MONITORING FIRES IN AREAS CHARACTERIZED BY GRAZING PRESSURE

M.d'Angelo, G.Enne - Nucleo Ricerca Desertificazione, Università di Sassari

Abstract

Fire is widely recognized as a factor of deforestation and land degradation in the Mediterranean basin. Mediterranean vegetation is provided with different mechanisms for resisting fire; the limiting factor is constituted by fire frequency which can transform fire from ecological factor into destructive factor. The present paper deals with monitoring of affected surfaces in order to inventory areas threatened by desertification because of the high fire frequency. Remote sensed data (Landsat TM) were used to monitor land cover changes due to forest fires in two test areas in Sardinia, an Italian region where fire has historically played an important role and is closely related to agropastoral activities. The application of standardized digital change detection techniques (multitemporal vegetation index difference, supervised classification on multitemporal bands or principal components extracted from a set of multitemporal TM bands) has shown a high classification accuracy in burnt areas inventorying (>93%). The application of simple digital change detection techniques to satellite data on different test areas provided high accuracy in burnt areas inventorying thus assuring an operational use of such techniques.

Introduction

Fire is a major concern among the environmental issues of Mediterranean Europe; it is widely recognized as an important factor of deforestation and land degradation largely favoured by the typical semi-arid climate and vegetation characteristics. Fire has always been a component of the Mediterranean ecosystems whose vegetation is provided with different resisting mechanisms; the limiting factor is constituted by fire frequency which can transform fire from ecological factor into destructive factor. Fire causes in fact the destruction of the vegetation cover as well as modifications to soil characteristics (Chandler et al., 1983) which result in an increased erosion risk.

With reference to Italy, in the period 1985-90 an area of 874,577 ha was affected by fire, 40% of which represented by wooded areas. About 60% of burned areas are located in the less-favoured regions of southern Italy, a geographical region where agropastoralism represents the main economic activity.

Sardinia, a western Mediterranean island, is the Italian region most affected by fires and it can be considered representative of the situation in semi-arid Mediterranean environments. Statistical data and historical sources show that this phenomenon is endemic and that it has destroyed about 600,000 ha of woodland in the last 120 years.

During the period 1985-95 38,884 fires have occurred for a total surface of 483,760 ha (RAS, 1989 & 1995), 97,149 ha of which were wooded areas and 386,611 ha other areas (mainly grasslands); in particular, in 1993 there were 4,558 individual fires affecting 79,218 ha of land, 24,374 ha of which represented by woodland.

A detailed analysis about the causes of forest fires highlights that more than 90% of the total number of fires are wilful, and historically and traditionally related to anthropic activities; among these, agropastoralism has played and still plays an important role.

Fire has been considered an important practical and economical tool for clearing lands for grazing; land fragmentation and the heterogeneity of soil cover, typical of Mediterranean environments, have in many cases favoured fire propagation from grasslands to shrublands and wooded areas thus compromising forested ecosystems.

In these areas in particular monitoring is essential to identify areas subjected to land degradation due to high fire frequency; the present paper deals with monitoring of affected surfaces by means of remote sensed data (Landsat TM) and tries to contribute to the definition of an operational methodology.

Material and methods

The investigation was carried out in two test areas chosen according to the main landscapes and actual land use typologies of Sardinia.

Area 1 is located in north-eastern Sardinia, and was swept by a wide fire in August 1989. This area is representative of the marginal Sardinian areas on granitic landscapes, covered with the typical maquis; extensive grazing is the main economic activity also favoured by the gradual land abandonment due to the increased tourist pressure on the coastal areas.

Area 2 is located in central-western Sardinia and is characterized by land cover heterogeneity: pasture lands alternate with wooded areas (*Quercus Suber, Quercus Ilex and Quercus Pubescens*); during the last decade this area was affected by frequent fires and, with particular reference to 1994, a wide fire swept about 8,000 ha of land.

Multitemporal Landsat Thematic Mapper digital data were acquired as close as possible to the fire events (193-32 II q 20/9/87 and 193/31 IV q 25/9/1989 for Area 1; 193-32 IV q 12/9/1987 and 9/9/1990 for Area 2).

Two windows of 1024x1024 pixels (about 900 km^2) centred on the two test areas were extracted (figure 1) from the multitemporal scenes and pre-processed to homogenize the data; atmospheric corrections were made by the improved dark object subtraction (Chavez, 1988) and then the multitemporal scenes were co-registered on the basis of control points. An accurate preliminary interpretation of the multitemporal images and ground data previously available allowed the identification of five classes, corresponding to two changed and three unchanged classes. Finally, on these areas different techniques of digital change detection were applied.

