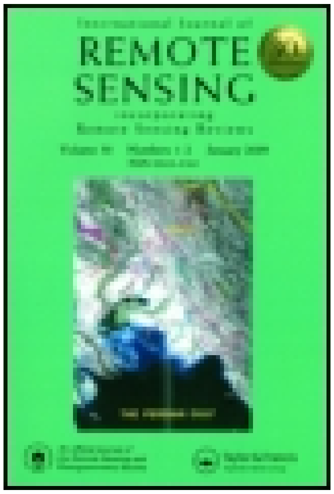

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Temporal evolution of the NDVI as an indicator of forest fire danger

P. ILLERA [a], A. FERNÁNDEZ [a] & J. A. DELGADO [a]

[a] Departmento Fisica Aplicada I, University of Valladolid, Avda Madrid 57, Palencia, 34071, Spain

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Temporal evolution of the NDVI as an indicator of forest fire danger

P. ILLERA, A. FERNÁNDEZ and J. A. DELGADO
University of Valladolid, Departmento Física Aplicada I, Avda Madrid 57, 34071 Palencia, Spain

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Abstract. This work presents a study of the possibility of estimating forest fire danger by means of the analysis of the temporal evolution of the Normalized Difference Vegetation Index (NDVI) Advanced Very High Resolution Radiometer (AVHRR). Images of Spain corresponding to areas of Valencia and Eastern Andalusia in 1993 have been used. The slope of the evolution curve of the NDVI is an indicator of water stress and it is used to estimate danger. Forested areas are previously selected using the NDVI integral in the period studied. In order to determine the reliability of the index, ground data measured by the Spanish National Forestry Service (ICONA) are available to us.

1. Introduction

Forest fires are one of the main problems facing Mediterranean forests. There has been an alarming number of fires in Spain in the last 10 years and, in spite of an increasing awareness and an improvement in prevention as well as fire fighting techniques, each summer large areas of forest are destroyed.

According to the data provided by the Spanish Forestry Service ICONA (ICONA 1993), in the province of Valencia, which has a forested area of 935 700 ha, 63 085 ha were destroyed by 1019 fires in 1991, 1992 and 1993. A mere 17 fires caused 86 per cent of the total damage. This phenomenon is common to all Spanish Mediterranean forests, as a result of which the setting up of a danger index for these large fires is of the greatest importance.

Remote sensing is a very useful tool for monitoring the state of forests. The Normalized Difference Vegetation Index (NDVI) offers a good correlation with different physiological variables such as green biomass, leaf area index, evapotranspiration and photosynthetically active radiation absorbed by plants, (Tucker 1979, Sellers 1989). In particular, polar orbiting meteorological satellites, such as the National Oceanic and Atmospheric Administration (NOAA) Series offer good possibilities for monitoring the state of the vegetation, as they provide multi-spectral data over large areas of land with an extremely adequate temporal frequency, sweeping over the same area of land several times a day (Kidwell 1991).

The NDVI obtained from the NOAA-AVHRR images has been used to evaluate the danger of fire (Chuvieco and Martin 1994). The majority of studies use the NDVI temporal evolution as a measure of vegetal fuel moisture. Good correlations are generally found in grasslands, (Paltridge and Barber 1988) and an effort is being made to extend the results to forests (Eideshink *et al.* 1990, López *et al.* 1991, Burgan and Hartford 1993, González and Casanova 1993).

Our aim is to develop an operational system to monitor forest fires using NOAA

AVHRR images which we obtain by means of an HRPT receiver installed in our Department, (Illera *et al.* 1995). In this study, we have used the temporal evolution of the NDVI in Spain to evaluate forest fire danger which is linked to the state of the vegetation. In order to do this, images were captured in 1993 and the behaviour of the NDVI in Valencia and Eastern Andalusia was analysed. The slope of the temporal evolution of the NDVI is used to evaluate the danger. As a previous step, areas of interest are chosen using the NDVI integral during the period of study. The results are compared with ground data measured by the Spanish National Forestry Service ICONA.

2. Description of the study area

In order to carry out the study, the two areas shown in figure 1 have been chosen. The first area includes the provinces of Castellon and Valencia, situated on the East coast of the Iberian Peninsula. The second area includes the provinces of Almeria, Granada, Cordoba, Jaen and Malaga, in the south-east of the peninsula. We shall refer to these areas as Valencia and Eastern Andalusia.

