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IN FOREST FIRE MANAGEMENT

TOWARDS AN OPERATIONAL USE OF REMOTE SENSING IN FOREST FIRE MANAGEMENT

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Evolution of $dNBR_{extended}$ in terms of different fire-severity levels and plant communities in wildfires areas of the Pre-Pyrenees (Spain)

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ABSTRACT: Fire severity, time since fire extinction, and ecosystem adaptations to fire are some of the most important factors that influence burn severity, defined as the impact of fire on soil and plants. According to Key and Benson (2006), there are two scenarios under which burn severity can be assessed using the dNBR index: (i) an initial postfire image obtained immediately after the fire, and (ii) an extended postfire image taken during the first growing season following the fire. An extended assessment of the dNBR index provides a better account of burn severity because the delay in the acquisition of postfire images enables the ecosystem to reveal additional responses. Consequently, $dNBR_{initial}$ and $dNBR_{extended}$ can be considered to be representative of fire severity and burn severity, respectively, although long-term monitoring of the temporal evolution of burn severity may provide a better approach to assessing the impact of fire. The objective of this paper is to analyze the temporal evolution of burn severity, taking into account different fire-severity levels and the response to fire of the different plant communities that are representative of sub-Mediterranean forest.

A multitemporal dataset was extracted from 6 wildfires that occurred in 1986 in the Pre-Pyrenees of Huesca province, Northeast Spain. Four different plant communities were considered: (a) pine forest (*Pinus sylvestris* and *Pinus nigra*), (b) oaklands (*Quercus gr. cerrioides* and *Quercus rotundifoliae*, (c) submontane shrubland dominated by *Buxus sempervirens* and *Echinospartum horridum*, and (d) meso-Mediterranean shrubland dominated by *Q. coccifera* and *Genista scorpius*. The images were processed to correct geometric and radiometric distortions. A second-order polynomial equation and a nearest neighbour interpolation method were used for the geometric correction, while the radiometric correction involved conversion to spectral reflectance by normalizing the topographic and atmospheric effects. A long-term application of $dNBR_{extended}$ was then calculated for a continuous series of years (1984–2003), keeping the prefire image (1984) constant and using a postfire image for periods of 1, 3, 5, 7, 9, 11, and 17 years after the fire. Moreover, the first derivative between $dNBR_{initial}$ and every $dNBR_{extended}$ throughout the study period (DBSR) was calculated to quantify changes in plant communities and fire-severity levels.

As expected, the lower the fire severity, the shorter the time taken to reach unburned conditions according to the $dNBR_{initial}$ levels of Key and Benson (2006); however, the lengths of these time periods differ for different plant communities and fire-severity levels: meso-Mediterranean shrubland was the first in neutralizing the fire severity, followed by submontane shrubland, oakland forest, and pine forest. Moreover, only the submontane shrubland took a different period of time to reach the unburned level for each fire-severity level, following the general observed trend. The other plant communities show similar results for the four different levels. Calculation of the first derivative throughout the study period demonstrates the importance of the first year following the fire in terms of changes in the severity variable, thereby enabling its quantification based on plant communities. Meso-Mediterranean shrubland shows the greatest changes regardless of severity level; pine forest shows the least changes.

1 INTRODUCTION

Remote sensing data have considerable potential in terms of analyzing damage levels resulting from wildland fires (Siegert and Hoffmann, 2000) and in monitoring regional-scale postfire recovery processes (Díaz-Delgado and Pons, 2001). Important postfire changes in radiometric response are produced by the modification of soil surface properties and vegetation cover. A number of different methodological approaches based on multitemporal datasets have been used to monitor postfire regeneration, including the Normalized Difference Vegetation Index (NDVI) (Viedma et al., 1997; Pérez-Cabello, 2002; Díaz-Delgado et al., 2003) and Spectral Mixture Analysis (SMA) (Riaño et al., 2002).

