BURNED AREAS DETECTION AND FIRE WEATHER INDEX. A STUDY CASE IN NW ITALY

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ABSTRACT

The study was carried out in NW-Italy and focused on the detection of burned areas and the evaluation of the fire danger. The first aim was to extract the areas affected by fire in a semiautomatic way from Landsat images; the second one to evaluate the use of the Fire Weather Index (FWI) for defining the fire danger, as the weather factors influence a lot the fire, mainly their ignition and propagation. Automatic Burned Area Detection Software (ABAMS) was used for the detection and the best indexes to be utilized in its two phases were chosen. The burned areas and the FWI daily data were studied considering a period of four years. The U Mann-Whitney analysis was applied to verify the relationships between burned areas and weather indexes. The results seem to show that the FWI and the Drought Code (DC) can explain well the fires event and their extension. A first definition of the indexes thresholds that could be used to discriminate among classes of danger was made. The study highlights the connection of fires frequency and extension with the weather conditions, confirming that these factors, combined in a meteorological index, can be useful to estimate the fire danger.

KEY WORDS: burned areas, Landsat images, Fire Weather Index, fire danger rating

INTRODUCTION

Forests hold a fundamental role as biodiversity sources, as interchange medium between earth surface and atmosphere through photosynthetic and respiration processes and as land protection in the hydrologic sphere. Therefore, the health of forests is essential for life on Earth and in particular to humans. Fires caused by humans and deforestation are the main threats for the forests. Wildfires are destructive and devastating for forest ecosystems, In recent years, particularly in 2019 - a year characterized by a significant drought - the images of many and extensive fires in the Amazon, California, Southeast Asia, Australia, Siberia, Canary Islands, Greece and the Iberian Peninsula have impressed the international public (NASA Earth Observatory, 2019). Therefore the monitoring of the burned areas and the study of fire danger turn out to be topical subjects.

To date there is no standard classification procedure to identify and map burnt areas, although there are several indexes in technical literature with different efficiency and tested in different areas. The analysis of the satellite data, once accurate extraction methods are designed, may complement or even replace ground surveys in areas affected by fire, especially when they are wide or inaccessible/hard to reach.

Concerning the monitoring of the burned areas, also the fire danger prediction is a fundamental point to protect forests. Fire danger is linked to three class of interconnected variables: fuel, topography and weather factors. Weather is a fundamental component of the fire environment. Prolonged drought and high temperatures of the summer period in the Mediterranean climate are the typical drivers that demarcate the temporal and spatial boundaries of this fire season (Camia & Amatulli, 2009). On the other hand, wind plays an important role when fire has started. For this key role that they play in fire occurrence and behavior, weather variables are often combined in specific meteorological fire danger indexes that provide estimations of fire danger level at a given time (Bovio & Camia, 1997).

Obviously the inflammability and the severity of the damage caused by the fire also depend strictly on the different types of plant communities. During the past several decades the evaluation of the characteristics of the vegetation as fuel have been the subject of numerous works in the Mediterranean basin (Maselli et al., 2000; Keane et al., 2001; Riano et al., 2002; Hessburg 2007; Bajocco et al.. 2009; Silva et al., 2009). The typical method for mapping fire risk using vegetation maps cannot produce high resolutions [pixel size = 10^{-1} – 10^{1} Ha], and a different approach is required. Fuel load is a major component of fire risk. However, the risk level is also affected by other factors, such as weather conditions, ignition sources and topography (Carmel et al., 2009). Nevertheless, there are few studies to assess other methods, in particular those most widely used by institutions responsible for land management at the local scale (Ryu, 2007; Dimitrakopoulos et al., 2011; Sirtori, 2013).

One of the fire danger rating methods used in most of the European Mediterranean countries is the Canadian Forest Fire Weather Index – CFFWI (Bovio & Camia, 1997; Viegas et al., 1999) adopted also by the European Forest Fire Information System (Camia et al., 2006).

Liguria is an Italian region, characterized by one of the mildest climates of the Mediterranean area with warm yet never torrid summers, that extend till November and winters that never record too rigid temperatures (Regione Liguria, 2018, Sacchini et al., 2012). These climatic conditions make Liguria atypical with respect to the other Italian regions because it benefits from a typical Mediterranean climate in the south and is protected against the cold winds coming from north thanks to the Apennines-Alps dorsal. The 75% of its total surface is covered by woodlands, 18.76% by cultivated areas, and 5.73% by urban areas, placed almost exclusively along the coast. Liguria is the Italian region that has the largest forested surface with respect to total surface (Gorziglia et al., 2007).