In both cases, the forest systems which are most representative are those with conifers, the pine being the main species. As regards broad-leaf trees, the holm oak is prominent and although it covers smaller areas it is quite common in the provinces of Castellon, Jaen, Cordoba and Granada. The presence of areas of thickets and shrub-like formations should also be mentioned.

As regards the incidence of forest fires, table 1 shows the data corresponding to 1991, 1992 and 1993 which were recorded by the Spanish National Forestry Service, (ICONA 1993). The number of fires is shown together with the total area affected for the different provinces in the study. The phenomenon is quite intense in Valencia with 1701 fires and 87 800 ha. If an analysis is made of the areas affected by large fires, it

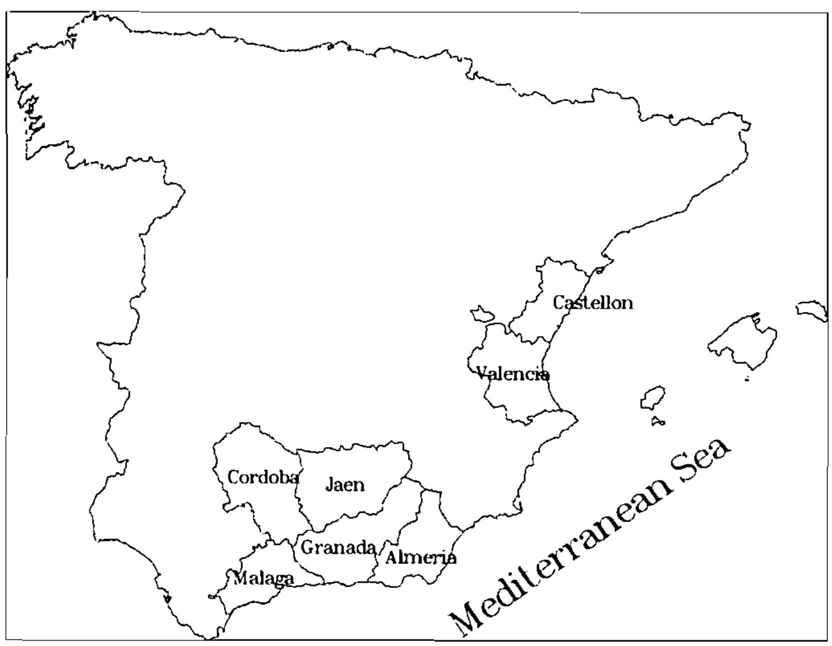


Figure 1. Study area.

Table 1. Forest fires in the study area. Years 1991, 1992 and 1993.

	Year		1991		Year		1992		Year		1993	
			> = 500 ha				> = 500 ha				> = 500 ha	
Area	No	Area (ha)	No	Area (ha)	No	Area (ha)	No	Area (ha)	No	Area (ha)	No	Area (ha)
Castellon	252	3365	2	2400	214	9233	3	7976	216	12116	3	10551
Valencia	358	38670	9	35170	354	12970	4	9144	307	11445	4	10025
Almeria	158	14962	1	12324	100	2850	1	737	98	1665	1	800
Granada	229	1560	0	0	160	1164	0	0	115	7872	2	7353
Malaga	351	13454	3	10915	399	5675	2	1455	280	4615	2	1953
Cordoba	336	4214	0	0	168	307	0	0	138	167	0	0
Jaen	187	6221	4	3050	122	534	0	0	169	500	0	0

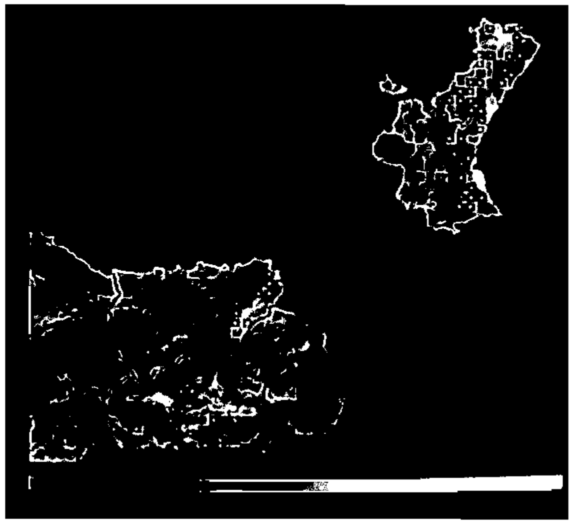


Figure 2.