Fire severity, time since fire extinction, and ecosystem response to fire are some of the factors that influence burn severity and regeneration dynamics. Burn severity is here defined as the impact of fire on

ecosystem components. According to Key and Benson (2006), burn severity can be measured via an extended assessment of the dNBR index. This ratio makes use of a postfire Landsat TM/ETM+ image from 1 year after the fire and a prefire image from 1–2 years before the fire, provided that the area conditions are comparable. The delay in the acquisition of the postfire image enables the ecosystem to show additional responses in terms of the regeneration intensity of vegetation cover. Therefore, long-term monitoring of the evolution of burn severity (using different postfire images taken over a period of time) may provide a better approach to assessing the impact of fire. Taking into account the fact that fire severity and the strategies of plant communities are important factors in understanding the effect of fire on the postfire vegetation succession (Epting et al., 2005), the objective of the present paper is to analyze the temporal evolution of burn severity in terms of different severity levels and plant communities that are representative of sub-Mediterranean forest in a Pre-Pyrenean area.

1.1 *Site description*

This study was conducted in six areas burned in 1986 within a Pre-Pyrenean range in the northern part of Huesca province (Aragón, Spain). This area has an extensive history of land use and is especially prone to wildland fires. Its location, situated between continental Mediterranean (SE) and Atlantic influences (NE), in tandem with variable topography, generates a heterogeneous climate that can be generally defined as sub-Mediterranean with varying levels of continental influence. The mean annual rainfall varies from 750 to 1000 mm, with an equinoctial rainfall pattern. The mean annual temperature ranges from 10 to 12°C, with warm summers and a high risk of freezing in winter. Four plant communities are considered in this study: (a) pine forest (*Pinus sylvestris* and *Pinus nigra*), (b) oaklands (*Quercus* gr. *cerrioides* and *Quercus rotundifoliae*), (c) submontane shrubland dominated by *Buxus sempervirens* and *Echinospartum horridum*, and (d) meso-Mediterranean shrubland dominated by *Q. coccifera* and *Genista scorpius*.

2 METHODOLOGY

2.1 *Pre-processing the image dataset*

Nine Landsat 5 Thematic Mapper (TM) images (path 30, row 199) recorded in summertime were acquired from 1984 (prefire image) to 2003 (1984, 1986, 1987, 1989, 1991, 1993, 1995, 1997, and 2003). All of the images were geometrically rectified into a local UTM projection (International 1909 Ellipsoid, European Datum 1950, Zone 30 North) using a second-order polynomial model included in ERDAS IMAGINE 8.7. In this rectification model, we incorporated a DEM acquired from the Centro Nacional de Información Geográfica (CNIG) of Spain (pixel size = 10 × 10 m). Ground control points were taken from high-resolution ortho-photographs available in digital format (pixel size = 1 × 1 m). A nearest neighbor resampling technique was used to minimize changes in the radiometric values of the ground data, with the pixels re-projected to 25 m. Moreover, the 1986 image was used as a reference to co-register the remaining images.

To compensate for variations in the radiometric response of the sensor, as well as for the natural conditions of solar radiance and solar angles, data were converted to spectral reflectance values by normalizing the topographic and atmospheric effects. First, the dark-object method (Chávez, 1996) was applied to eliminate the atmospheric effects present in all optical remote-sensing images. Second, conversion from digital values to reflectance was performed via the method proposed by Pons and Solé-Sugrañes (1994).

2.2 *Indexes for monitoring burn severity*

To map burn severity, we calculated the normalized burn ratio (NBR) according to the method proposed by Key and Benson (2006). This index integrates the two most responsive optical regions (albeit in opposite ways) to burning: NIR (from 0.76 to 0.90 μm) and mid-infrared (SWIR) (from 2.08 to 2.35 μm) are combined as follows: $\mathrm{NBR} = \mathrm{NIR}–\mathrm{SWIR}/\mathrm{NIR}+\mathrm{SWIR}$. dNBR, obtained by subtracting the NBR dataset derived after burning from the NBR dataset derived before burning, provides a quantitative measure of change.