Among all the standardized digital change detection techniques (Singh, 1989), the following were applied and tested: i) visual interpretation of multitemporal images and post-interpretation multidate comparison; ii) maximum-likelihood classification on multitemporal principal components; iii) density slicing on image difference produced between multitemporal original bands or vegetation indexes.

The first technique is based on the visual interpretation carried out by means of classical procedures of photointerpretation on two contrast stretched false colour composites (before and after changes). According to previous experience, the 432 false colour image was found to be a good composition for land cover change detection; this composition, which uses the Landsat Thematic Mapper bands 4, 3 and 2 (near infrared, red and green reflectances) displayed as red, green and blue layers of a RGB monitor respectively, allows the discrimination of naturally vegetated areas (maquis and forested lands), cultivated lands and recently burned areas. By comparing the pre-fire image and the post-fire image, the areas subjected to changes are manually extracted by digitizing on video the areas undergone to spectral changes.

The second technique used is a standardized supervised classification carried out by means of the Maximum-likelihood (MXL) classifier on multitemporal principal components. The principal component analysis is widely used in remote sensing applications and it consists in choosing a linear combinations of original bands (in this case 8 bands, i.e. TM1, TM4, TM5, TM7, from the two Landsat scenes covering the same area) in such a way that each component subsequently extracted has a smaller variance (Singh and Harrison, 1985).

The last technique, after a preliminary evaluation on the discrimination of different land cover typologies, was only applied to the image difference deriving from the Normalized Difference Vegetation Indexes (pre-fire and post-fire).

FIGURE 1 - LANDSAT TM FALSE COLOUR COMPOSITES 432 (WINDOW OF 512X512 PIXELS).
AREA 1, SEPTEMBER 1989; AREA 2 SEPTEMBER 1990.

The NDVI represents a standardized image processing technique, easy to implement, which gives reliable information about the vegetation cover amount as well as on the different vegetation typologies for a certain area.

A simple density slicing is then applied to the image difference according to the data available from the training area: high values in the image difference correspond to land cover changes while low values represent unchanged areas.

The classification accuracy was determined by comparing the results of the classification procedures applied with those derived from ground truth data previously available and from photointerpretation of aerial photographs (scale 1:33.000 taken in 1988 over the study areas) for specific test areas chosen through a stratified random sampling approach. Figure 2 summarizes the methodology used in the present application.

Landsat images were processed by using ILWIS (Integrated Land and Water Information System) software.

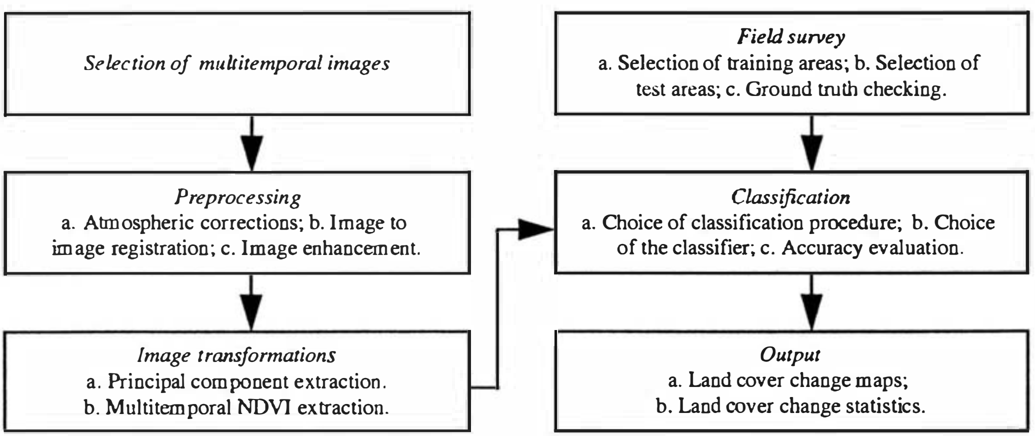

FIGURE 2 - METHODOLOGY USED FOR LAND COVER CHANGE DETECTION.

Results

Table 1 shows the main classes which have been considered during the investigation; the visual interpretation of Landsat TM false colour composite 432 allows the discrimination of natural vegetated areas covered by maquis and groves of holly oaks (reddish tones), agricultural lands without standing crops (from light to brownish tones) and recently burned areas (from black to greyish tones).

