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Notes

Validation of MEDALUS Fire Risk Index using Forest Fires Statistics through a multivariate approach

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A B S T R A C T

A Fire Risk Index (FIRISK) based on an original land cover/land use nomenclature has been developed in the framework of EU-funded MEDALUS projects and integrated into a composite index of sensitivity to desertification (the so called environmentally sensitive area index: ESAI). The objective of the present study is to introduce a validation approach assessing the correlation between the FIRISK and seven independent fire indicators and quantifying the similarity in their spatial distribution in a study area (Attica, Greece) characterized by high fire risk and fragmented land-use structure. The FIRISK correlated positively with four out of seven fire indicators (average fire size, percentage of burnt area on the total municipal area, percentage of cropland and pastures burnt in each fire) in a non-linear fashion. Cluster analysis indicates that FIRISK spatial distribution was coherent with variables describing both fire size and the use of land endangered by fire. Results of the present study demonstrate that the FIRISK is a reliable indicator of fire risk within the ESAI framework. Moreover, the index is considered a key component of multi-criteria decision support systems classifying land according to the level of fire sensitivity.

1. Introduction

Forest fires are one of the most relevant factors shaping the ecological fragility of the Mediterranean landscape triggering soil degradation and determining a higher desertification risk in certain environments (Economidou, 1993; Basso et al., 2000; Salvati and Bajocco, 2011). Fires have become very frequent especially in conifer forests during the last decades with dramatic consequences in soil erosion rates and biodiversity loss (Kosmas et al., 2000). The frequency of fire occurrence was found relatively high also in grasslands and mixed Mediterranean macchia with evergreen forest (Kosmas et al., 1999). In addition, Mediterranean pastures are frequently subjected to human-induced fires in order to renew the biomass production (Oliveras et al., 2009). The Mediterranean vegetation type is highly flammable and combustible due to the existence of species with high content of resins or essential oils (Bajocco and Ricotta, 2008).

In addition to the loss of vegetation, forest fires induce changes in physical and chemical properties of soils such as water repellency, loss in nutrients and increased runoff (Kosmas et al., 2000). They also impact biodiversity, cause loss of human life and damage infrastructure (Moreira et al., 2011). The loss of vegetation after fire and the progressive inability of soils to regenerate adequate vegetation cover due to erosion led to severe degradation and desertification of extensive hilly areas in the Mediterranean region (Bajocco et al., 2011, 2012).

Forest fire dynamics and risk assessment are becoming a key environmental issue in Europe (European Commission, 2011) because of the synergic impact of biophysical (e.g. global warming, drought, aridity) and socioeconomic (e.g. deregulated urban expansion, infrastructure development, land abandonment) drivers and the ecological consequences on both the continental and regional scales (Moreira et al., 2011; Turner et al., 2011; Salvati et al., 2012). A number of indicators and composite indexes using various computation approaches have been proposed to monitor forest fire risk in Europe (e.g. Basso et al., 2010; Turner et al., 2011; Raulier et al., 2013; Sankey et al., 2013; Whitman et al., 2013) and especially in southern Europe (e.g. Martínez et al., 2009; Oliveras et al., 2009; Bajocco et al., 2011; Martín-Martín et al., 2013).

A Fire Risk Index (FIRISK) based on an original land cover/land use nomenclature was developed in the framework of EU-funded Medalus (Mediterranean Desertification and Land Use) project and

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integrated into a composite index of sensitivity to desertification (the so called environmentally sensitive area index: ESAI). The Medalus–ESAI approach was widely used to classify land according to its level of sensitivity to desertification in Europe, Middle East and northern Africa (see Salvati et al., 2009 for a review). The present study illustrates a validation approach assessing pair-wise correlations between the FIRISK and seven independent indicators quantifying density, severity and land-use selectivity of forest fires in the area derived from a fire inventory (2008–2012) in Attica, Greece. The investigated area is characterized by high fire risk, fragmented land-use structure and deregulated urban expansion and is considered an example of the environmental problems found in several Mediterranean coastal regions experiencing rapid urbanization. The study demonstrates that (i) the FIRISK is as a reliable indicator of fire risk in the ESAI framework and that (ii) the index can be considered as a key component of a multi-criteria decision support system classifying land according to the (changing over time) level of fire sensitivity.