The conservation of the Italian forest resources and their defence against fires as irreplaceable welfare for the life quality is the purpose of the Italian law 353/2000 (Parlamento italiano, 2000). Fires are a major cause of depletion and degradation of the Liguria region, whose territory extends for 5420.24 km^2, of which 3751.34 are forest. The analysis of the historic series 1987-2002 highlights an average nearly 1000 fires per year (13,521 in 15 years) that destroyed 64,524 ha of forest areas (Barichello et al., 2004). Therefore the aims of this project are to test and improve the use of the Automatic Burned Area Detection Software – ABAMS (Bastarrika Izaguirre & Chuvieco Salinero, 2006) to monitor burned areas using Landsat images in the Liguria region and to test their relationship with the Fire Weather Index (FWI) components in a period of four years, to analyse and propose the use of this danger rating system in the same region.

STUDY AREA

The test area is located in north-western Italy, in Liguria. The morphology is particularly complex, being its orographic system constituted by the union of Maritimes Alps and Northern Apennines. The dominant species of vegetation are *Pinus pinaster* Aiton, *P. halepensis* Mill., *P. sylvestris* L., *P. nigra* J.F. Arnolds, among the conifers, *Castanea sativa* Mill., *Quercus pubescens* Willd., *Q. petraea* (Matt.) Liebl., *Q. ilex* L., *Fraxinus ornus* L., *Ostrya carpinifolia* Scop., and *Fagus sylvatica* L. among the broadleaves.

A synthetic statistic of fire occurrence in Liguria is shown in Table 1 for the period 1987-2009 (Regione Liguria, 2018). A monthly analysis of the fire occurrences for the same period suggests that they are characterized by two peaks, one in winter (during January – March) and one in summer (during July – September). The summer season is characterized by a high number of fires in August (114 per year), while the most extended burned surface is registered in September (650.81 ha per year). This behavior is due to the favorable conditions for fire spread in September, still characterized by high temperatures but also by strong winds. The same behavior is shown in the winter season where the greatest number of fires is registered in March (131 per year), while the most relevant damages in terms of burned hectares is registered in February (1211.86 ha per year), a month characterized by climatic condition more favorable to fire propagation, due to the influence of strong winds.

On the other hand, the Italian climatic conditions (ISTAT, 2010) show for the period 2000-2009 a growth of the mean temperatures compared to the reference climatic values calculated for the period 1971-2000 (12.5°C), with an increase of 1.4°C in the 2003. The 2003 has been the hottest year in the period 2000-2009 with a mean temperature of 13.9°C, due mainly to the high values of maximum temperature (Tmax) registered over the year, higher by 2.1°C than the Tmax reference climatic value (17.1°C). As for the precipitation, 2011 was the driest year, with a gap of 189 mm (- 4%) with respect to the reference climatic average (793 mm), while the 2002 has been an especially rainy year with a plus of 88 mm (+ 1.1%).

METHODS

The first step of the study was to detect burned areas in a semiautomatic way. Therefore, the software ABAMS was tested applying different indexes. Afterwards, we compared the total burned areas per day with the Drought Code (DC), a cumulative index, and FWI.

Data

The analysis reported in the following paragraphs was based on Landsat ETM+ / TM images acquired from 1999 to 2003. The set is composed by one image per year acquired at the end of the summer fire season. Dates vary according to the availability and quality of the recorded images (Table 1). The study was limited between the 31 May (first day in which the FWI data are available for all the four years) and the day of the image acquisition for each year.

The acquired images were already geometrically corrected. Landsat data have been downloaded from Global Visualization Viewer (GloVis) as standard level-one terrain-corrected (L1T) product (http://glovis.usgs.gov). The L1T correction process utilizes both ground control points and DEM to attain absolute geodetic accuracy (NASA, 2011). The radiometric and topographic correction had already applied according Chander & Markham (2003), Chander et al. (2009), Teillet et al. (1982) and Veraverbeke et al. (2010).

Table 1. Fire events and satellite data

Fire statistics 1987-2009	
No. of fire per year	717
Burned area per year (ha)	5893
Yearly burned forested area (ha)	3796
Yearly burned not-forested area (ha)	2097
Average burned area per fire (ha)	8.2

Satellite data used in this study

DATE	SENSOR
6 oct. 1999	ETM+
22 sept. 2000	ETM+
24 aug. 2001	ETM+
28 sept. 2002	ETM+
7 sept. 2003	TM5

We used the Digital Elevation Model (DEM), with 5m resolution, of the Liguria Region in the topographic correction to correct the slope and aspect values of the pixels.