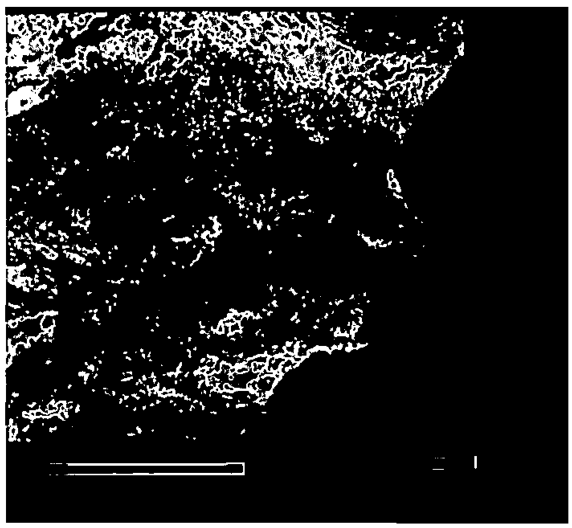


Figure 4.

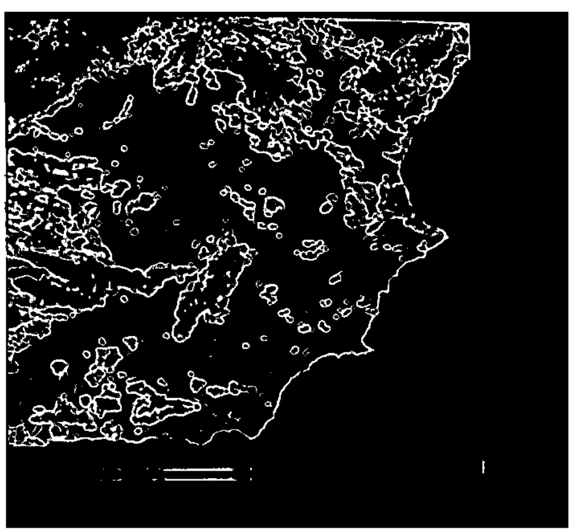


Figure 6.

can be seen that 1·5 per cent of the cases accounted for the destruction of 85·7 per cent of the total surface, which confirms the interest in establishing a danger index for extreme cases. In Andalusia the conclusions are analogous although fires destroyed only quite small areas and the incidence of large fires is not as great.

Among the causes of fires, one might mention the prolonged drought which has been affecting these areas as well as the high temperatures which are reached in summer with July, August and September being the periods of greatest danger. Finally, although from the data in table 1 one might conclude that the importance of fires has diminished in recent years, preliminary data of 1994 provides results which might be described as catastrophic, with over 70 000 ha destroyed by six large fires in the province of Valencia alone (ICONA 1994).

3. Data

NOAA AVHRR images captured at the University of Valladolid have been used. We have an HRPT-NOAA receiver which allows us to capture 10-bit images of up to 2000 km by 2000 km. The signal received contains the radiance values of the HIRS, MSU, SSU and AVHRR radiometers. In order to establish the danger index, the NDVI is generated from channels 1 and 2 of the AVHRR the images are calibrated (Kaufman and Holben 1993) and are georeferenced in a UTM projection and a 1 km by 1 km resolution using our own software (Illera *et al.* 1996).

Table 2. Forest fires in the study area in July, August and September 1993. Frequencies and burnt surfaces for different fire sizes are shown.

	Valencia		East Andalucia	
Size (ha)	Number	Area	Number	Area
0	57		83	
0 to 100	204	809	253	1376
100 to 200	1	100	3	470
200 to 300	5	1205		
300 to 400			1	390
400 to 500				
500 to 600	1	505		
600 to 700				
700 to 800			1	800
1100 to 1200			1	1130
2000 to 2100	1	2087		
2100 to 2200	1	2135		
2200 to 2300	1	2233		
>3200	3	13346	1	6223

Figure 2. 617 fires in Valencia and East Andalusia during July, August and September 1993. They are located in a 10 km by 10 km grid and have been superimposed on the NDVI-MVC from 9 to 18 August. Green: one; blue: two to six; red: more than six.

