Fire–weather relationship in the Italian peninsula

Masala F.[1], Bacciu V.[1,2], Sirca C.[1,2], Spano D.[1,2]

[1]*Department of Science for Nature and Environmental Resources (DipNeT), University of Sassari, Italy,* [2]*Euro Mediterranean Center on Climate Change (CMCC IAFENT), Sassari, Italy*

masala.francesco@email.it, valentina.bacciu@cmcc.it

Abstract

Climate and weather are two of the main key factors influencing fire regime and they have a number of different effects on fire. The objective of this work is to improve our knowledge of the relationship between meteorological variables and forest fire across Italian peninsula. In the first part of this work, we collected meteorological and fire events data. The second part of the work involved the assemblage of fire and weather data into a GIS to facilitate manipulation and display of the data and the classification of Italian peninsula in homogeneous climatic areas, through hierarchical cluster analysis of meteorological data. A set of parametric and not parametric statistical tests were used to analyse the fire-weather relathionships. The results showed that both fire number and burned area are highly related with rainfall in summer and winter, considering both peninsular Italy and each cluster. The results confirmed the crucial role of high resolution datasets in analyzing fire and weather trends and relationships, and could be promisingly applied as input to develop and calibrate models for studying the impacts of climate change on fires.

Keywords: fire regime, MARS, piro-climatic areas

1. INTRODUCTION

Fire is one of the most frequent and widespread ecosystem disturbing phenomena (Bowman et al. 2009; Krawchuk et al. 2009), in particular in areas with a Mediterranean climate (Keeley et al. 1999; San Miguel and Camia 2009; van Wilgen et al. 2010). According to several studies, the Mediterranean Basin wooded areas affected by fires cover annually an area of 1000 x 10^3 ha, causing significant economic and ecological damage (Velez 1997). On average, from 2000 to 2005, about 95,000 fires occurred annually in 23 European countries, burning almost 600,000 ha of forest land every year. Within these, about two-thirds (65,000 fires) occurred in 5 Euro-Mediterranean countries (France, Greece, Italy, Portugal, and Spain) where, on average, half a million hectares of forest land were burned every year (Barbosa et al. 2008).

Climate and weather are two of the main key factors influencing fire regime and they have a number of different effects on fire. Weather determines fuel moisture, influences lightning ignitions, and contributes to fire growth through wind action (Carvalho et al. 2008). Worldwide, a number of studies have analyzed the relationship between weather and forest fires but only few analyzed this relationship in Mediterranean ecosystems and at broader scale.

In Spain, Vázquez and Moreno (1993) showed strong relationships between temperature and precipitation variables, particularly of extreme values of these variables and burned area. These relationships, however, varied among areas with different climate. In Portugal, Viegas and Viegas (1994) indicated a non-linear relationship between burned area and rainfall so that, depending on the time of rainfall, this could promote or deter the burned surfaces. Pausas (2004) showed how summer rainfall was significantly related to the inter-annual variability in the burned area, showing also a significant cross-correlation for a time lag of two years in Valencia district (Spain). In Canada, weather–climate has been established as the most important natural factor influencing forest fires (Stocks and Street 1983; Flannigan and Wotton 2001; Hely et al. 2001).

Despite all these efforts, region specific analysis of the driving forces of fire regime are still needed to better understand this issue. In this context, this paper aims to contribute and improve our knowledge about the relationships between meteorological variables and wildfires at National level in Mediterranean ecosystems.

2. MATERIALS AND METHODS

In the first part of this work we collected meteorological and fire data to analyze the relationships between fire and weather in the Italian peninsula. The meteorological variables (maximum and minimum temperature, relative humidity, precipitation and wind speed) were obtained at daily scale through the MARS (Monitoring Agricultural Resources) database interpolated at 25x25 km scale. The fire database available for Italy was provided by JRC (Join Research Center) and contains the monthly number of fires and total area burned at provincial level from 1985 to 2008.

To analyze the effects of weather variables on fire, it was decided to homogenize the time scale of MARS database to the JRC, therefore monthly mean were calculated from MARS daily data for each year.

