple years (2018-19 to 2021-22), distinct patterns emerge, shedding light on the vegetation health and density within these ecosystems.

The *coniferous* forest consistently flaunted a dNDVI range of 0.1 to 0.2, signifying robust, healthy vegetation recovery. Higher dNDVI values were sporadic. Contrasting this, the mixed forest showed fluctuations, ranging from low to moderate dNDVI values. In recent years, a notable shift towards lower values has been seen, hinting at changing vegetation health. Meanwhile, the *sclerophyll* forest remained steady, maintaining moderate dNDVI values consistently. Its narrative whispered of unwavering stability in vegetation health over time.

The dNDVI for *coniferous* forests predominantly favored the 0.1 to 0.2 dNDVI range throughout, suggesting a consistent presence of healthy vegetation, while the higher dNDVI ranges remained marginal (Fig. 2).

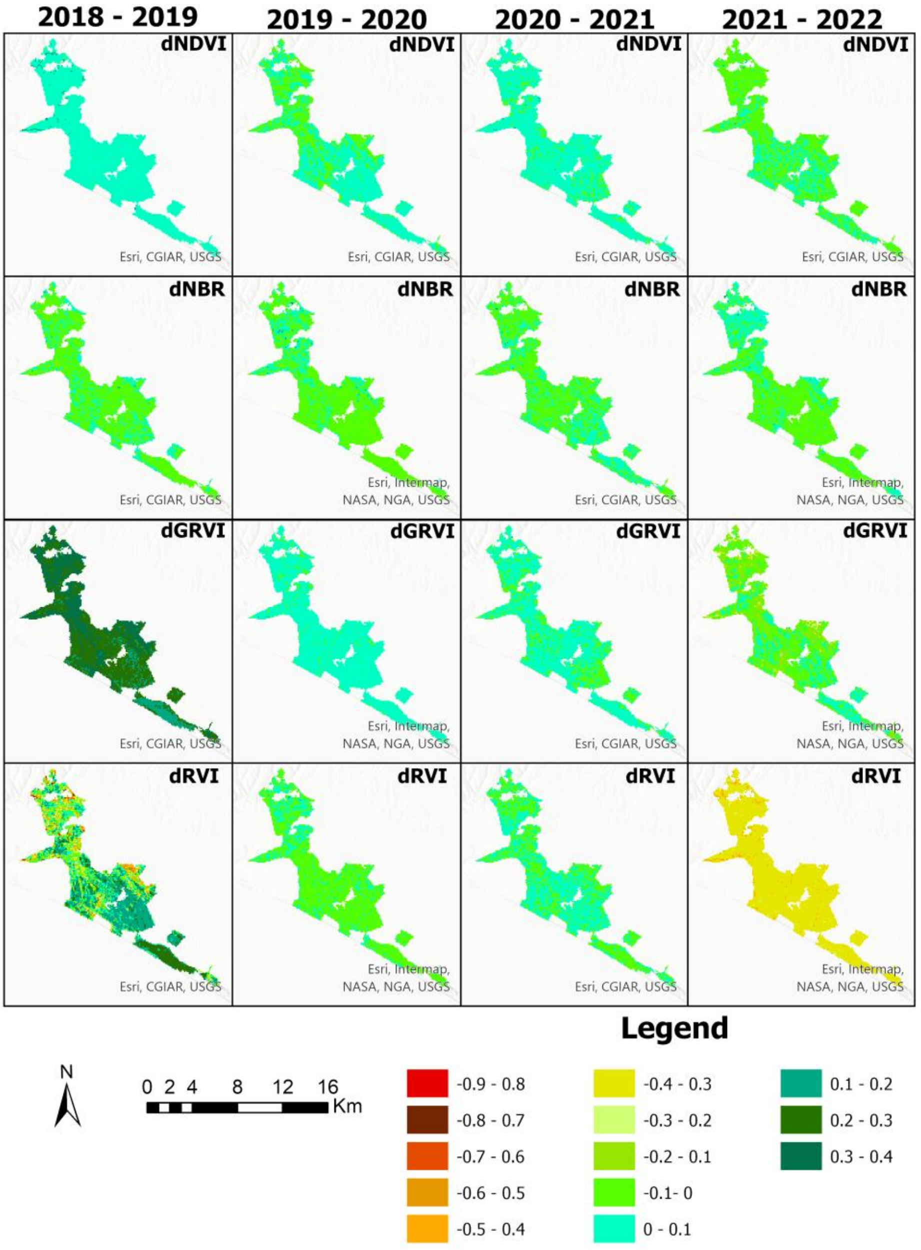

Fig. 2. Classification Results of Four Differential Indexes Four Years Post-Wildfire. The figure illustrates the distinct categorization and evolution of four key differential indexes post-wildfire over a four-year period.