2. Methods

2.1. Study area

The study area covers nearly 3000 km^2 in mainland Attica, central Greece. According to the local authorities' reform enforced in 2011 (the so called 'Kallikratis' law), the region was subdivided in 59 municipalities (including a municipality administering Salamina island), with the urban area of Athens occupying nearly 430 km^2 (Fig. 1). Attica mostly consists of mountains with the highest elevation in Mount Parnitha (1413 m above sea level) at only 20 km northwest of Athens. Three flat areas cultivated since ancient Greece (Messoghia, Marathon and Thriasio) are located in Attica outside the urban area of Athens (Salvati et al., 2012). Population residing in the study area amounted to 2.7 million people in 1971 (with a density above 900 inhabitants/km^2), growing to 3.4 million people in 1991 and reaching 3.8 million people in 2011 (with a density of 1250 inhabitants/km^2). Urban population declined from 92% in 1971 to 82% in 2011.

2.2. Land cover map

The surface area covered by defined land cover classes was assessed according to Corine Land Cover (CLC) pan-European digital map available at 1:100,000 nominal scale and referring to the early 2000s (European Environment Agency, 2006). Based on satellite imagery as the primary information source, the CLC project was aimed at providing land cover maps at various times for the whole of Europe and was coordinated by the European Environment Agency (EEA). The choice of resolution scale, minimum mapping unit (25 ha) and minimum width of linear elements (100 m) for CLC mapping represents a trade-off between production costs and level of detail of land cover information. The standard CLC nomenclature includes 44 land cover classes fully reported in Salvati and Bajocco (2011) and grouped into a three-level hierarchy (1: artificial surfaces, 2: agricultural areas, 3: forests and semi-natural areas, 4: wetlands and 5: water bodies). The 44 CLC classes provided a comprehensive description of the landscape in the study area (Economidou, 1993).

2.3. Forest Fire Risk Index

Following the environmentally sensitive area index (ESAI) approach developed in the framework of Medalus II project (Kosmas et al., 1999), a Fire Risk Index (FIRISK) was proposed to rank the sensitivity of vegetation to forest fires with the aim of identifying, together with several other indicators, the land vulnerable to desertification in Mediterranean Europe. This framework was successfully applied on both regional and local study sites in various Mediterranean countries (Portugal, Spain, Italy and Greece) with diverging environmental conditions and socioeconomic contexts. The results of the ESAI approach have been extensively validated in several target sites through comparison with field and remote sensing indicators (Basso et al., 2000; Ferrara et al., 2012).

The information on the different sensitivity of vegetation to forest fires have been derived from the available CLC map (see above) and from previous experimental studies (Kosmas et al., 1999). The FIRISK is a score indicator ranging from 1 to 2 (the score increases with fire risk). A score between 1 and 2 is attributed to each land cover class following CLC third-level nomenclature (see Salvati and Bajocco, 2011 for the full table of scores and land cover types). Scores were derived from the previously described analysis and from additional information gathered from the available literature (Kosmas et al., 2000). A sensitivity analysis and a focus group analysis were finally carried out in order to indicate the most valid, low-cost and efficient score set (Kosmas et al., 1999). Four FIRISK classes were identified: (i) low risk (FIRISK < 1.25), (ii) medium-low risk (1.26 < FIRISK < 1.50), (iii) medium-high risk (1.51 < FIRISK < 1.75) and (iv) high risk (FIRISK > 1.75). Zero values were attributed to some land cover classes that were excluded from the analysis (e.g. compact urban areas: Salvati and Zitti, 2012).