The second part of the work involved the assemblage of fire and weather data into a GIS to facilitate manipulation and display of the data, and the classification of Italian peninsula in homogeneous piro-climatic areas, through a non-hierarchical cluster analysis of meteorological and fire data. In each identified area, descriptive statistics were initially calculated to determine the differences on fire regime and weather conditions. Then, we proceeded with the seasonal and annual trend analysis through parametric and non-parametric tests to assess whether the inter-annual variability in weather patterns and in fire events had a significant trend. Finally, Pearson correlation and linear regressions were carried out to characterize the relationship between meteorological variables and forest fires.

3. RESULTS

The results obtained from cluster analysis showed, for peninsular Italy, five different piroclimatic areas with different fire regime (Figure 1). Cluster 1 represents the Alpine zone with severe winter and high amount of cumulative rainfall, where the fire regime is typically concentrated in winter and fire occurrence is very low compared with the other areas. Cluster 2 and 3 are very different from fire statistic and termo-pluviometric points of view. Cluster 3, mainly constituted by Liguria region, has a typically Mediterranean climate (T max 17.26 °C, T min 9.87 °C, rainfall 780 mm), but fire regime is not exclusively on summer and occurrence is higher than Cluster 2 and 1 (Table 1). Cluster 4 represents

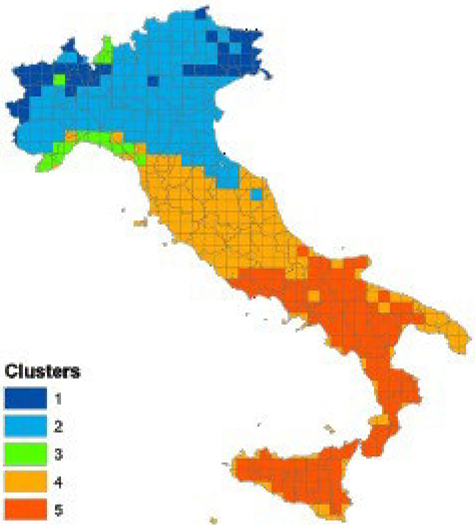

Figure 1. Categorization of Italy in the five cluster recognized by the cluster analysis.

mainly the center of the peninsula, and although fire regime is framed mainly during summer, it has some fire occurrence during spring. Finally, Cluster 5 is represented by Southern Italy. In this zone, fire occurrence is concentrated during summer. This Cluster represents the area were the fire occurrence is the highest among all clusters: the recorded number of fire is more than 89,000 and the burned area is more than 1,086,000 ha. This is probably due to the type of climate, represented by mild winters, T min 11.47 °C, and dry summers, with T max of 19.97 °C and rainfall of 626 mm (Table 2).

Table1. Fire statistics and fire seasonal occurrence for the 5 different clusters recognized by the cluster analysis

Region	Burned area (ha)	Number of Fires	Fire season
CL 1	96,794	9,981	Jan-Apr
CL 2	178,867	20,892	Jan-Apr, Jul-Sept
CL 3	179,576	19,989	Jan-Apr, Jul-Sept
CL 4	407,519	43,167	Mar, Jul-Sept
CL 5	1,086,523	89,092	Jun-Sept

Table 2. Termo-pluviometric characteristics for the 5 clusters recognized by the cluster analysis

Region	Tmax (°C)	Tmin (°C)	Rainfall (mm)
CL 1	14.12	5.26	1,123
CL 2	16.31	7.00	734
CL 3	17.26	9.87	780
CL 4	19.80	10.48	666
CL 5	19.97	11.47	626

The trends of the fire data were analyzed both for all peninsula and for each cluster to have some inferences on the evolution of fires through the investigated period, and in the different piro-climatic areas. Trend analysis was done using parametric and non-parametric tests. Table 3 and 4 show the slope of the regression line, the standard error, and the Mann-Kendall test for fire and weather data. In general, our study showed that fire activity is decreasing, despite the overall trend of increasing temperatures in most of Italy (Table 3, 4). Considering the entire peninsula, the annual trend of burned area is decreasing ($F = 0.75$, $p<0.05$), even if the result is not confirmed by the Mann-Kendall test. On the other hand, the Mann-Kendall test confirmed the decreasing trend of fire number ($p<0.01$). Different clusters have been undergoing different trends. For example, in Northern Italy the Cluster 1 showed a significant decreasing trend for fire number, and for burned area, while Cluster 2 had a significant trend only for fire number. Cluster 3 showed a very significant decreasing trend for both fire number and burned area, while Cluster 4 trend was not confirmed by Mann-Kendall test (Table 3). Finally, Cluster 5, that represents the Southern part of the Peninsula, showed not significant trends.