We have also used data of the forest fire archives based on ground fire observations done by the Italian National Forestry Service, that report for each fire the location, the starting date, the shape and the extension of the affected area. Moreover, the FWI archive for the period 2000-2003 was acquired, created with the meteorological data registered from May to September.

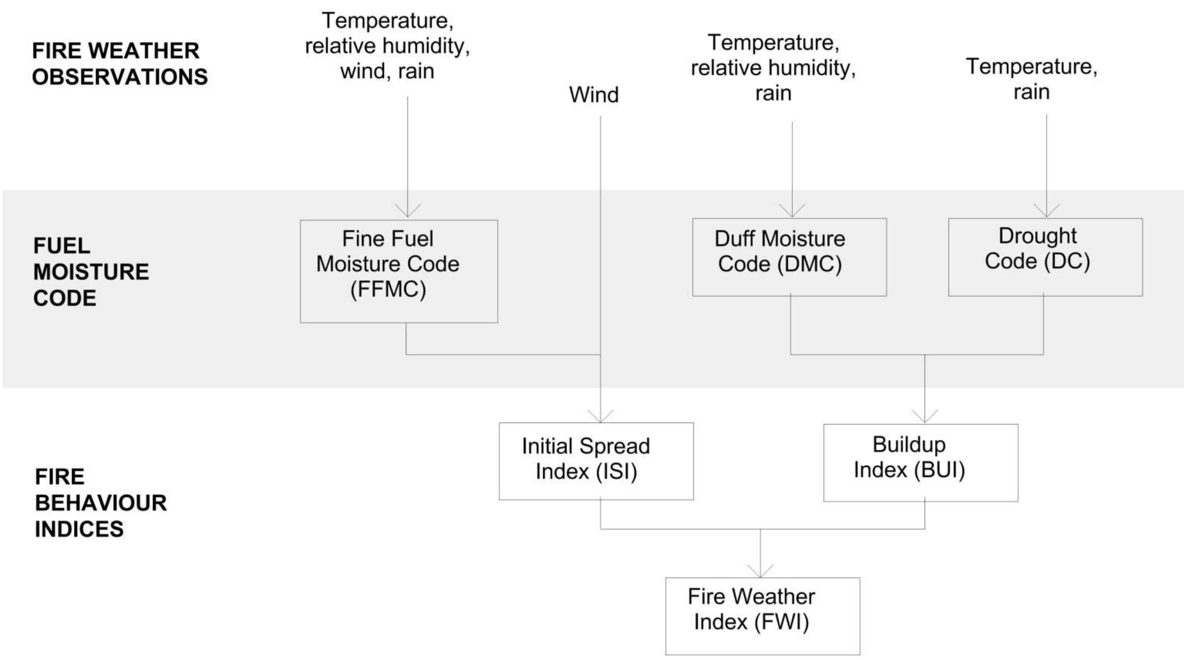

Figure1. Structure of the Fire Weather Index.

The **Canadian FWI System** (Van Wagner, 1987) consists of six components that account for the effects of fuel moisture and wind on fire behavior (Fig. 1). Calculation of the components is based on consecutive daily observations of temperature, relative humidity, wind speed, and 24-hour rainfall. The six standard components provide numeric ratings of relative potential for wildland fire.

We focus particularly on the final FWI value, a numeric rating of fire intensity, and on the DC, a numeric rating of the average moisture content of deep, compact organic layers. This code is a useful indicator of seasonal drought effects on forest fuels and the amount of smoldering in deep duff layers and large logs; additionally, DC have been used in Mediterranean areas to estimate fuel moisture content (Viegas et al., 2001). We obtained the FWI data from the European Forest Fire Information System (EFFIS) network (San-Miguel-Ayanz et al., 2012) that has adopted this index as method to assess the fire danger level throughout Europe in a harmonized way using a cells grid with a spatial resolution of half a degree.

