EVALUATION OF FOREST FIRE RISK BY THE ANALYSIS OF ENVIRONMENTAL DATA AND TM IMAGES

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ABSTRACT

The evaluation of forest fire risk is an important issue in Mediterranean areas where the long arid season often creates favourable conditions for the occurrence of fires. In the present letter three indices related to this risk have been produced and compared concerning the western part of the Elba Island (Central Italy). The first index is based on the analysis of environmental information layers (topography, vegetation and soil type) within a Land Information System, while the other two are derived from a summer Landsat TM scene processed by unsupervised and supervised procedures, respectively. The results show the effectiveness of all these approaches for the study purpose, and, in particular, a certain superiority of the supervised spectral index.

INTRODUCTION

The risk of forest fires is a pressing problem in most tropical and sub-tropical countries as well as in many Mediterranean areas. The presence of a long arid season tends to stress vegetation communities thus creating the conditions for the occurrence of fires. The evaluation of this risk is therefore of primary importance in the context of environmental management. This operation generally requires the acquisition and processing of several information layers which can presently be carried out by the use of Land Information Systems (LIS). Clearly, the LIS must be specifically oriented to this objective and particular processing techniques are needed. It has recently been demonstrated that the utilisation of remote sensing data is particularly effective for this purpose (Chuvieco and Congalton, 1989, Eidenshink et al., 1989).

Spectral indices are by now standard procedures in image analysis and interpretation. In particular, vegetation indices derived from the visible and near infrared channels of airborne and satellite sensors are widely used for the discrimination and study of vegetation cover types. These indices, among which the Normalized Difference Vegetation Index (NDVI) is probably the most common, are generally related to active green biomass and Leaf Area Index, and can be indirectly employed to assess plant conditions (Perry and Lautenschlager, 1984). Their usefulness for more specific purposes such as the evaluation of fire risk is however still dubious and deserves further investigations (Lopez et al., 1991).

The current research is focused on the use of LIS and remotely sensed data for the generation of indices related to the risk of forest fires in a typical Mediterranean environment. The study has been conducted in the western part of the Elba Island (Tuscany, Central Italy) with the contribution of the CEC Environment II Project "Integrated assessment of environmental degradation connected with forest fires in European areas". By means of different analysis methods three indices have been produced showing various degrees of efficiency.

Study Area

The island of Elba has a surface of 223 km^2 and is situated in the North of the Tyrrhenian Sea, between 42°40' and 42°55' North latitude and 10° and 10°30' East longitude. From an altimetric point of view its territory is mainly characterised by medium-low hills. The most important orographic complex is represented, in the Western part, by a particular circular structure, while some coastal plains are present in the central part of the island. The climate is typically Mediterranean, with a primary maximum of precipitation in autumn, a second maximum in winter and a main minimum in summer. The greater rainfall contribution occurs due to Western currents, so that the most favoured slopes are the ones facing North and North-West, which are also less exposed to direct sun radiation. As far as temperatures are concerned, the coastal region, affected by the influence of the sea, shows higher air temperatures (annual average of about 16.4 C°).

Because of the geographical position, the climatic and topographic conditions and the human activities during the centuries, the vegetation in the island is characterised by dense associations of shrub species derived from the degradation of the primitive forests. The term "Mediterranean maquis" refers to bushland formed basically by small thickly packed trees, shrubs and bushes, which are scarcely penetrable due to the presence of lianose and thorny species. Such type of vegetation, common along all the coasts of the Mediterranean sea, has a rich specific composition. Moreover, various physiognomic types are found, which go from "*gariga*" to low maquis, tall maquis, bush and forest. Within the latter formations, the prevalent tree species are oak (*Quercus pubescens L.*) and chestnut (*Castanea sativa L.*); pines (*Pinus pinaster L.* and *Pinus pinea L.*) have been planted in the reforested areas. The distribution of all these formations, as well as their conditions, are strongly controlled by the variable environmental factors, which produce different levels of fire risk.

Data Used

The study focused on the western, mountainous part of the Island, which is mainly covered by forests and maquis. For this area, the following data layers were collected from various sources and prepared for further processing:

- A Digital Terrain Model (DTM), constructed by digitising and processing the contour lines every 10 meters from the Regione Toscana 1:10.000 topographic maps. The DTM is composed of three raster files reporting Elevation, Slope and Aspect with a pixel size of 30x30 m.
- A Land Unit map of the Elba Island at 1:50.000 scale. This was produced and digitised by the Istituto Agronomico per l'Oltremare (IAO, 1991), and consisted of five distinct layers (Land suitability, Vegetation, Naturalistic evaluation, Soils and Land units).
- Information on the distribution and size of forest fires occurred in the Island from 1984 to 1993 (approximately 130 fire events). This information was taken from the archives of the forest service in the Island, and was digitised in the same reference system as above.
- A Landsat 5 Thematic Mapper scene taken on 25 August 1992 (frame 192, track 30). This scene was first georeferenced by a nearest neighbour algorithm trained on ground control points (Figure 1). Then, the six reflective bands were corrected for the atmospheric and topographic effect by a procedure which yields reflectance images as output (Conese et al., 1993, Gilabert et al., 1994).