The dNDVI for mixed forest type varied between 0 to 0.2 dNDVI values, showcasing a dynamic response to environmental changes, especially with a significant shift towards lower dNDVI values in recent years (Fig. 3). The dNDVI for *sclerophyll* forest type maintained a consistent presence within moderate dNDVI values, hinting at stable vegetation health trends over the observed years (Fig. 4). Figure 2. Classification Results of Four Differential Indexes Four Years Post-Wildfire. The figure illustrates the distinct categorization and evolution of four key differential indexes post-wildfire over a four-year period.

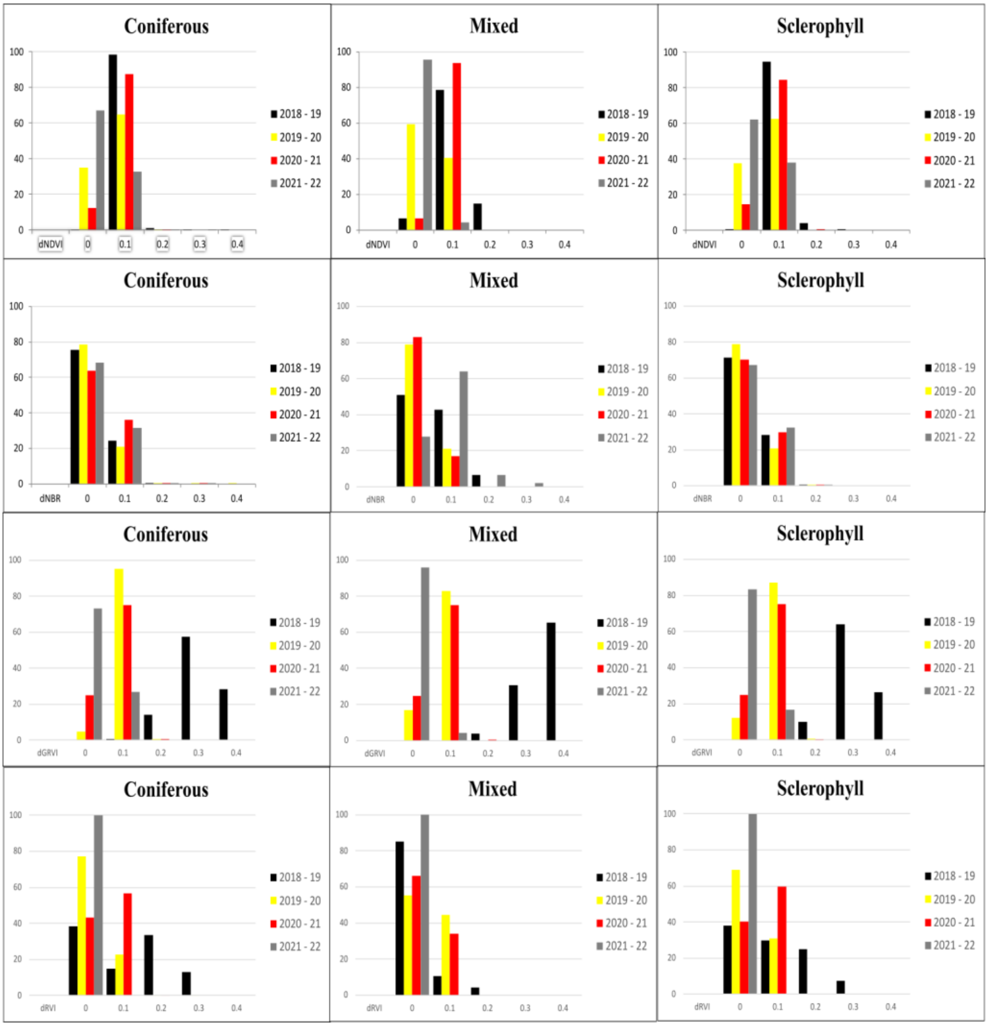

Fig. 3. Percentage covered area per value for every index used for the study

The dNBR for the *coniferous* forest showcased stability in burn severity, primarily residing within the 0 to 0.1 and 0.1 to 0.2 dNBR ranges, indicating minimal changes in post-fire recovery or severity (Fig. 3). The dNBR for mixed forest type notably fluctuated between 0 to 0.3, indicating varied recovery stages or potential environmental stressors influencing the forest (Fig. 2).