Burned area extraction

To date, there is no standard procedure to identify and map burned areas. We decided to use the ABAMS software on the base of a preliminary study (Sirtori et al., 2011). This approach is based on a two phase algorithm: in the first one, the goal is to reduce the commission errors by means of severe criteria and aims to detect the more clearly burned pixels (seed pixel), even at the cost of omitting many burned pixels within each burn patch; the second phase analyses only the vicinity of the seed pixels, applying looser criteria to extend the burned area up to the actual burned perimeter, and thus reducing omission errors (Bastarrika Izaguirre, 2011). The Burned Area Mapping Algorithm must be configured. We used a multitemporal strategy. The criterion to be used depends on the work objective. In this case the aim was to detect all the burned areas in the studied period even accepting a larger commission error. Initially we chose the RELAXED criterion, already included in the software, that uses the following indexes or bands: Normalized Burn Ratio (NBR_post and NBR-difference in the seed phase), Mid-Infrared Burned Index (MIRBI_post), Burned Area Index (BAI_difference) and Logistic Regression Multitemporal (LR_multi) and Band TM4_post in the growing phase (Bastarrika Izaguirre et al., 2011). Then, to minimize both the omission and the commission errors, we changed some parameters and thresholds, starting from the ones pre-defined in ABAMS; adopted parameters and thresholds are showed in Table 2. Once the automatic results from the ABAMS software were obtained, clearly erroneous areas (e.g., urban area, bare soil, and clouds) were manually excluded. The validation of the extracted burned areas was performed through a visual comparison with the fire perimeters detected in situ by the Forest Service. The different solutions (of parameters and thresholds) were evaluated considering as discriminating factor the number of burned areas detected that coincide with the Forest Fires perimeters. In case of equal performances, the method with the best visual comparison result was selected. We applied this validation approach because the field data turned out to be, both visually and according to the results in a previous work (Sirtori et al., 2011), not accurate enough to be used in a per-pixel comparison.

Table 2. Parameters and related thresholds used in ABAMS to extract the burned areas. Thresholds used in ABAMS for the extraction of burned areas from the Landsat data series 1999-2003. The abbreviations are shown in the tex t.

years	*Seed*				*region growing*	
	NBR_post	BAI_diff	NBR_diff	MIRBI_post	TM4_post	NBR_diff
1999-2000	< 0.32	> 10	< - 0.2	> 0.9	< 0.25	< - 0.15
2000-2001	< 0.2	> 10	< - 0.20	> 1	< 0.25	< - 0.20
2001-2002	< 0.3	> 0	< - 0.15	> 1	< 0.3	< - 0.05
2002-2003	< 0.1	> 10	< -0.35	> 1.5	< 0.22	< - 0.4

Burned area and FWI relation

The extracted burned areas were overlapped with the Forest Fires perimeters to assign to each area the corresponding fire date. In this way it was possible to connect the burned area and the FWI data using the events date as link. The following analysis has been carried out on the whole study area as defined in Fig. 2. This choice allows riding out the cells variability due to the territory extension, the land use, the topographic characteristics and the type of fuels that influence the fire events. Unique indexes values computed daily for the overall area were the FWI and DC median value per day. Then, a non-parametric statistical test was applied to verify the relation between fires incidence and FWI. Using the U Mann-Whitney (Mann & Whitney, 1947, Averill, 1972) and the Kruskal-Wallis (Kruskal & Wallis, 1952) tests, it was evaluated whether the medians on a test variable differ significantly between two or more groups respectively. To run these tests, each case must have scores on two variables, the grouping variable (categorical variable) and the test variable (dependent variable), and then the observations from each group are combined and ranked.