Figure 4. AS_n for the period from the 9 to the 18 of August.

Figure 6. NDVI integral over the same period as AS_n in figure 4.

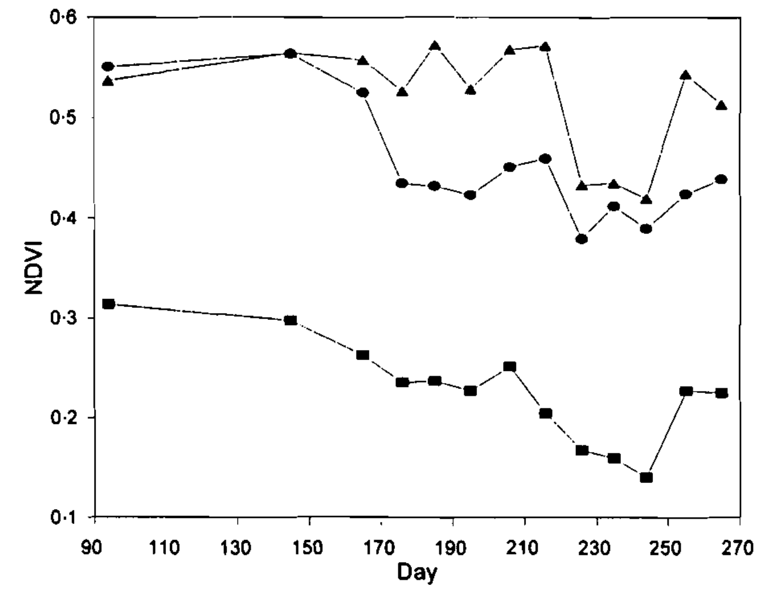


Figure 3. NDVI temporal evolution in three sectors of the study area. ▲ pines, ● holm oaks and ■ shrubs.

The images correspond to 1993 and the period between the beginning of April and the end of September has been analysed because, as we have said, the months of greatest danger in the area studied are July, August and September.

In order to analyse the temporal evolution of the NDVI, the maximum value composite (MVC) image is generated every 10-day period. During the period from 1 April to 10 May only two MVC images are generated (1 April to 10 April and 21 May

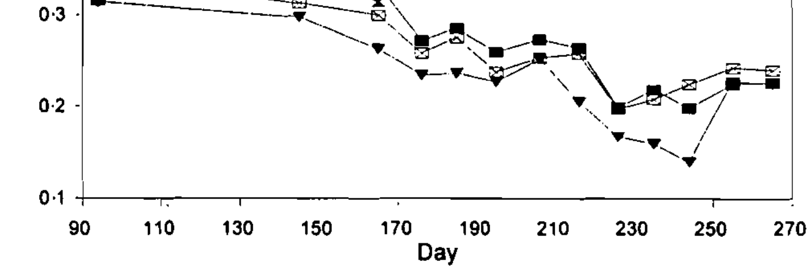


Figure 5. NDVI evolution for different vegetal covers. ▲ pines, ● holm oaks, ▼ shrubs, ⧗ vineyards, ⊠ olive trees, ■ crops.