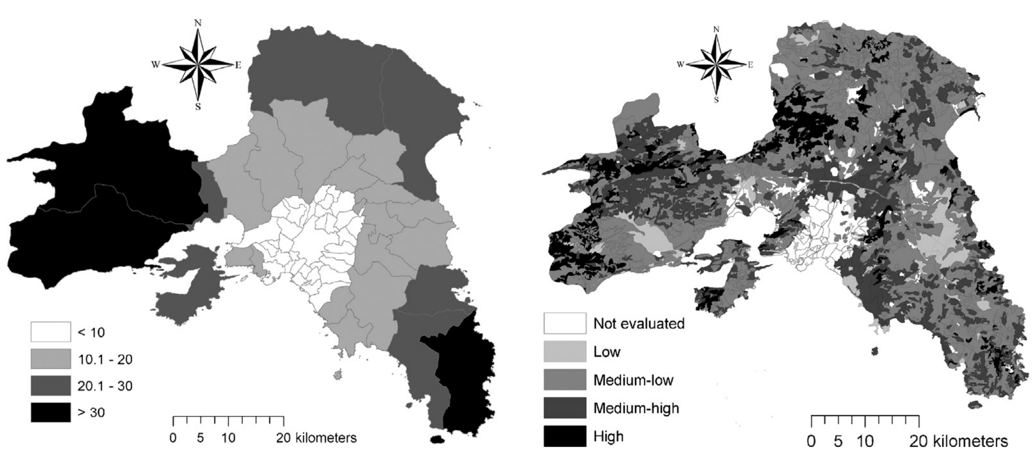

Fig. 1. The investigated area (Attica, central Greece) illustrating the boundary of local municipalities and the distance from the inner city of Athens (left), and the forest fires risk index (FIRISK) in 2000 (right).

2.4. Forest fire statistics

A total of 1129 records of the Hellenic Fire Brigade on individual forest fires occurred in the investigated area between 2008 and 2012 have been considered here. For each fire, the data collection includes a field estimate of the burnt area, the date and hour of ignition, the municipality of the ignition point and a description of the place of ignition (usually the name of the main road or the neighbouring settlement or similar information useful to the geo-referencing process); these information allowed to precisely assign each fire to one of the 59 municipalities of the study region. The database contains all fires that were recorded by the Fire Brigade, and is assumed to be complete and reliable even for the smallest fires.

The average density of fires per year was 0.08 events/km^2 along the period 2008–2012 with the average burnt area per fire amounting to 23 ha; fires destroyed 8.6% of the investigated land during the study period (Table 1). According to previous studies (see Bajocco and Ricotta, 2008 and references, therein), fire size distribution in Attica was adequately described by a power–law over many orders of magnitude with nearly 80% fires < 1 ha and only 1% > 100 ha. Like in most Mediterranean regions, the large majority of fires included in this analysis are human-caused rather than 'natural' in origin and mainly concentrated during hot and dry months spanning from late spring to early autumn.

The available database includes information on the surface area of different land cover classes affected by each fire event. Four classes were considered here: (i) forests and related natural habitats including macchia, garrigue and shrubland, (ii) urban parks, gardens and other types of green urban areas; (iii) cropland and (iv) pastures.

The events examined in this study may be regarded to be an enough representative of the fire regime characterizing the study region in the last decade. The investigated time interval (2008–2012) include years with few but extremely severe events (2009), years with a high number of fires and moderate severity in terms of total area and forest land affected (2010), favourable years with a reduced number of events characterized by low fire severity (2011) and years with an intermediate fire profile (2008 and 2012). According to meteorological data recorded in Thissio station (Athens) by the National Observatory of Athens, the five years also showed an heterogeneous climatic pattern, with a relatively wet year (2009) and a hot and exceptionally dry year (2010) intermixed with years showing a normal climatic regime.

2.5. Data analysis

The spatial distribution of the FIRISK was mapped using the same resolution offered by the CLC cartography (Fig. 1) referring to the early 2000s. A FIRISK mean score was attributed to each municipality of the study area as a surface-weighted average of the scores assigned to each class polygon using the 'intersect' tool provided with ArcGIS software (ESRI Inc., Redwoods, USA) after the overlap between the FIRISK map and the shapefile representing the municipalities' boundaries.

Seven forest fires' indicators and three ancillary socioeconomic variables were calculated on a municipal scale from data made available by Hellenic Statistical Authority. The selected indicators assess fire density, severity and selectivity (fire density [fires/year/km^2: FIRDEN], average fire size [ha: AVGFIR], percentage of burnt area on the municipal area [% per year: BURSUR], as well as the proportion of forests (WOOD), cropland (CROP), pastures (PAST) and green urban areas (PARK) destroyed in each fire). The three ancillary variables describe the main gradients in Attica's geography (population density in 2011 [inhabitants/km^2: DEN], average distance of each municipality centroid from the inner city of Athens [km: DIS] and average municipal elevation [m: ELE]) possibly influencing the spatial distribution of fires.