Table 3. Anova and Mann-Kendall results for burned area (BN) and fire number (FN) trend for peninsular Italy and for each cluster

	Variable	Slope	Standard error	F	p	Test Z	Sig.	Q
Italy	BA	-1176.88	1354.96	0.75	*	-1.46	n.s.	-1693.696
	FN	-195.76	70.13	7.79	n.s.	-2.60	**	-181.654
CL 1	BA	-244.92	113.24	4.68	*	-2.80	**	-153.30
	FN	-15.93	4.54	12.33	**	-2.95	**	-13.88
CL 2	BA	-440.41	244.18	3.25	+	-2.21	+	-224.22
	FN	-28.80	11.06	6.78	*	-2.51	*	-25.57
CL 3	BA	-480.98	187.54	12.23	**	-3.55	***	-412.30
	FN	-49.42	8.44	34.29	***	-4.29	***	45.51
CL 4	FN	-48.51	20.39	5.66	*	-1.86	+	-41.37

n.s.= not significative; + p= 0.10; * p= 0.05; ** p= 0.01; ***p= 0.001

Table 4. Anova and Mann-Kendall results and for maximum temperature (Tmax), minimum temperature (Tmin) and Rainfall for peninsular Italy

	Variable	Slope	Standard error	F	p	Test Z	Sig.	Q
Italy	Tmax (°C)	0.04	0.01	12.58	**	2.95	**	0.045
	Tmin (°C)	0.06	0.010	35.29	***	4.14	***	0.062
	Rainfall (mm)	3.19	2.63	1.47	n.s.	0.97	n.s.	3.098

n.s.= not significative; + p= 0.10; * p= 0.05; ** p= 0.01; ***p= 0.001

In order to analyze the relationships between fire and weather, Pearson's correlation coefficients were calculated at national and cluster scale, both annually and seasonally. The variable that seems to be mostly correlated with the fire occurrence is the precipitation (Table 5, Figure 2). Considering the whole Italy, summer and winter rainfall are highly correlated with summer and winter fire number ($r=0.68$, $p<0.01$). This pattern is also present at cluster scale: for example, in the Southern Clusters (4 and 5) summer rainfall is strongly correlated with fire number (respectively, $r= -0.72$ and -0.70, for $p<0.01$) and burned area ($r=-0.66$ and -0.65, with $p<0.01$). On the other hand, Northern Clusters 1 and 2 are highly correlated with summer Tmax (respectively, $r= 0.75$ and 0.71 with $p<0.01$ for fire number, and $r=0.73$ and 0.62 with $p<0.001$ considering burned area).

Finally, linear regressions were calculated for all Italy and for all significant Pearson' correlation (Table 6). In particular, the best results were obtained analysing the relationship between winter and summer rainfall and fire number ($r^2=0.46$, $p<0.001$; $r^2=0.47$, $p<0.001$).

Table 5. Statistically significant Pearson's correlation between number of fires, burned area and selected meteorological variables.

	Italy		Pearson's correlation
Annual	Rainfall (mm)	Fire Number	-0.51 *
		Area burned (ha)	-0.56**
Winter	Rainfall (mm)	Fire Number	-0.68**
		Area burned (ha)	-0.58**
Spring	Rainfall (mm)	Fire Number	-0.43*
	Tmin (°C)	Fire Number	-0.50*
Summer	Rainfall (mm)	Fire Number	-0.68**
		Area burned (ha)	-0.52**