Table 2 shows the classification accuracies achieved in the two test areas by applying the different techniques.

	Classes	*Description*
1.	From vegetated to burned areas	Areas covered by natural vegetation at time t1 (forested lands) and affected by fires at time t2.; these areas are characterized by reddish tones (vegetated areas) on the pre-fire image and black to grey tones in the post-fire image.
2.	From bare to vegetated areas	Agricultural areas (arable land and grazing lands) not covered by vegetation at time t1 and covered at time t2. These changes are natural and related to the different rainfall regimes for the years considered.
3.	Unchanged vegetated areas	Areas naturally vegetated at time t1 and t2.
4.	Unchanged bare soil	Areas not covered by vegetation at time t1 and t2.
5.	Unchanged burned areas	Areas affected by fire at time t1 and t2.

TABLE 1 - MAIN LAND COVER CLASSES AND DERIVED LAND COVER CHANGE CLASSES.

.Classes	*Accuracy Area 1*			*Accuracy Area 2*	
	PI	MXL	DVI	PI	MXL
1. Vegetated to burned	90.25	95.21	93.12	89.24	94.25
2. Unvegetated to vegetated	80.21	84.18	-	-	-
3. No change (vegetation)	85.12	90.93	-	80.72	90.25
4. No change (unvegetated)	70.04	46.93	-	80.40	67.12
5. No change (burned)	89.25	57.12	-	85.20	90.15

PI=Photointerpretation and post date comparison; MXL= Maximum likelihood classifier on standardized multitemporal principal components; DVI = Slicing on NDVI's image difference.

TABLE 2 - CLASSIFICATION ACCURACY ASSESSMENT BASED ON TEST SAMPLE AREAS

It must be noted that the accuracy achieved by the maximum likelihood classifier on the first three principal components provides good results (overall accuracy of 74.44% for Area 1 and 85.44% for Area 2). The main problems were encountered for unchanged classes; here the accuracy varies between 46.94% (class 4 Area 1) and 90,93% (class 3 Area 1).

The principal component transformation has been proved to be an important data compression tool; the first three principal components contain 95.75%

original eight bands data variance for Area 1 and 2 respectively.

components displayed as false colour composition (Figure 2) are very effective in discriminating the different land cover change classes, with particular emphasis on the ones due to forest fires; the effectiveness is widely related to the selection of significant bands in relation to the original land cover classes.

FIGURE 2 - FALSE COLOUR COMPOSITES OF PC1, PC2 AND PC3 STANDARDIZED MULTITEMPORAL PRINCIPAL COMPONENTS FOR AREA 1

Similar accuracies in the classification of land cover changes have been achieved by applying a simple slicing on the NDVI difference image (93.12% for class 1), but no information can be achieved about the different typologies. Good results have also been achieved by visual interpretation of multitemporal 432 Landsat false colour composite (overall accuracy of 82.74% and 83,89% for Area 1 and Area 2 respectively) but they are closely related to the previous knowledge of the photointerpreter of the study areas.

It must be noted that burned areas can be accurately classified also by considering a single scene recorded after fire events (>90%) due to their characteristic spectral signature, but no information is gathered about their frequency.

Table 3 summarizes the results of the overlaying GIS-based process between the burned area map and the pre-fire land cover map for a part of study area 1 (F.182 Loiri Porto S.Paolo, IGMI scale 1:25.000). The forested lands completely destroyed by fire on steep slopes may be considered sensitive to land degradation and must be monitored during their evolution.

Land cover		*Slope*		*Aspect*	
Class	Surface	Class	Surface	Class	Surface
Coniferous forest land	102.63	0 - 2 %	506.54	N	264.50
Deciduous forest land	181.04	2 - 5 %	77.09	NE	298.73
Shrub rangeland	206.08	5 - 10%	330.14	E	293.76
Maquis	1842.83	10 - 20%	440.21	SE	293.57
Maquis (sparse)	128.62	20 - 35%	486.81	S	190.18
		35 - 50%	362.24	SW	191.86
		>50%	258.17	W	184.24
				NW	367.02
				(flat)	377.34

TABLE 3 - LAND COVER STATISTICS DERIVED BY OVERLAYING THE BURNED AREA MAP AND THE LAND COVER MAP BEFORE THE FIRE EVENT OF THE SUMMER 1989 (AREA 1).

Discussion

The study carried out in two test areas showed that the main land cover changes due to fires can be accurately classified using multitemporal Landsat Thematic Mapper data thanks to their spatial and spectral resolution.