Although, the spatial unit of analysis adopted in this study depict arbitrary (administrative) boundaries with regard to the landscape, the use of local administrative units allows a detailed diachronic analysis of a number of different indicators derived from official statistics (Salvati et al., 2013). Municipal data allow within-region reliable comparisons over relatively long time intervals. Moreover, municipalities in the study area are designed as the local authorities deciding on land destination, building volume, settlement size, land taxation, forest management and other variables impacting the structure of the landscape (Chorianopoulos et al., 2010).

The spatial distribution of the FIRISK, the seven fires' indicators and the three ancillary variables was explored through different approaches including (i) a visual analysis based on maps, (ii) a pair-wise correlation analysis and (iii) an analysis of similarity in the indicators' spatial pattern. An exploratory correlation analysis based on four parametric and non-parametric metrics (Pearson, Spearman, Kendall and Gamma) was carried out comparing the distribution of the FIRISK and the seven fire's indicators testing at $p < 0.05$ after Bonferroni's correction for multiple comparisons. These eight variables were in turn correlated using Spearman non-parametric coefficient with the three socioeconomic variables that describe the most relevant geographical gradients in the study region to verify the coherence of their spatial patterns. Finally, a non-hierarchical cluster analysis (using Euclidean metric with weighted pair-group centroid (median) agglomeration rule) was developed to identify similarities in the spatial distribution of the seven fire indicators and the FIRISK.

3. Results and discussion

Fig. 1 illustrates the spatial distribution of the FIRISK in the early 2000s in Attica. The highest scores of the index concentrated in the urban fringe of Athens and in sloping areas surrounding the city. Medium-high scores were also found in marginal, rural areas with cropland and pastures dominating the landscape. Results of the pair-wise correlation analysis between FIRISK and the selected fires' indicators were reported in Table 1 using different coefficient metrics. Non-significant correlations were detected using Pearson moment-product coefficient, apart from the weak correlation (bordering the significance level) detected between FIRISK and the proportion of cropland burnt in each fire. To the contrary, non-parametric Spearman, Kendall and Gamma metrics identified four significant and positive pair-wise correlations between FIRISK and AVGFIR, BURSUR, CROP, PAST. A weak correlation (bordering the significance level) was also observed between FIRISK and FIRDEN, which in turn correlated with both CROP ($r_s = 0.39$, $p < 0.05$) and PAST ($r_s = 0.39$, $p < 0.05$).

Table 2 illustrates Spearman non-parametric correlation analysis between the eight fires' indicators (including FIRISK) and three ancillary variables representing the dominant

Table 1
Correlation analysis between FIRISK and the seven forest fires' indicators by metric coefficient (* indicates significant correlation at $p < 0.05$; see Section 2 for further details).

Variable	Pearson	Spearman	Kendall	Gamma
FIRDEN	0.20	0.23	0.16	0.16
AVGFIR	−0.03	0.43*	0.31*	0.32*
BURSUR	0.02	0.41*	0.29*	0.30*
WOOD	0.04	−0.01	0.01	0.00
PARK	0.02	−0.13	−0.11	−0.24
CROP	0.25	0.43*	0.33*	0.44*
PAST	0.18	0.31*	0.22*	0.25*

Table 2
Spearman pair-wise rank correlation analysis between fires' indicators (including the FIRISK) and the three ancillary variables (DIS, DEN and ELE) representing the dominant urban gradients in Attica (* indicates a significant correlation at $p < 0.05$; see Section 2 for further details).

Variable	DIS	DEN	ELE
FIRISK	0.39*	−0.43*	0.25*
FIRDEN	0.40*	−0.38*	0.47*
AVGFIR	0.62*	−0.71*	0.47*
BURSUR	0.61*	−0.67*	0.49*
WOOD	0.20	−0.22	0.48*
PARK	0.06	−0.02	0.11
CROP	0.75*	−0.75*	0.06
PAST	0.54*	−0.57*	0.35*

geographic gradients in the study region possibly influencing the distribution of forest fires. Spearman coefficients indicate a comparable spatial pattern of the eight fires' indicators, showing positive and significant pair-wise correlations with DIS and ELE and negative correlations with DEN. Results indicate that FIRISK distribution was influenced by both the urban gradient and the elevation gradient. Fire density, average size and land cover selectivity were in turn correlated with these gradients with the same coefficients found for the FIRISK.

