UNIVERSITÀ DEGLI STUDI DI SASSARI

A.D. MDLXII

SCUOLA DI DOTTORATO DI RICERCA
Scienze e Biotecnologie
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Indirizzo *Agrometeorologia ed Ecofisiologia dei Sistemi Forestali e Ambientali*

Ciclo XXV

Assessment of fire seasonality, and evaluation of fire-weather relationship, and fire danger models in Italy

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RVRALIS ET SILVESTRIS SAPIENTIA

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INDEX

ABSTRACT

The main aim of this work was to improve our understanding of wildfires in the Mediterranean context through the characterization of fire regime and the assessment of the main driving forces..

The study was conducted in Italy, considering the whole national territory, for the period 1985-2008. A preliminary hierarchical cluster analysis, based on the fire occurrence and weather data has allowed to identify 6 homogeneous areas for the fire regime and climate. Subsequently, three specific chapters have been developed.

In the first chapter, the fire seasonality has been assessed for each area using the von Mises probability distribution to characterize the patterns of seasonality in terms of season(s), start, end, length, and day of peak of fire occurrence; the analysis also demonstrated that some changes in the seasonality have occurred.

Then, the fire-weather relationships have been characterized using the Spearman's correlation and multiple linear regression analysis. Moreover, a statistical analysis of weather and fire trends, using parametric and non-parametric tests, has been made to define the patterns during the study periods.

In the last chapter, two wide diffuse fire danger indexes (the Canadian Fire Weather Index FWI, and the Keetch-Byram Drought Index KBDI) have been used to characterise the fire danger pattern across Italy, its potential to reproduce the fire occurrence, and the fire danger trends.

The results improve our knowledge of wildfire occurrence in Italy. The fire regime under current climate conditions has been characterized with a statistical and descriptive analysis. In addition, the analysis of the relationships between fire occurrence, weather, and fire danger can be usefully applied to assess the impacts of climate changes on fire regimes in Italy.

RIASSUNTO

In questa tesi di dottorato, la complessa problematica legata agli incendi nel bacino del Mediterraneo è stata analizzata da diversi punti di vista. In particolare, si è voluto dare un contributo alle attuali conoscenze attraverso la caratterizzazione del regime degli incendi, l'analisi delle relazioni con i fattori guida che ne determinano le dinamiche e la presenza di trend avvenuti negli ultimi anni.

Il lavoro è stato condotto considerando il periodo 1985-2008 e ha riguardato l'intera Italia.

Il primo passo dell'analisi ha riguardato l'identificazione, attraverso una procedura di analisi gerarchica, di sei aree omogenee dal punto di vista climatico e degli incendi. Successivamente, il lavoro è stato sviluppato in tre specifici capitoli.

Nel primo capitolo è stata caratterizzata la stagionalità degli incendi per ogni area omogenea utilizzando la distribuzione di probabilità di von Mises. È stata inoltre evidenziata la presenza di cambiamenti nella stagionalità osservati negli anni dell'analisi.

Nel secondo capitolo sono state analizzate le relazioni esistenti tra incendi e variabili meteorologiche attraverso l'uso della correlazione di Spearman e la regressione lineare multipla. Inoltre sono stati stimati i trend delle variabili meteorologiche e gli incendi utilizzando due test uno parametrico e uno non parametrico.

Infine, nell'ultimo capitolo, sono stati utilizzati due diffusi indici di pericolosità (l'indice canadese Fire Weather Index-FWI e il Keetch-Byram Drought Index-KBDI) per caratterizzare la pericolosità potenziale d'incendio in Italia, la validità di questi indici nella previsione degli incendi e i loro trend nel corso del periodo di studio.

I risultati ottenuti attraverso le analisi statistiche e descrittive migliorano la conoscenza del regime degli incendi in Italia, illustrando per le diverse aree omogenee le caratteristiche temporali e i cambiamenti avvenuti nel periodo d'analisi. Inoltre, le analisi delle relazioni tra incendi, variabili meteorologiche e pericolosità di incendio potranno essere utilmente applicate per valutare l'impatto dei cambiamenti climatici sul regime degli incendi in Italia.

1 INTRODUCTION

Fire is one of the most frequent and widespread ecosystem disturbing phenomena (Bowman et al. 2009; Krawchuk et al. 2009; San Miguel and Camia 2009; Keeley et al. 1999), and it can cause several problems such economic losses and damage of property, besides the hazard for human populations (Zumbrunnen, 2010; Bonan et al. 2009). The role of fire in ecosystems is the objective of several discussions in literature. Fire plays a relevant role in determining landscape structure and plant community composition. In some areas, such as areas with Mediterranean climate, fire influences the evolution of many species that are selected with structural and physiological characteristics of fire resistance (Pausas et al. 2008; Pausas et al. 2004; Dìaz-Delgado et al. 2004; Trabaud et al. 1994).
As an indicator of the relevance of this phenomenon, reports from various sources have estimated fires to affect on average 3.5 million km^2 of vegetation in recent years (e.g., Le Page et al. 2008). By simulating a world without fires, Bond et al. (2005) obtained a virtual land cover where closed forests had doubled their area relatively to the actual contemporary extent.