The dNBR for the *sclerophyll* forest type showed stability, predominantly residing within 0 to 0.2 ranges, indicating consistent post-fire recovery or limited variations (Fig. 3).

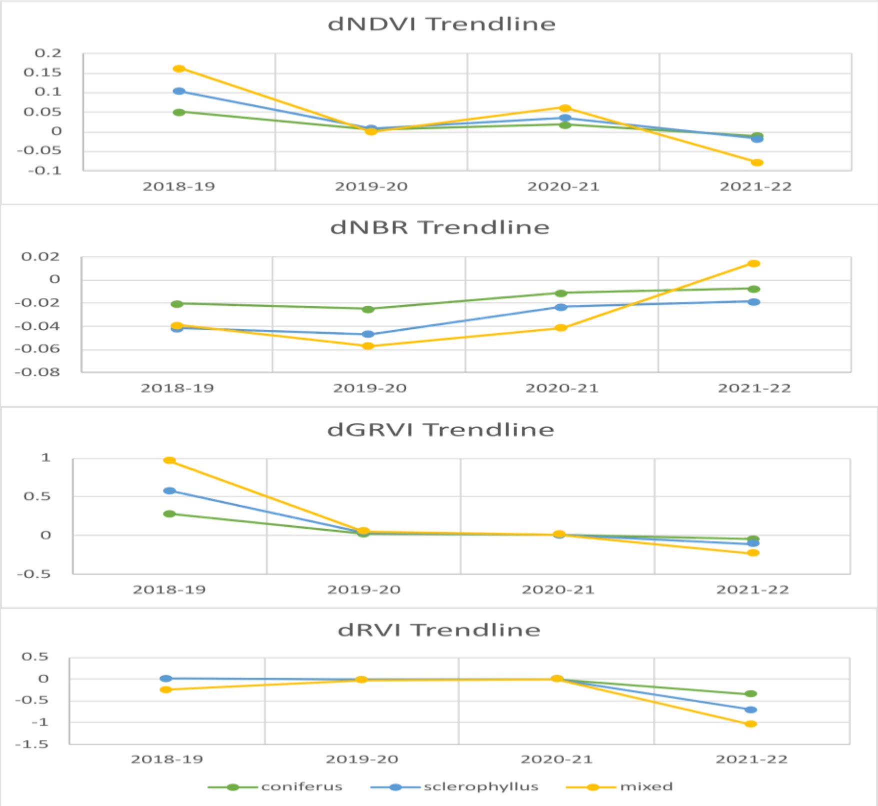

Fig. 4. Trendlines through the years from 2018 to 2022 of the differencial indices dNDVI, dNBR, dGRVI and dRVI

The dGRVI measurements for the three types of forests demonstrated fluctuating patterns, showcasing 0.2 to 0.4 values initially, indicative of robust vegetation recovery, particularly in grasses, within the first year. The subsequent years displayed consistent but comparatively lower recovery rates, characterized by fluctuating dGRVI values, signifying a sustained yet moderated vegetation health and density within this specialized primary growth environment (Fig. 2).

The initial high values of dRVI in certain sites during the first year indicated robust recovery post-disturbance. However, subsequent years revealed declining trends, with dRVI values decreasing over time and eventually reaching negative values by the fourth year.