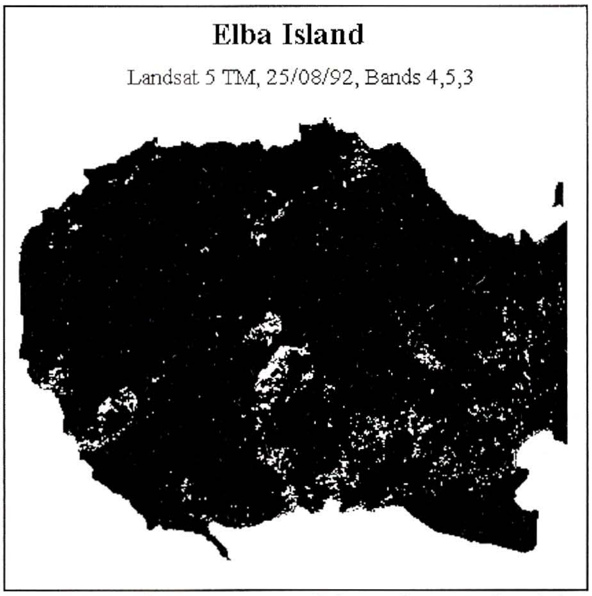

Figure 1 - Colour composite of the study scene (band 4 = red, band 5 = green, band 3 = blue)

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Data Analysis

A first fire risk index was generated from the layers of the LIS by means of a methodology developed in a previous work (Conese et al., 1991). This consists of an analysis of relative frequencies on the historical data to derive the weighting factors for the generation of the index. In practice, the weights for the composition of the environmental information layers are computed as proportional to the relative frequencies of past fire events on the layers' intervals. Elevation, slope, aspect, soil and vegetation cover were considered as input information layers related to forest fire risk. The index produced was divided into eight levels with approximately the same number of pixels, and the number of fires occurred in the study decade was computed for each level. A regression

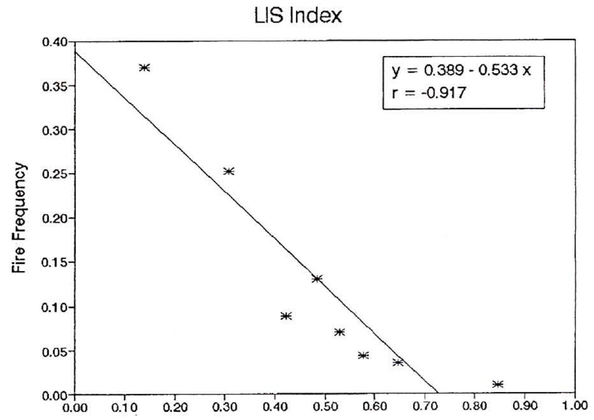

Figure 2 - Linear regression between the levels of the environmental risk index and the fire frequency in the study decade

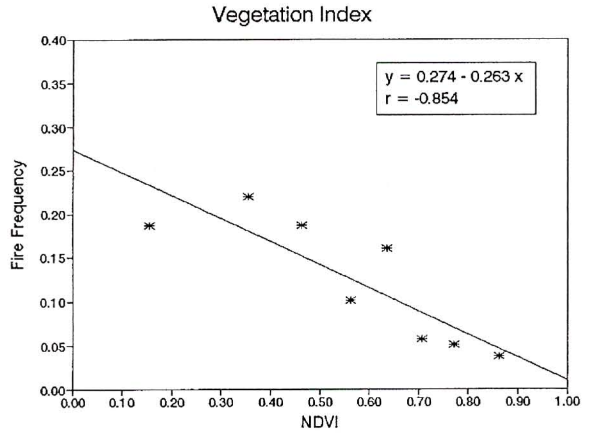

Figure 3 - Linear regression between the NDVI levels and the fire frequency in the study decade.

analysis was then performed between the index levels and the frequency of fires occurred (Figure 2).

A relatively high correlation coefficient was obtained (r = -0.917), which testified to the effectiveness of the procedure.

A second analysis was conducted to assess the value of a usual vegetation index as an indicator of fire risk. The rationale for this is that vegetation indices are strongly related to the quantity of active green biomass, which, in turn, is an indicator of vegetation density and health. In practice, it can be reasonably hypothesised that, at the peak of the arid season, vegetation activity is mainly controlled by water availability, so that dense, healthy vegetation is less subjected to fire hazard (Chuvieco and Martin, 1994). A Normalized Difference Vegetation Index (NDVI) was generated from the atmospherically and topographically corrected TM bands 3 and 4. Only small fires had occurred in the two years prior to the scene acquisition, so that it could be assumed that vegetation conditions were mainly controlled by environmental factors. The NDVI image obtained was divided into eight levels and statistically analysed as above (Figure 3). A correlation coefficient slightly lower than that from the previous analysis was obtained (r = -0.854), indicating the substantial validity of the hypothesis formulated.