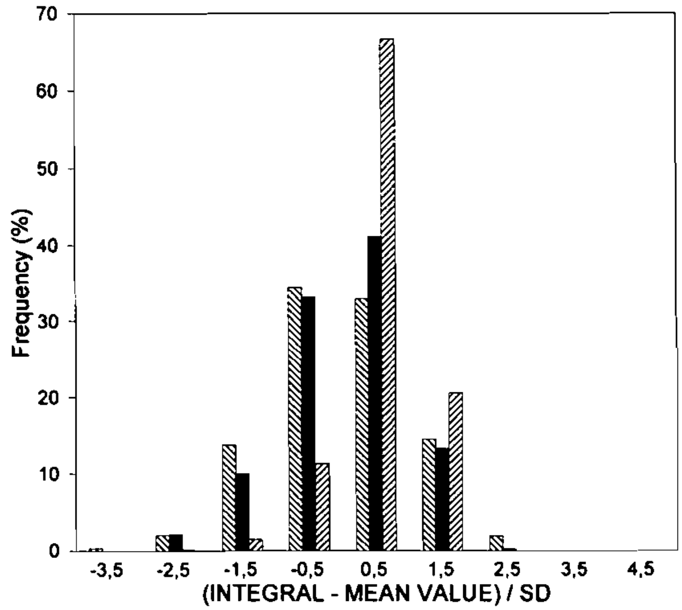


Figure 7. NDVI integral and fire occurrence. The classes correspond to typified values of the NDVI integral for the whole analysed period. Ground data have been superimposed. 58 per cent of fires and 87 per cent of the burnt surface take place for integral values higher than the average over each period analysed. ▧ all, ◨ fires, ▨ burnt surface.

to 30 May) which serve as a reference for the state of the vegetation in spring. After 10 June a MVC image is used for each 10 days as this now corresponds to the danger period. This represents a total of 13 NDVI MVC images.

Ground data provided by the Spanish National Forestry Service are also used. The affected areas and locations of the fires in a 10 km by 10 km network are available, which gives rise to a certain inaccuracy when superimposing the fires and the data from the images. Figure 2 shows the 617 forest fires which occurred in Valencia and Eastern Andalusia in July, August and September 1993, superimposed on the NDVI-MVC for the period from 9 to 19 August. 274 fires and 22 690 ha correspond to the community of Valencia, where the phenomenon is extremely common every summer. In Eastern Andalusia there were 343 fires with a total of 10 389 ha destroyed by fire.

Table 2 shows the frequencies of the fires in terms of the area affected for both communities. It can be seen that there are a large number of small fires but, as we have already mentioned, most of the area that is destroyed is the result of an extremely small number of fires.

Finally, given that the location of the fires in the 10 km by 10 km network used by ICONA is available to us, in order to superimpose the ground and image data we averaged the 10 by 10 corresponding pixels in the NOAA image.

4. NDVI evolution and fire danger

The idea of deriving a danger index for forest fires using the NDVI temporal evolution is based on monitoring the state of the vegetation and, especially, vegetation moisture. A decrease in the NDVI may sometimes be linked to an increase in

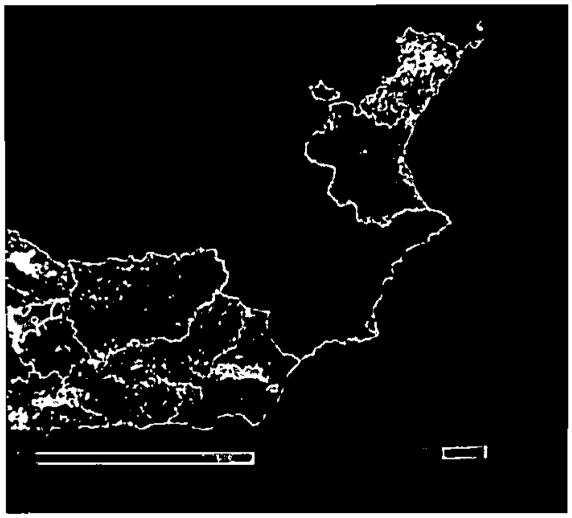


Figure 8. Result of filtering the AS_n values in figure 4 using NDVI integral values.

water stress, with the resulting increase in fire danger. Figure 3 shows the evolution of the NDVI in three sectors of the study area corresponding to pine and holm oak forests and to shrub formations.

As a danger indicator, the accumulated slope of the curve of the NDVI temporal evolution has been studied from spring to the period at which the fire occurred

$$AS_n = \sum_{i=1}^{n} \frac{\mathrm{NDVI}(t_i) - \mathrm{NDVI}(t_{i-1})}{t_i - t_{i-1}} \tag{1}$$