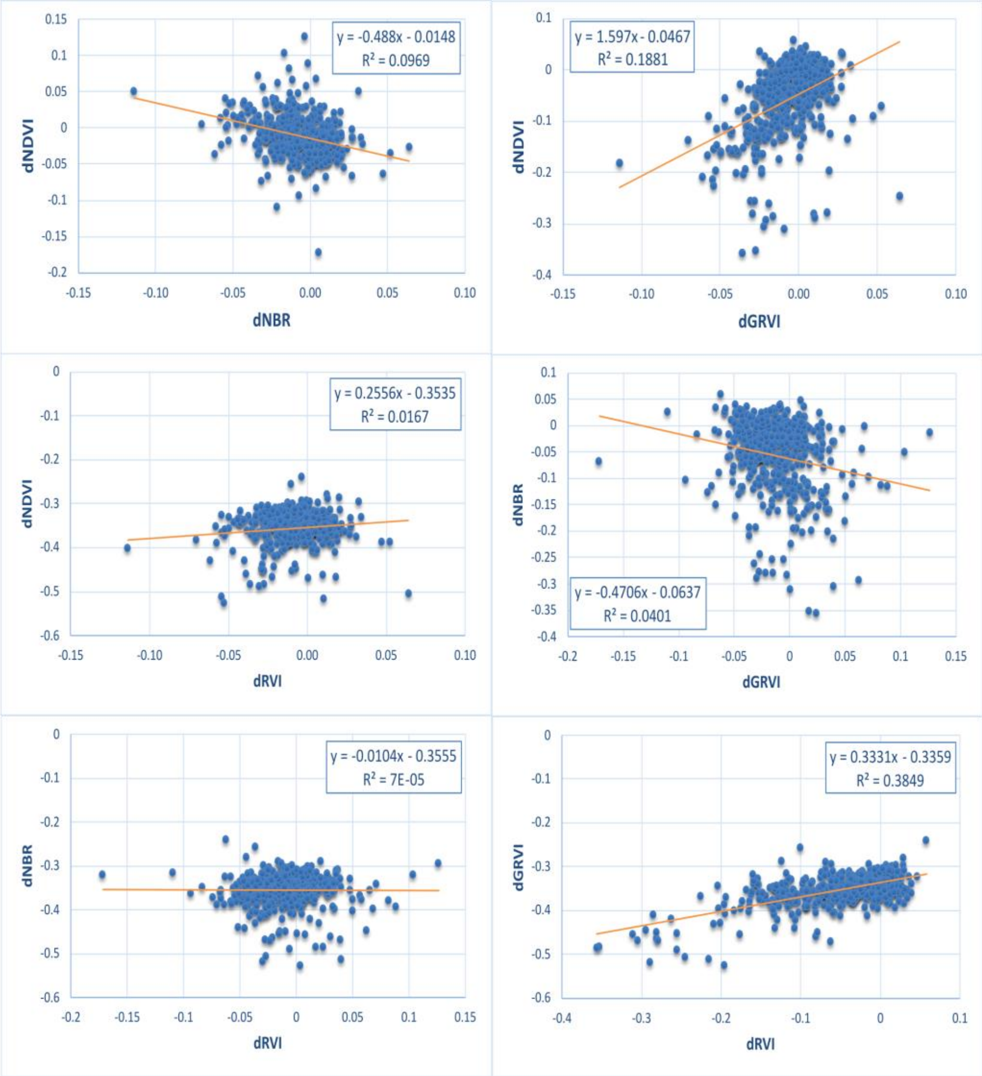

Fig. 5. Correlations between the indices used in this study using linear regression

This diminishing trajectory suggests an initial promising recovery that was not sustained over the long term (Fig. 2).

The integration of dNDVI, dNBR, and dGRVI across the *coniferous*, Mixed, and *sclerophyll* forests presents a multi-faceted understanding of these ecosystems. While the *coniferous* and *sclerophyll* forests displayed relatively consistent trends in vegetation health and recovery, the Mixed Forest stood out with its pronounced variability, indicating a more dynamic response to environmental factors or disturbances (Fig. 4).

The correlation analysis among the indices reveals distinct relationships: a weak negative correlation (r = -0.311) between the change in dNDVI and dNBR, hinting at a slight inverse trend between vegetation health and burn severity. Meanwhile, a moderately positive correlation (r = 0.434) emerges between dNDVI and dGRVI, suggesting parallel movements and potentially similar trends in vegetation health and density changes.

The moderately positive correlation between these indices implies a more aligned relationship between both, hinting that they may respond similarly to changes in vegetation health.

This suggests that dGRVI might serve as a complementary indicator to dNDVI in monitoring vegetation recovery, potentially capturing different types of vegetation response after disturbances. However, the correlation between dNDVI and dRVI is weak (r = 0.129), indicating a lesser association in measuring vegetation recovery. Additionally, a weak negative correlation (r = -0.200) between dNBR and dGRVI implies a subtle inverse relationship between burn severity and fluctuations in vegetation health, while the correlation between dNBR and dRVI is negligible (r = -0.008), suggesting a lack of meaningful relationship between burn severity and the RVI differential index in assessing recovery. This might suggest that the dRVI measures aspects of recovery unrelated to burn severity, emphasizing other factors influencing vegetation dynamics post-fire. Notably, a relatively strong positive correlation (r = 0.620) between dGRVI and dRVI signifies a notable tendency for these indices to move together, potentially reflecting similar patterns in assessing vegetation health and density changes within the study area (Fig. 5). This suggests that dGRVI and dRVI might capture similar aspects of vegetation recovery, potentially providing redundant information or reinforcing each other's assessments.