Fig. 2 shows the results of a hierarchical clustering evaluating the similarity in the spatial distribution of the eight fires' indicators in the study area. The dendrogram indicates a marked similarity of FIRISK with the variables PAST, CROP and FIRDEN and a moderate similarity with AVGFIR and BURSUR. This confirms the results derived from the correlation analysis.

Taken together, the FIRISK positively correlated with four out of seven fire indicators (average fire size, percentage of burnt area on the municipal area, percentage of cropland and pastures burnt in each fire) quantifying density, severity and land-use selectivity of forest fires in the area. Interestingly, the results of the correlation analysis reflect mainly non-linear relationships between FIRISK and the selected fires' indicators. The results obtained for a region, such as Attica, characterized by high fire risk, a marked urban–rural gradient, a fragmented agro-forest landscape and massive urban expansion, can be extended to other southern European areas with similar environmental characteristics and a comparable socioeconomic context on a local scale.

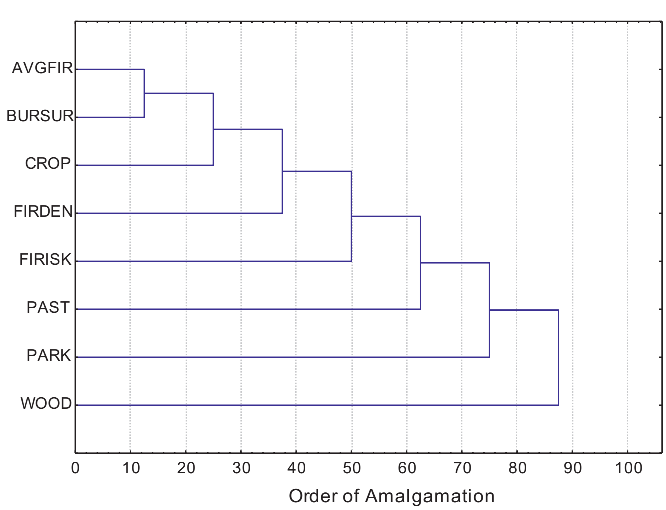

Fig. 2. Cluster analysis (see for technical details) assessing the similarity in the spatial pattern of the eight fires' indicators.

4. Conclusions

Using a validation approach that assesses the correlation between the FIRISK and several forest fire statistics and the similarity in their spatial distribution along various geographical gradients (Ferrara et al., 2012), the present study demonstrates that the Fire Risk Index originally developed in the ESAI framework of EU-funded Medalus projects is a reliable indicator of fire risk and can be used to classify the sensitivity of land (both forest and non-forest) to soil degradation and desertification (Salvati et al., 2009). Cluster analysis indicated that the spatial distribution of FIRISK is coherent with variables describing fire size and the composition of burnt land classes suggesting that indexes derived from land-use maps may provide important indications for fire risk management (but see also Guglietta et al., 2011).

The FIRISK could be also considered as a key component of a multi-criteria decision support system classifying land according to the (changing over time) level of fire sensitivity (Salvati and Bajocco, 2011). In this perspective, the FIRISK shows interesting characteristics (e.g. Ferrara et al., 2012) since it was derived from regularly-updatable data sources freely available on a detailed spatial resolution and with supra-national geographical coverage. Simplified but reliable indicators derived from official data sources covering large areas, possibly integrated with indicators derived from remote sensing (e.g. Koutsias et al., 2010; Moreira et al., 2011; Turner et al., 2011; Mancino et al., 2013; Nolè et al., 2013) and field surveys (Scarascia-Mugnozza et al., 2000; Keane et al., 2001; Badia-Perpinyà and Pallares-Barbera, 2006; Salvati et al., 2013), are crucial to support permanent forest monitoring systems that are informative for policy implementation.

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