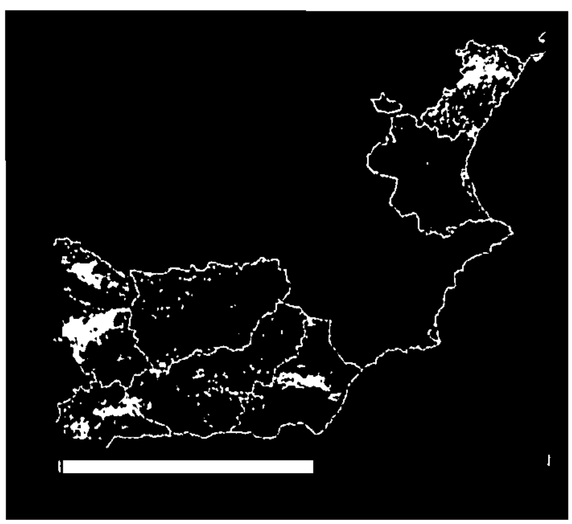
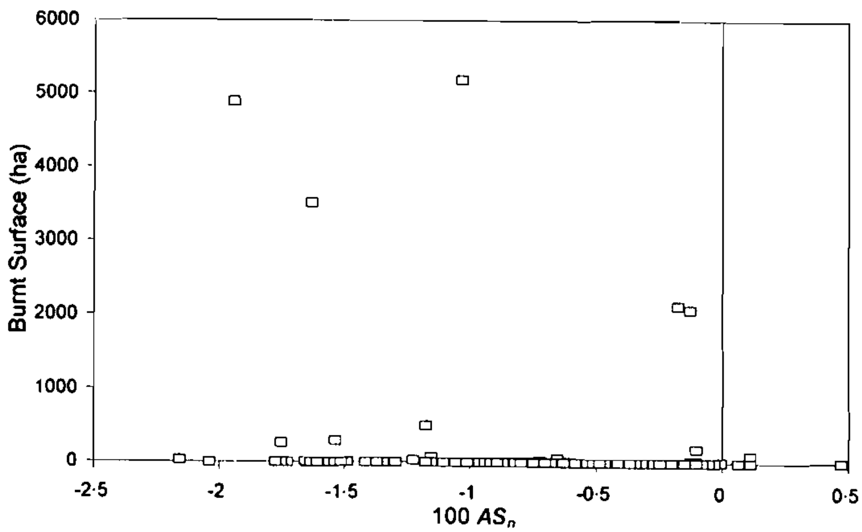


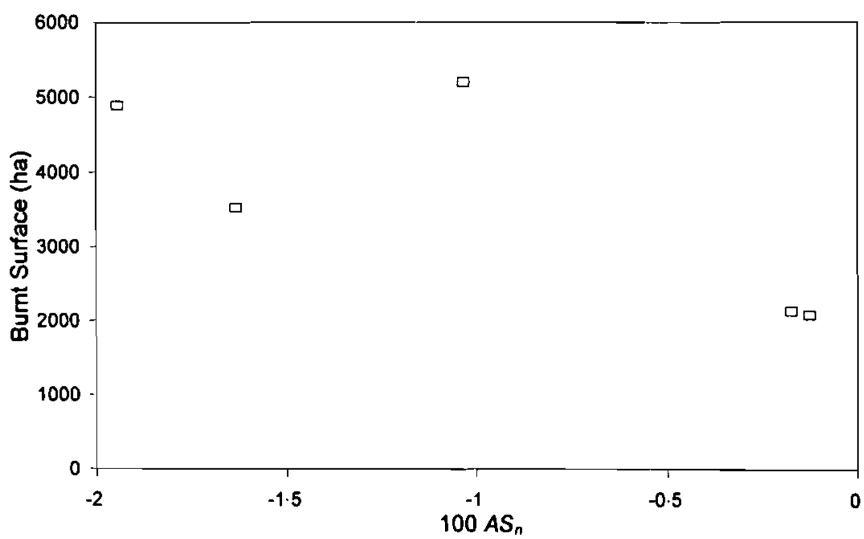
Figure 10. Danger mapping. Areas in danger are shown in white. It corresponds to the same period as the figures 4, 6 and 8.

It is hoped that this indicator will have negative values during danger periods. We therefore assume that a decrease in the accumulated slope implies an increase in the danger of a forest fire.