Conclusions

The comprehensive analysis spanning a four-year period from 2018 to 2022 has unearthed nuanced insights into the recovery dynamics of *coniferous*, *sclerophyllous*, and mixed forests. Through the meticulous examination of differential indices - NBR, NDVI, GRVI, and RVI - distinct patterns emerged, painting a vivid picture of vegetation health, density, and recovery post-disturbance.

The *coniferous* forests boasted a consistent dNDVI range, reflecting robust and sustained vegetation recovery, while sporadic higher values hinted at localized vigor. Contrasting this, the mixed forests exhibited fluctuations, especially towards lower dNDVI values in recent years, indicating evolving vegetation health. Meanwhile, the *sclerophyllous* forests remained steadfast, maintaining moderate dNDVI values, suggesting unwavering stability in vegetation health over time.

Similarly, the analysis of dNBR, dGRVI, and dRVI offered intriguing insights. *Coniferous* forests showcased stability in burn severity, while the mixed forests displayed fluctuations, hinting at varied recovery stages or environmental stressors. *Sclerophyllous* forests demonstrated consistent post-fire recovery.

The correlations among these indices highlighted intriguing relationships. A weak negative correlation between dNDVI and dNBR hinted at an inverse trend between vegetation health and burn severity. Conversely, a moderately positive correlation emerged between dNDVI and dGRVI, suggesting parallel movements in vegetation health and density changes. Interestingly, the correlation between dGRVI and dRVI indicated a notable tendency for these indices to move together, potentially reflecting similar patterns in assessing vegetation recovery.

Looking ahead, future studies could benefit from delving into the influence of various environmental factors, especially the dynamics of climate elements during the research period. Accounting for these factors may provide a more holistic understanding of vegetation dynamics post-disturbance. Conducting such an analysis, while keeping other variables constant, could offer valuable insights into the intricate interplay between environmental factors and vegetation recovery.

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СРАВНИТЕЛНИ АНАЛИЗИ НА ВТОРИЧНА ЕКОЛОГИЧНА СУКЦЕСИЯ СЛЕД ГОРСКИ ПОЖАРИ В ТРИ ОТДЕЛНИ ТИПА ГОРИ. ПРОУЧВАН СЛУЧАЙ ОТ МОГЕР, ИСПАНИЯ

Д. Мони, Д. Аветисян

Резюме

Горските пожари стават все по-разпространени и разрушителни в горските екосистеми по света, което налага цялостно разбиране на динамиката на възстановяване след пожар за ефективно опазване и управление. Технологията за дистанционно наблюдение, съчетана с индекси на растителността като нормализиран коефициент на изгаряне (NBR), нормализиран индекс на разликите в растителността (NDVI), зелен-червен индекс на растителност (GRVI) и червен индекс на растителност (RVI), предлага мощно средство за изследване на тези процеси. В това проучване ние използваме техники за дистанционно наблюдение, за да проведем сравнителен анализ на вторичната екологична сукцесия след горски пожари в три различни типа гори (иглолистни, широколистни и смесени) на гора, засегната от пожар близо до Могер, Испания. Чрез придобиването и анализа на мултиспектрални сателитни изображения ние наблюдавахме промените във възстановяването на растителността в интересуващия ни регион. Индексът NBR ни позволи да оценим тежестта и степента на щетите от горски пожари, докато NDVI количествено определи зелеността и повторния растеж на растителността. GRVI и RVI предоставиха представа за фините вариации в състава и здравето на растителността. Ние идентифицирахме различни времеви и пространствени модели при възстановяването след пожар сред различните типове

гори, като приложихме тези индекси за периода между 2017 г. и 2021 г. Нашите открития подчертават значението на разбирането на разнообразните реакции на тези екосистеми към горските пожари. Докато се появяват общи модели на възстановяване, като първоначално намаляване на NDVI, последвано от регенерация, се наблюдават вариации във времето и степента на възстановяване. Тези разлики се дължат на разликите във видовия състав, адаптациите към пожар и екологичните процеси, специфични за всеки тип гора. В заключение, използването на индекси NBR, NDVI, GRVI и RVI позволява по-нюансирана оценка на динамиката на възстановяване след пожар.