Finally, a spectral index specifically trained on the study data was generated by a supervised statistical method. For this aim, a mask was first created to divide the areas in which forest fires had occurred from those where this was not the case. A distance of 1 km around the areas with fires in the last decade was kept as a threshold between the two situations, and a Canonical Variate Analysis (CVA) was applied to the seven TM bands (six corrected reflective bands

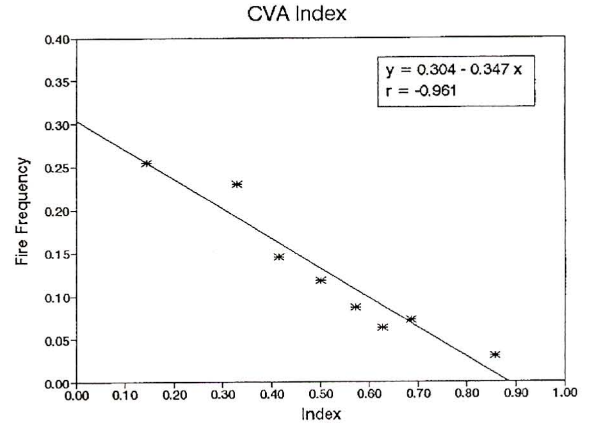

Figure 4 - Linear regression between the levels of the CV index and the fire frequency in the study decade.

plus thermal band) with respect to the resulting two levels (areas with and without fires). This analysis finds linear combinations of the original variables that maximise the ratio of between-group to within-group variations, thereby producing new variates which can be used to discriminate between the groups (Dillon and Goldstein, 1984, Richards, 1993). The first (and unique) Canonical Variate (CV 1) found in the present case was taken as a fire risk index. As can be seen from the loadings of Table 1, the index is actually a contrast between bands 2 and 3 (green and red), with some negative influence of the thermal infrared band. Band 4 (near infrared) has low influence, while the effect of band 5 tends to be counterbalanced by that of band 7 (middle infrared). In practice, this CV1 is a modified vegetation index which discriminates areas with increasing pigment absorption and decreasing surface temperature. The same processing of this index as above gave a correlation coefficient with fire frequency of -0.961 (Figure 4), which is an improvement with respect to previous cases. The distribution of this « optimum » index in the study area is shown in Figure 5; as can be seen, the southern part of the island is more subjected to the risk, which is in accordance with the relevant environmental conditions.

Table 1 - Parameters derived from the Canonical Variate Analysis performed on the study scene with référence to the areas with and without fires in the last decade (Latent root and loadings).

Latent root = 0.244	
Loadings	
TM 1	-0.0814
TM 2	0.2406
TM 3	-0.2584
TM 4	0.0207
TM 5	-0.0724
TM 6	-0.0866
TM 7	0.1592

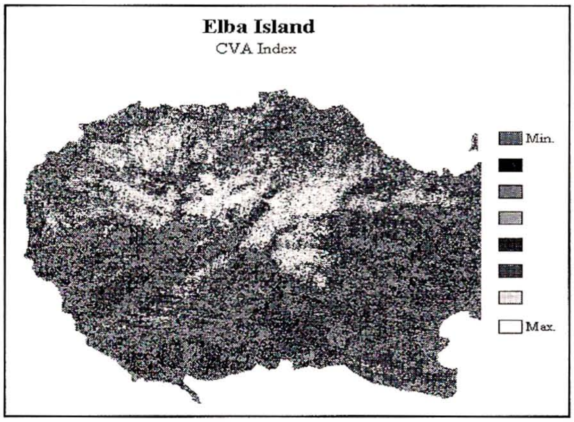

Figure 5 - Distribution of fire risk index derived from the Canonical Variate Analysis

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DISCUSSION AND CONCLUSIONS

Several methods to produce indices related to forest fire risk can be found in the literature. Most of the classical procedures are based on the definition of rules which compose various information layers connected to this risk (vegetation type, topography, pedology, climate). The generalisation of these rules is however often difficult, since they generally depend on local environmental situations and cannot be easily extended to other cases. To circumvent this drawback, recent works have proposed statistical approaches which are based on the study of local historical records of fire events. The analysis of fire frequencies on the main environmental factors usually allows the definition of rules with local validity and, consequently, the generation of useful maps. This approach has been used as a reference in the present investigation, which has also considered the generation of fire risk maps based on remotely sensed images.

From the analysis conducted, it was found that a usual spectral (vegetation) index is inferior to a locally standardised index based on environmental factors for the production of a risk map. On the contrary, a supervised spectral index trained on the specific ecological situation is even more efficient than the environmental index, showing high discrimination capability between areas with different fire risk levels. The effectiveness of Canonical Variate Analysis for the creation of the index must be highlighted. As suggested by Curran (1985), this is a procedure which should find a wider application in remote sensing data analysis. In the specific case a high importance of the visible and thermal bands was found, but this could vary for different situations. Further studies are therefore needed to extend the present testing to other images in the same and different areas. Also, more flexible procedures based on a "fuzzy" classification approach could be investigated following a method already experimented for the estimation of forest parameters (Maselli et al., 1995). In any case, the importance of fire prevention in the study island renders the maps produced already useful for operational applications.

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