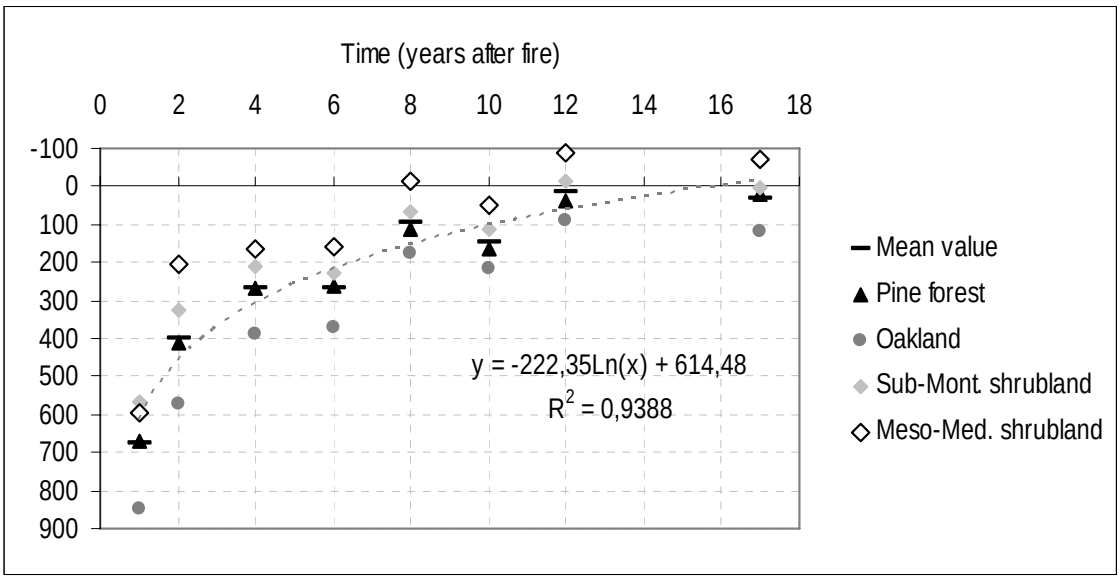
Take into account the period of analysis (1984–2003), a long-term application of $\mathrm{dNBR}_{\mathrm{extended}}$ was calculated, keeping the prefire image (1984) constant and using postfire images from periods of 1, 3, 5, 7, 9, 11, and 17 years after the fire. Moreover, to take into account the reduction in severity over time, the index of Decrease Burn Severity Rate (DBSR) per year was designed and calculated as follows: DBSR = ($\mathrm{dNBR}_{\mathrm{initial}} - \mathrm{dNBR}_{\mathrm{extended\ date\ (from\ 1987\ to\ 2003)}}$) / (number of years between $\mathrm{dNBR}_{\mathrm{initial\ date}}$ and $\mathrm{dNBR}_{\mathrm{extended\ date}}$). The degree of change was then analyzed considering four different plant communities and four fire-severity levels according to Key and Benson (2006). Thus, the continuous dNBR after fires have been

stratified into ordinal classes or severity levels is as follows: low (100–270), moderate-low severity (270–440), moderate-high severity (440–660), and high severity (>660).

3 RESULTS AND CONCLUSION

Tables 1 and 2 show the temporal evolution of $dNBR_{extended}$ and DBSR values, respectively, throughout the study period. As expected, the decrease in fire effects, as measured by $dNBR_{extended}$, generally fits a logarithmic function. This demonstrates the importance of the initial years following the fire in terms of changes in severity in these sub-Mediterranean environments (Figure 1).

Figure 1. dNBR temporal evolution regarding plant-communities



One year after the fire, none of the considered plant communities showed high burn-severity values; 9 years after the fire, all of the plant communities showed dNBR values less than 233 (low severity level).

The global model shows a number of peculiarities with regard to the interactions generated between plant communities (different regeneration strategies) and fire-severity levels. In terms of high severity levels, oakland, pine forest, and submontane shrubland show a decrease in burn-severity rate (DBSR) from 1986 to 1987 of 330–345 points (thereby attaining a moderate-high severity level), whereas meso-Mediterranean shrubland shows a decrease in severity rate of 500 points (attaining the moderate-low severity level). Consequently, statistically significant differences are observed between meso-Mediterranean shrubland and the remaining plant communities.

During stages of moderate-high burn severity, lower DBSR values were observed, and there were no statistically significant differences among plant communities immediately after the fire. DBSR values are similar for sub-montane shrubland and oakland, (approximately 250), very low for pine forest, and again very high for meso-Mediterranean shrubland (approximately 415). This enables the plant community to reach the moderate-low burn severity level after a period of just 1 year from the fire. At lower burn-severity levels (moderate-low and low), no differences are observed among the plant communities, although the smallest changes are recorded by meso-Mediterranean shrublands. Therefore, meso-Mediterranean shrublands are the most resilient plant communities from a radiometric viewpoint, regardless of severity stage. This capacity of meso-Mediterranean shrubland is also manifested from an ecological point of view (Pérez-Cabello, 2002). DBSR values measured 9 years after the fire are very low (approximately –75, –50, –35, and –15 for high, moderate-high, moderate-low, and low burn severity, respectively). At the end of the study period, no DBSR values were higher than –50.