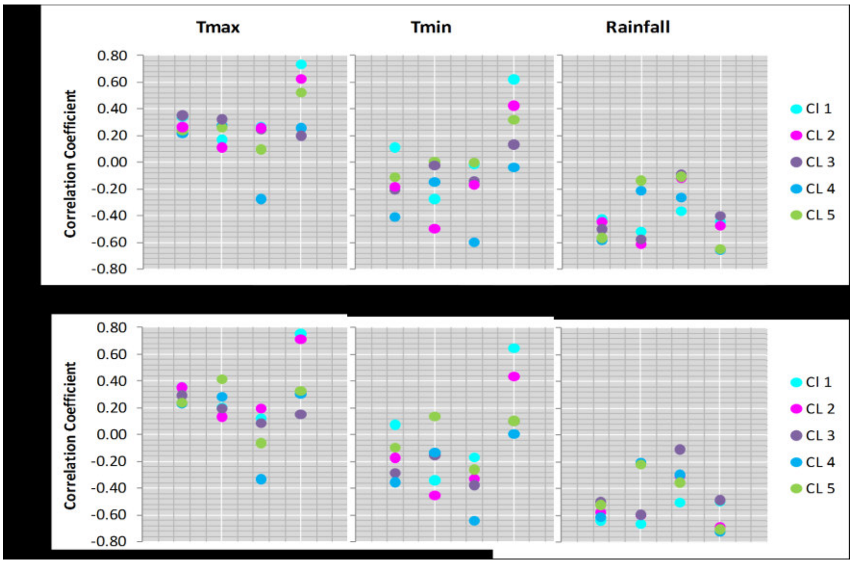

Figure 2. Pearson's correlation between the number of fires and burned area with meteorological variables (Tmax, Tmin and Rainfall) for each season and for each cluster

Table 6. Relation between yearly fire number and burned area and rainfall in Italy

Season	Fire variable (y)	Weather variable (x)	Slope	R^2	R^2adj	F	*p*
Annual	Fire number	Rainfall	- 15.34	0.26	0.23	7.7	*
	Burned area		- 285.67	0.32	0.29	10.2	**
Winter	Fire number	Rainfall	-11.86	0.46	0.43	18.64	***
	Burned area		-133.04	0.33	0.30	10.89	**
Summer	Fire number	Rainfall	- 35.25	0.47	0.44	19.35	***
	Burned area		- 583.28	0.30	0.24	8.12	**

* *p*= 0.05; ** *p*= 0.01; *** *p*= 0.001

4. CONCLUSION

The present work investigated the relationship between the weather and fire occurrence. The use of cluster analysis showed this tool as useful method to characterize fire-weather relationships at national level, allowing to clusterize the different piro-climatic situations.

In general, both the fire number and burned area are highly significantly related with rainfall in summer and winter in Southern Italy, while in the Northern areas, especially in the plains, both fire number and burned area are significantly related to summer Tmax. This could be due to the different factors that interfered with climatic variables. In Southern areas, for example, where the main economy is agriculture and the land use is highly exploited by anthropogenic activities, the fire causes are strongly related with socio-economic factors. Going Northern, as highlighted by Zumbrunnen et al. (2009), the abandonment of traditional land use, due to the transformation of the economy, could have incremented the debris in the forest, and then the influence of climatic factors in the indirect way could explain the fire activity.

The results of this work provide a valuable contribution in understanding the effect of weather conditions on fire number and burned area, and can be used as input for the development and calibration of models for the assessment of future impacts of climate change on fire.

5. ACKNOWLEDGEMENTS

This work was partially funded by the European Union Seventh Framework Programme (FP7/2007-2013) under Grant Agreement 243888 ("FUME" Project - Forest fires under climate, social and economic changes in Europe, the Mediterranean and other fire-affected areas of the world)

6. REFERENCES

Barbosa P., Camia A., Kucera J., Libertà G., Palumbo I., San-Miguel-Ayanz J., Schmuck G., 2008. *Chapter 8 Assessment of Forest Fire Impacts and Emissions in the European Union Based on the European Forest Fire Information System*. In: Andrzej Bytnerowicz, Michael J. Arbaugh, Allen R. Riebau and Christian Andersen, Editor(s), Developments in Environmental Sciences, Elsevier, 8: 197-208

Bowman D.M., Balch J.K., Artaxo P, Bond W.J., Carlson J.M., Cochrane M.A., D'Antonio C.M., Defries R.S., Doyle J.C., Harrison S.P., Johnston F.H., Keeley J.E., Krawchuk M.A., Kull C.A., Marston J.B., Moritz M.A., Prentice I.C., Roos C.I., Scott A.C., Swetnam T.W., van der Werf G.R., Pyne S.J., 2009. *Fire in the Earth system*. Science. 2009 Apr 24;324(5926):481-4.