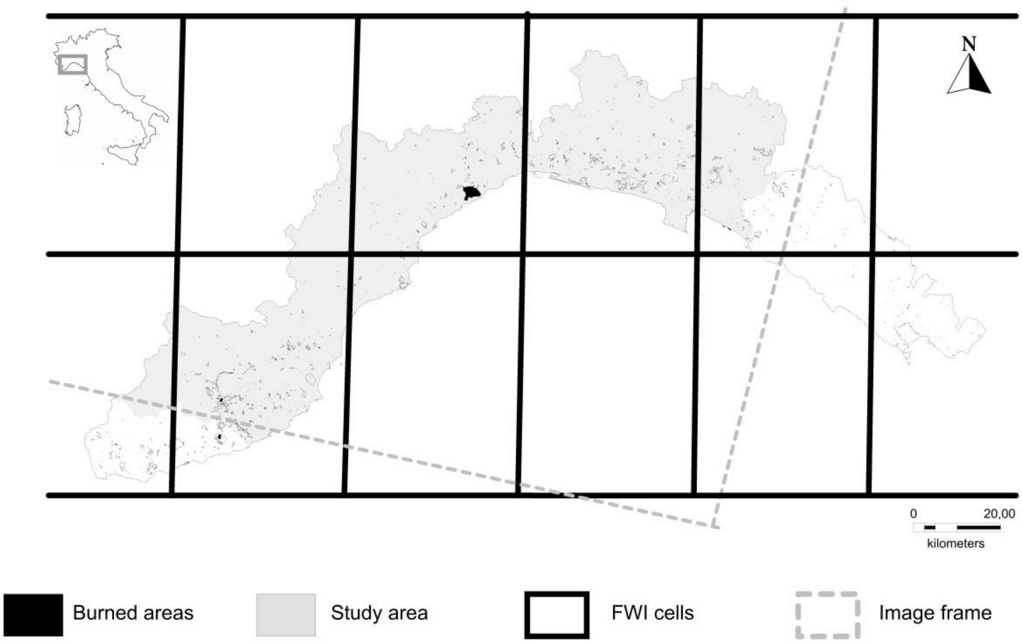

Figure 2. Results obtained analyzing the period 2000-2003. The excluded areas are the municipalities that stand outside the Landsat image frame or that overlay a non-continuous image border.

RESULTS AND DISCUSSION

The best result of the first phase of evaluation of different indices through ABAMS was obtained using the NBR difference index instead of the LR multi parameter in the Region Growing phase. The number of areas detected as burned that coincides with the Forest Service data increased with respect to the standard approach, greatly reducing the omission error. Figure 2 represents the burned areas extracted for the period 2000-2003 using this solution.

Fig. 3 shows the DC values for the four years of study and the burned areas extension for corresponding day. This analysis highlights that in the 2002 the index presents smaller values with respect to the other years. Moreover, making a comparison with the corresponding total burned hectares, we can see that in the 2002 the value for the same study period (31 May-24 August) is lower. On the contrary, the 2003 year shows the higher DC values and a high associated fire incidence (Table 3).

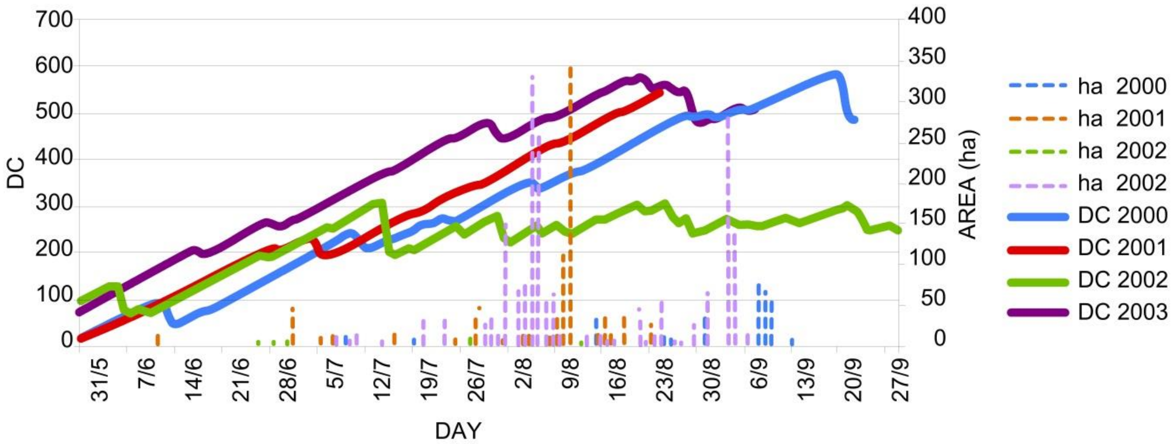

Figure 3. Comparison of Drought Code values with burned areas for the period 2000-2003.

Table 3. Total burned areas. The detected areas were burned between 31st May and 24th August for each year of study.

year	Ha tot
2000	49
2001	813
2002	14
2003	1299

This evidence suggests that there is a relation between DC and fire events. Carrying a deeper analysis, we considered the FWI and DC median values (test variables) per day of study and we grouped them considering the number of fires per day (categorical variable). We divided the days in two and four categories, corresponding to burned (one or more fires per day) and unburned (no fires per day) in the first case and to the number of fires per day in the second. The box plots in Fig. 4 represent the relations found between test and categorical variables.

Visually, the two classes seems to show a good separation (Fig. 4 a-b). To verify it, the U Mann-Whitney test was used. The results are significant (Sig.<0.05) with both Z values negative (Table 4a) and confirm that indeed the DC and FWI values are higher in the days affected by fires.