Table 1. $dNBR_{extended}$ values

	Burn severity levels »	*High*		*Moderate-high*		*Moderate-low*		*Low*	
Time	Plant-communities	N	Mean	N	Mean	N	Mean	N	Mean
1986	Oakland	338	876	139	555	47	365	27	200
1986	Pine forest	561	959	74	563	33	358	21	204
1986	Submontane shrubland	341	811	304	554	127	369	59	197
1986	Meso-Mediterranean shrubland	137	815	135	559	27	370	16	193
1 year after fire	Oakland	338	532	139	298	47	229	27	210
1 year after fire	Pine forest	561	625	74	431	33	380	21	239
1 year after fire	Submontane shrubland	341	475	304	305	127	185	59	124
1 year after fire	Meso-Mediterranean shrubland	137	315	135	144	27	122	16	104
9 years after fire	Oakland	338	221	139	106	47	87	27	74
9 years after fire	Pine forest	561	233	74	174	33	170	21	112
9 years after fire	Submontane shrubland	341	180	304	104	127	53	59	32
9 years after fire	Meso-Mediterranean shrubland	137	120	135	10	27	32	16	3
17 years after fire	Oakland	338	81	139	-40	47	-57	27	-59
17 years after fire	Pine forest	561	148	74	53	33	5	21	-50
17 years after fire	Submontane shrubland	341	72	304	11	127	-74	59	-86
17 years after fire	Meso-Mediterranean shrubland	137	-17	135	-98	27	-96	16	-53

Table 2. Decrease burn severity rate (DBSR) values

	Burn severity levels »	*High*		*Moderate-high*		*Moderate-low*		*Low*	
Years after fire	Plant-communities	N	Mean	N	Mean	N	Mean	N	Mean
1 year after fire	Oakland	338	-343	139	-257	47	-136	27	10
1 year after fire	Pine forest	561	-334	74	-132	33	22	21	35
1 year after fire	Submontane shrubland	341	-336	304	-249	127	-184	59	-73
1 year after fire	Meso-Mediterranean shrubland	137	-500	135	-415	27	-247	16	-89
9 years after fire	Oakland	338	-73	139	-50	47	-31	27	-14
9 years after fire	Pine forest	561	-81	74	-43	33	-21	21	-10
9 years after fire	Submontane shrubland	341	-70	304	-50	127	-35	59	-18
9 years after fire	Meso-Mediterranean shrubland	137	-77	135	-61	27	-37	16	-21
17 years after fire	Oakland	338	-47	139	-35	47	-25	27	-15
17 years after fire	Pine forest	561	-48	74	-30	33	-21	21	-15
17 years after fire	Submontane shrubland	341	-43	304	-32	127	-26	59	-17
17 years after fire	Meso-Mediterranean shrubland	137	-49	135	-39	27	-27	16	-14

We observed a statistically significant regression between fire severity and burn severity (dNBRextended at 17 years after the fire). From an ecological perspective, Robichaud and Waldrop (1994) and DeBano et al. (1998) reported that high-severity burned areas register lower rates of vegetation recovery due to the higher consumption of the forest floor and canopy; however, the regression value is low (r2 = 0.278), and considering images closer to the time of the fire, adjusted R squared values never exceed 0.55 (r2 = 0.543 1 year after fire at dNBRextended 1987). Therefore, taking into account measurements of dNBR based on multitemporal Landsat TM/ETM+ datasets, it can be said that the regression value between high severity values and low rates of vegetation recovery is not always high.

Three main conclusions can be drawn from the results of the present work: (1) DBSR can be used as an indicator in assessing the recovery of burned areas; (2) interactions between fire severity and plant communities are important in understanding long-term postfire effects; and (3) meso-Mediterranean shrubland shows high potential in lowering burn-severity levels, whereas pine forest registers the smallest changes.

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