As we have an NDVI MVC image available each 10 days, AS_n is calculated with this frequency during the months of greatest danger (July, August and September). Figure 4 shows the AS_n corresponding to the period 9 to 18 August for the SE quarter of the Iberian Peninsula. A certain confusion may be observed among areas which have different land uses and similar AS values. In order to interpret the result, figure 5 shows the NDVI evolution for different vegetation canopies. From the analysis of the curves, it may be concluded that the majority offer negative AS_n values. Forested

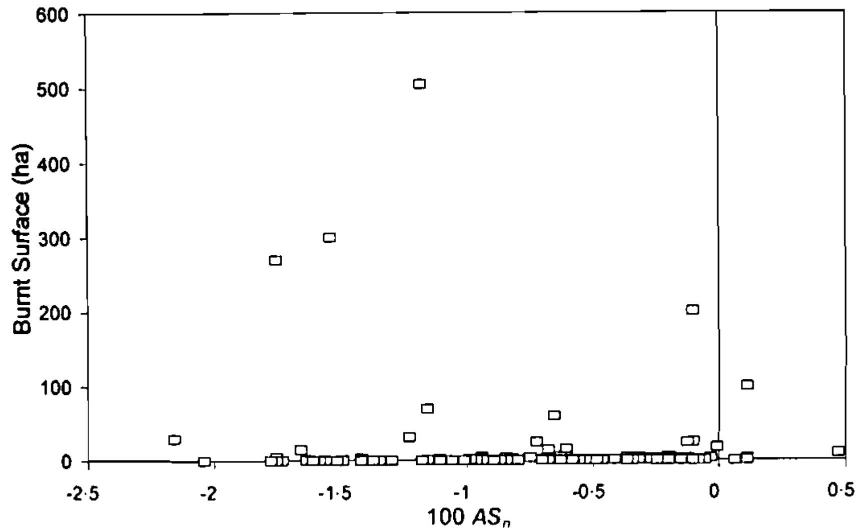


(*a*)

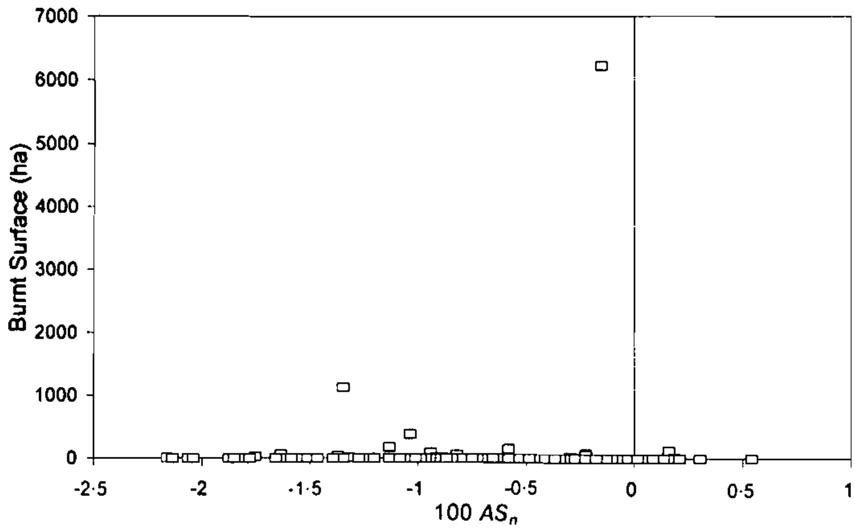


(*b*)

Figure 9.



(c)



(d)

Figure 9. Burnt surface and AS_n plotted for each fire. (a) Valencia, all size fires; (b) Valencia, burnt area $\geqslant 1000$ ha; (c) Valencia, burnt area < 1000 ha; (d) East Andalucia, all size fires.

areas offer intermediate values. The minimum values might correspond to crops, shrub-like formations and areas of forest which are at danger from fires. Vineyards, which are developing at this time of year, offer positive values as may also be the case of irrigated crops.

The evolution curves shown in figure 5 suggest that confusion among different types may be avoided by using the NDVI integral over the same period. Forested areas offer high values, as may be observed in figure 6, which correspond to the same period as the AS_n image in figure 4 in which the main forest areas in the region are

Table 3. Fire danger and burnt surface. Danger is assumed when the NDVI integral is above average and $AS_n <= -0{\cdot}01$.

(*a*) The whole sample.