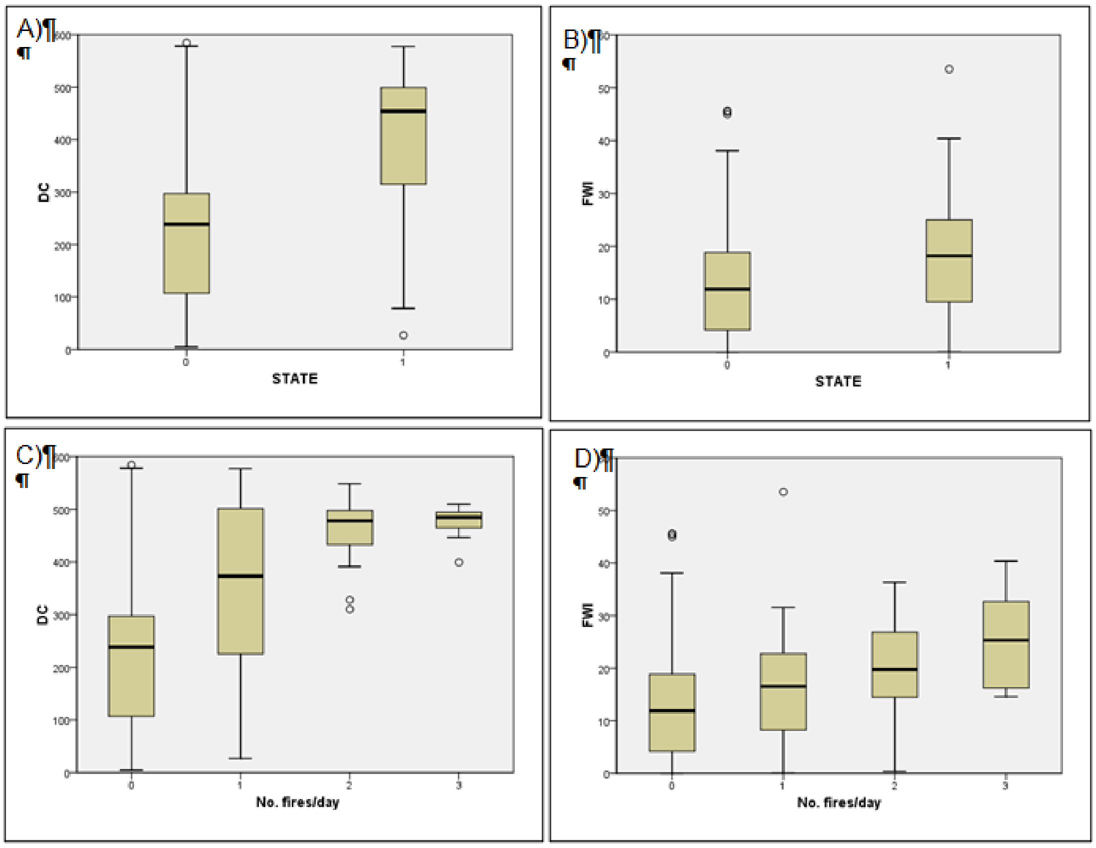

Figure 4. Box plots of the test variables DC (A-C) and FWI (B-D) grouped in two and four classes using as categorical variable the number of fire per day. In the two categories case, class0 and class1 correspond to the state unburned (zero fire/day) and burned (≥1 fire/day). In the four categories case, the class number corresponds to the number of fires per day, except for class3 that correspond to a number of fires ≥3.

The results of the Kruskal-Wallis test for the four category cases show in both cases a significance of zero, so the null hypotesis that the distribution of DC and FWI is the same across the four categories is rejected. The overall test was significant, but we still didn't know which groups differ significantly from which other groups, so a pair wise comparison was completed with the U Mann-Whitney test (Table 4 b). We can see that class '0' can be easily distinguished from others using both indexes. A good discrimination is also confirmed for the pairs '1-2' for the DC and '1-3' for the FWI. The results suggest that the two indexes can explain rather well the fire occurrence but the FWI apparently performs better than the DC when considering an higher number of fires per day (see the comparisons '1-3' and '2-3').