Carvalho A., Flannigan M.D., Logan K., Miranda A.I., Borrego C., 2008. *Fire activity in Portugal and its relationship to weather and the Canadian Fire Weather Index System*. International Journal of Wildland Fire 17: 328-338.

Clark J.S., 1990. *Fire and Climate Change During the Last 750 Yr in Northwestern Minnesota*. Ecological Monographs 60:135–159

Flannigan M.D., Harrington J.B., 1988. *A study of the relation of meteorological variables to monthly provincial area burned by wildfire in Canada 1953–1980*. J Appl Meteorol 27:441–452

Flannigan M.D. and Wotton B.M., 2001. *Climate, weather and area burned.* In E.A. Johnson and K. Miyanishi (eds.), Forest Fires: Behavior and Ecological Effects, Academic Press, pp. 335–357.

Harrington J.B., Flannigan M.D., Van Wagner C.E., 1983. *A study of the relation of components of the Fire Weather Index System to monthly provincial area burned by* *wildfire in Canada 1953–80*. Canadian Forestry Services, National Forestry Institute, Information Report PI-X-25 (Petawawa, ON)

Hély C., Flannigan M., Bergeron Y., McRae D., 2001. *Role of vegetation and weather on fire behavior in the Canadian mixedwood boreal forest using two fire behavior prediction systems*. Can J For Res 31:430–441

Keeley J.E, Fotheringham C.J., Morais M., 1999. *Reexamining Fire Suppression Impacts on Brushland Fire Regimes*. SCIENCE, 284:1829-1832

Krawchuk, M.A., Moritz, M.A., Parisien, M.A., Van Dorn, J., Hayhoe, K., 2009. *Global Pyrogeography: the Current and Future Distribution of Wildfire*. PLoS ONE 4(4): e5102. doi:10.1371/journal.pone.0005102)

Pausas J.G., 2004. *Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean Basin)*. Climatic Change 63:337-350.

San-Miguel J. and Camia A., 2009. *Forest fires at a glance: Facts, Figures and trend in the EU. In: Living with wildfires: What science can tell us?* Y. Birot (ed). European Forest institute, Discussion paper 15, pp 11-18;

Stocks B., Street R., 1983. *Forest fire weather and wildfire occurrence in the boreal forest of northwestern Ontario*. In: Wein RW, Riewe RR, Methven IR (eds) Resources and dynamics of the Boreal zone. Assoc. Can. For Northern Studies, Ottawa, pp 249–265

van Wilgen B.W., Forsyth G.G., De Klerk H., Das S., Khuluse S., and Schmitz P., 2010. *Fire management in Mediterranean-climate shrublands: a case study from the Cape fynbos, South Africa*. Journal of Applied Ecology 47:631-638.

Vázquez A. and Moreno J.M., 1993. *Sensitivity of fire occurrence to meteorological variables in Mediterranean and Atlantic areas of Spain*. Landscape and Urban Planning 24:129-142.

Vélez R., 1997. *Recent history of fires in Mediterranean area*. In: Balabanis P, Eftichidis G, Fantechi R (eds) Forest fire risk and management, Proceedings of the European School of Climatology and Natural Hazards course. European Commission, Brussels, pp. 15-26

Viegas D.X. and Viegas M.T., 1994. *A relationship between rainfall and burned area for Portugal*. International Journal of Wildland Fire 4, 11–16. DOI 10.1071/WF9940011

Zumbrunnen T., Bugmann H., Conedera M., Bürgi M., 2009. *Linking forest fire regimes and climate - a historical analysis in a dry inner Alpine valley*. Ecosystems Vol. 12 No. 1 pp. 73-86