For an operational application finalized to the classification of burned areas in Mediterranean environments it is very important to acquire cloud-free summer images as close as possible to the fire events; images acquired later do not provide reliable information about the real extent of the events due to the natural herbaceous vegetation regrowth after late summer precipitation, as shown in the application to the 1989 wild fire in test area 1.

The visual interpretation of false colour composites displayed on video represents an important technique to classify land cover changes; its main disadvantage is that, like all photointerpretation-based procedures, it is highly related to the analyst experience. Furthermore, the interpretation is carried out separately for the two dates, so that the classification accuracy of the resulting land cover change map is given by the product of the accuracies of the two original maps. A standardized technique based on a simple multitemporal NDVI image difference can give reliable information about land cover change classification providing a high accuracy for changes like the ones due to summer fires, but lack of information has been observed when the kind of changes are considered (from bare soil to vegetation with low covering rates).

Being interested in vegetation changes, in particular from vegetated to non-vegetated areas, the extraction of principal components from a set of multitemporal lands has been proved to be an important technique for reducing data amount and to discriminate the main land cover changes. As highlighted in the application to area 1, the first three principal components represent almost all the variance of the set of eight original bands, and the derived false colour composite (displayed as RGB image) allow the visual discrimination of changed and unchanged areas further divided in different typologies.

A land cover change map with an overall accuracy of 90% is sufficient for application at regional scale of a monitoring programme finalized to the identification of sensitive areas to land degradation due to forest fires. At present, maps of forest fires at regional level are not available and the frequencies at which a given area is affected is unknown; the integration of remote sensed-base burned area inventory into a Geographic Information System for land management can represent an operational tool.

Conclusions

Given the importance of natural vegetation and in particular of the Mediterranean maquis in protecting soil against erosion, the research highlighted the essential contribution of satellite data (Landsat TM) to monitor land cover changes at regional level, with particular reference to the ones due to forest fires. The research has shown the importance of a monitoring programme finalized to the identification of areas susceptible to land degradation in Sardinia; the accurate results achieved in the digital classification of land cover changes for different Sardinian test areas (a classification accuracy of over 92% for burned areas) suggest the application of remote sensing-based methodologies as operational tool at regional level.

From an operational point of view the results of the research led to the following conclusions:

i) the inventory of burnt areas is the most important step in damage assessment; the processing and interpretation of remote sensing data represents an operational tool in inventorying and georeferencing areas affected by fires at a good spatial and temporal resolution;

ii) digital image processing techniques of remote sensed data can further contribute to achieve data on indicators of land degradation (burnt areas, human-induced land cover changes) for erosion risk assessment at a regional scale;

iii) the integration of remote sensed data into a Geographical Information System can contribute to the identification of areas threatened by anthropogenic desertification and to plan reclamation actions in areas affected by fires.

Acnowledgements

The research was supported by the EC Environment and Climate Program and carried out within the MEDALUS (Mediterranean Desertification and Land Use) Project, contract ENV4-CT95-0115. The support is gratefully acknowledged. The authors are grateful to Chiara Zanolla for her contribution.

References

Chandler, C., Cheney, P., Thomas, P., Trabaud, L., Williams, D. 1983. *Fire in Forestry. Forest Fires Behaviour and Effects*. John Wiley & Sons, Nw York.

Chavez, P.S. 1988. *An improved dark-object subtraction technique for atmospheric scattering corrections of multispectral data*, Remote Sensing of Environment, 24, 459-479.

Regione Autonoma della Sardegna 1995. *Sommario delle superrficie percorse da incendio; 1984-1994,* RAS, Cagliari.

Regione Autonoma Sardegna, 1989. *La lotta contro il fuoco; analisi del rischio e prevenzione. Proposte per un programma di azione*. La programmazione in Sardegna n. 109-111.

Singh, A. 1989. *Digital change detection techniques using remotely-sensed data*, International Journal of Remote Sensing, **10**, 6, 883-896.

Singh, A. and Harrison, A. 1985. *Standardized principal component*, International Journal of Remote Sensing, **6**,6, 883-896.

LEGAL NOTICE

A great deal of additional information on the European Union is available on the Internet.
It can be accessed through the Europa server (http://europa.eu.int).

Cataloguing data can be found at the end of this publication.

Luxembourg: Office for Official Publications of the European Communities, 2000

ISBN 92-828-8128-8

Printed in Belgium

PRINTED ON WHITE CHLORINE-FREE PAPER