Additionally, a different categorical variable was used. The days were divided considering the corresponding fire extensions expressed as burned hectares per day. Five classes were created (Fig. 5*A-B*) considering on its own the class '0', equivalent to zero hectares per day per cell, and using as other thresholds for the fires extension the percentile values (25%= 2.60ha; 50%= 10.16ha; 75%= 32.21ha). Observing Fig. 5*A-B*, the box plots show a positive relation (the values get higher increasing the fires extension) with both the indexes, even if the median values for the FWI are very close. The Kruskal-Wallis test turned significant (sig.= 0.00) for both indexes, so the U Mann-Whitney test was applied (Table 4c). The FWI shows a clear difference only for three combinations in contrast with the class ‘0’. Considering the DC, the test is significant for almost all the comparisons. Only the pairs ‘1-2’ and ‘3-4’ are difficult to separate. Accordingly, these classes were merged obtaining finally three classes (Fig. 5*A*-*D*). Table 4d suggests that in this case the DC can explain well the fire extension (sig. < 0.05).

Table 4. U Mann-Whitney test and analysis. Z values and significances are displayed in (a). The analysis (b) tests for each column the null hypothesis that a sample “a” and a sample “b” distributions are the same. The test is applied to five (c) and three (d) classes obtained using the fires extension as categorical variable. The significance level is 0.05.

(a)	U Mann-Whitney	DC	FWI
	Z	-8.256	-4.475
	Sig.	0.000	0.000

(b)	U Mann-Whitney	0-1	0-2	0-3	1-2	1-3	2-3
DC	Z	-5.018	-6.393	-4.316	-2.050	-1.520	0.000
	Sig.	0.000	0.000	0.000	0.040	0.129	1.000
FWI	Z	-2.311	-3.228	-3.673	-1.664	-2.591	-1.567
	Sig.	0.021	0.001	0.000	0.096	0.010	0.117

(c)	U Mann-Whitney	0-1	0-2	0-3	0-4	1-2	1-3	1-4	2-3	2-4	3-4
DC	Z	-2.831	-2.943	-5.968	-6.007	-0.013	-2.314	-2.528	-2.365	-2.315	-0.478
	Sig.	0.005	0.003	0.000	0.000	0.990	0.021	0.011	0.018	0.021	0.633
FWI	Z	-1.346	-2.146	-2.523	-3.603	-0.591	-1.170	-1.748	-0.491	-1.195	-0.491
	Sig.	0.178	0.032	0.012	0.000	0.554	0.242	0.080	0.624	0.232	0.624

(d)	U Mann-Whitney	0-1	0-2	1-2
DC	Z	-3.981	-8.256	-3.386
	Sig.	0.000	0.000	0.001
FWI	Z	-2.408	-4.224	-1.637
	Sig.	0.016	0.000	0.102

Finally, we tried to obtain different classes of danger. The FWI median values of each of the four groups obtained using as variable the number of fires per day were considered (Table 5a). These values were rounded and used as thresholds to define the classes of danger. As mentioned above, class ‘2’ is difficult to discriminate from the other ones and thus a unique class of danger C3, that includes the values from 16 to 28, was created.

DC can be used to define fire danger too, since, as mentioned above, this index can explain better than FWI the fire extension. Therefore, it was decided to express with DC the fire propagation danger once the fire has started. Three classes were created using the median values of each of the three groups obtained using as variable the burned hectares per day (Table 5b).