	The whole sample			
	Danger		No danger	
	Burnt surface		Burnt surface	
	ha	%	ha	%
Valencia	14862	75·5	4830	24·5
East Andalucia	1945	21·3	7168	78·7*

(*b*) Burnt surface > = 1000 ha

	Burnt surface > = 1000 ha			
	Danger		No danger	
	Burnt Surface		Burnt Surface	
	ha	%	ha	%
Valencia	13346	76.0	4222	24.0
East Andalucia	1130	15·4	6223	84·6*

* = 6223 ha in the same fire.

marked out in green. Based on this result, we suggest using the NDVI integral as a mask and analysing the danger only in areas with values above average. The confusion observed in figure 4 may thus be eliminated. Irrigated crops are also linked to high integral values, as may be observed in the basin of the River Tagus, in the north-east of the image. An observation of the AS_n values indicates that no confusion is possible in this case as the areas under irrigation are linked to much higher values of AS_n than the forested areas.

When the ground data are superimposed on the NDVI integral values calculated for each 10 days during the three danger months, we can see that 58 per cent of the fires and 87 per cent of the burned land occur when there are integral values higher than the average for the period analysed, as shown in figure 7. The typified values of the integral have been calculated for the three danger months corresponding to all types of situations and situations involving fires. The histogram shows the number of fires and the burned land for different values of the integral.

It would therefore seem advisable to use the NDVI integral as a mask to eliminate non-forest land uses from the study. This result could be extremely interesting in areas where up-to-date mapping is not available.

Finally, figure 8 shows the result of masking the AS_n image in figure 4 using the values of the NDVI integral. Only the two areas under study are shown.

5. Results

In order to analyse the behaviour of the index proposed, its value is calculated for all fire situations. As we have already pointed out, an increase in danger is linked to a decrease in the AS_n. Figure 9 shows the relation between the AS_n values and the area of burned land for the Valencia region. The whole sample, as well as the results for burnt areas smaller and greater than 1000 ha, are shown.

It can be seen that fires of less than 1000 ha are found for all types of AS_n values. On the other hand, there does appear to be a relation between the increase in area and the danger measured using the AS_n in the case of large fires. The result may be explained if we think of only one of the many danger factors involved in forest fires is being taken into account; namely, that which is associated with the state of the vegetation. If the vegetation is in a situation of danger, it seems logical to assume that the chance of a fire spreading and being difficult to control is likely to increase.

If the same study is carried out for Andalusia (figure 10), the same conclusions are reached for areas under 500 ha. For large areas, no statistics which offer a tendency are available, as there is only one 6223 ha fire, which, according to ICONA data, was deliberately broken up at several points.

To sum up, the AS_n may be used as an indicator for fire danger linked to the water stress of the vegetation. Its values allow us to establish a danger index for large fires, which are of extreme importance in the study areas.

The proposed procedure allows us to create a mapping for danger. If the AS_n values are divided into danger or no danger situations, maps may be produced. An analysis similar to the one carried out with the NDVI integral (figure 7) suggests a threshold of $-0{\cdot}01$ in the AS_n values. By applying the procedure to the 3 months under study, we can obtain the results shown in table 3 for the areas affected.

6. Conclusions

In this work, a study is made of the possibility of establishing forest fire danger due to the water stress of the vegetation using the NDVI temporal evolution obtained from NOAA AVHRR images. As an indicator of danger, we use the accumulated slope AS_n or the sum of the slopes of this curve, calculated from spring to the time of the fire (equation (1)). In order to determine the reliability of the index, ground data recorded by the Spanish National Forestry Service (ICONA) have been used. The study has been carried out in two areas of Spain: Valencia and Eastern Andalusia, during July, August and September 1993.

As a first step for avoiding confusion in areas of different land use, the integral of the NDVI evolution curve over the same period is used. It may be seen that forested areas offer above average values. By superimposing fire land data, it may be concluded that 87 per cent of the burnt area also corresponds to these types. The use of this integral is therefore proposed as a forest mask. We believe that this result could be extremely useful in areas where an up-to-date mapping of land uses does not exist.

The second stage consists of an analysis of the values of the proposed index or AS_n for the fires which occurred within the areas marked out by the forest mask. It may be seen that fires of less than 500 ha occur for all types of AS_n values, but that for large fires a relation appears to exist between the danger measured by the AS_n and the area affected.

The proposed procedure allows us to derive a mapping of fire danger due to the state of the vegetation in an operational form, which may be integrated into a

Geographical Information System and then superimposed on to other factors in a global index.

Acknowledgments

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