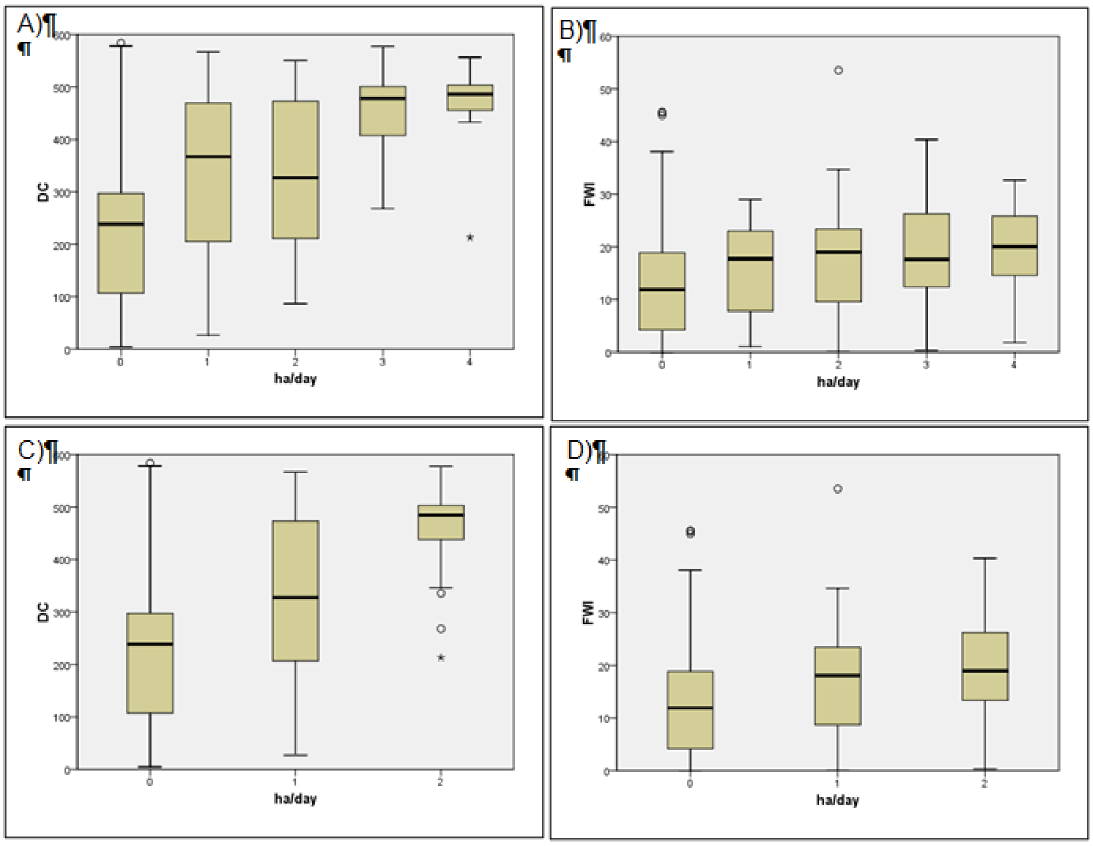

Figure 5. Box plots of the test variables DC (A-C) and FWI (B-D) grouped in five and three classes using as categorical variable the fires extension expressed as hectares of fire per day. The five categories are obtained using as thresholds the percentile values (class0: =0ha; class1: 0 – 2.60ha; class2: 2.60 – 10.16ha; class3: 10.16 – 32.21ha; class4: >32.21ha). The three categories consider as threshold the median value (class0: = 0ha; class1: 0 – 10.16ha; class2: > 10.16ha).

Table 5. Classes of danger obtained starting from the medians values of FWI and DC

(a)	n°fires/day Class	FWI median value	FWI thresholds	Class of danger
	0	11.4221	< 11.4	C1
			11.4-16	C2
	1	15.9602		
	2	20.2675	16-28	C3
	3	28.0530		
			>28	C4
(b)	**ha/day Class**	**DC median value**	**DC threshold**	**Class of danger**
	0	245.50	< 245.5	C1
			245.5-343	C2
	1	343		
			343-483.5	C3
	2	483.50		
			> 483.5	C4

CONCLUSIONS

Fires play a fundamental role in the Mediterranean environment. They are particularly relevant in a forested and mountain region like Liguria. This study shows the results obtained in two topics: the detection of burned areas and the fire danger rating. For the first topic, the ABAMS (a two phases algorithm) has proved to be able to provide good results in monitoring burned areas with Landsat images using the indexes NBR_post, MIRBI_post, BAI_difference, NBR difference in the seed phase and NBR_difference and TM4_post in the growing phase.

For the second topic, the U-Mann Whitney test was applied to the detected burned areas and the FWI - DC values, considering a period of four years. Results suggest the use of the FWI to predict if there is danger that a fire starts in a certain day, while DC seems useful to determinate the danger that a fire spreads in a wide area. We highlight that there are many other variables that control the fire danger that are not used in this study. The type of fuels, the topographic characteristics and specially the human factor are some examples. Despite that, the indexes discussed in this work show a good relation with the burned areas. Finally, the analysis was used to define also possible thresholds of a danger rating system. The classes of danger delineated were four for both indexes. A further step of the study will be the validation of FWI and DC thresholds using data from a different temporal series that includes a longer period. On the other hand, this study would be applied in this step to manage specifically summer fires as the danger conditions can change during the year because of the different phenological state of vegetation.

ACKNOWLEDGEMENTS

The study was funded by the University of Genova as part of the PhD program in Botany Applied to Agriculture and Environment (XXV cycle). The authors wish to thank Aitor Bastarrika Izaguirre for the software ABAMS, the European Forest Fire Information System for the FWI data and Regione Liguria for the forest fire archives.

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DOI: 10.15167/2612-2960/BELS2019.1.1.1182