The most fire-affected regions in the world are South America, South Africa, Eastern Europe, and the areas with a Mediterranean climate (Figure 1.1). The budget of fire economic losses is measured in billions of U.S. dollars, and the numbers found lead to a very significant monetary quantification of fire damage (Cova 2011). For example, during 1997 and 1998, fires in Southeast Asia's tropical forest cost between $U.S. 8.8 to 9.3 billion (Bowman et al. 2009; Schweithelm et al.1999, 2006). During the same period in Latin America, fire damage was estimated between $U.S. 10 to 15 billion (Bowman et al. 2009; UNEP 2002). On the western area of the Unites States of America, firefighting expenditures by federal land management agencies exceed $U.S. 1-1.6 billion/year (Westerling 2006; Whitlock 2004;). In 2003 and 2007 in Southern California, fire caused several casualties and the loss of thousands of houses in a single event. Only in 2007, losses for 1.8 billion of $U.S. were estimated and over 400,000 ha were burned (Karter 2008).

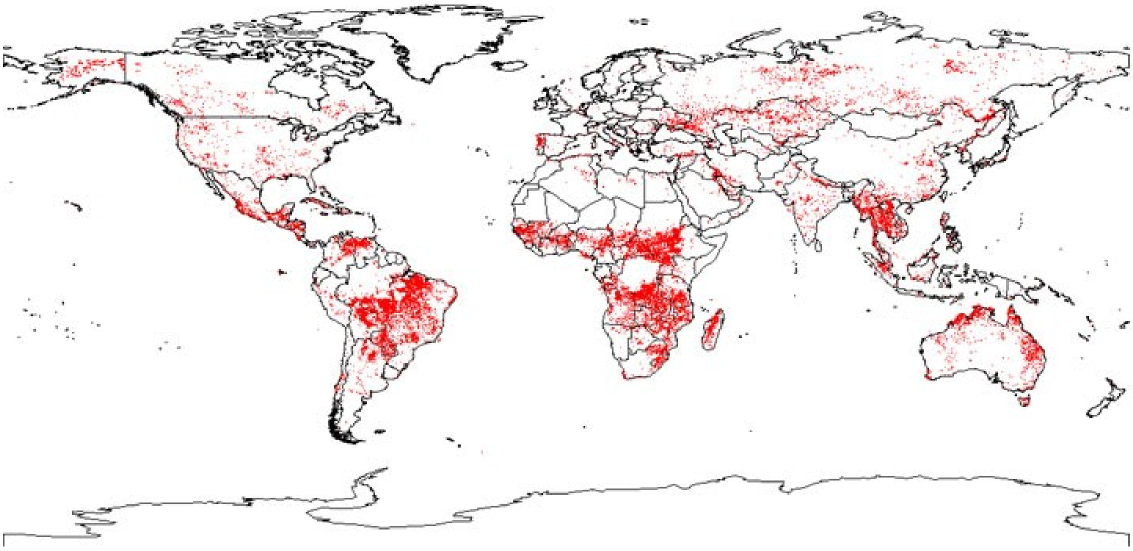

Figure 1.1 Most fire-affected areas in the world (Source: University of Maryland).

Regions with Mediterranean climate are, in general, highly prone to fire. According to several studies, wooded areas affected by fires in the Mediterranean Basin cover an area of 1000 x 10^3 ha $year^{-1}$, causing a huge 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. About two-thirds of these fires (65,000) occurred in 5 European Union (EU) 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., 2009). Furthermore, the improvement of firefighting strategy has contributed to increase the cost of fire, in consequence of the better technology used in comparison with the past (Mendes 2010).
In addition to the economic damage, fire has caused the deaths of many people over the years. 203,749 ha were burned in Italy during 1993, causing the deaths of 12 people (Rego et al. 2009). In 1994 in Spain, a single fire burned more than 430,000 ha, causing 31 human casualties (Velez 1995, 1996). In 2000, 30 people died in Europe, more specifically in France, Spain, Italy and Greece, and fires burned more than 370,000 ha (Viegas 2009). In 2001 in Italy, fires burned 76,427 ha with 3 casualties; in the same year in Greece, 316,110 ha were burned with 12 casualties (Rego et al. 2009). In Europe, the list of casualties continues year by year: 38 people in 2003, 38 in 2005, up to the record of 103 casualties in 2007 and almost 500,000 ha burned in Italy and Greece. Only in Greece 80 people died in that year.

Moreover, fires cause a lot of damage not directly quantifiable, for example disturbance to ecological succession (Bowman et al. 2009; Krawchuk et al. 2009), the healthiness of the air, the influence on the carbon cycle and climate change with the changes in the planetary albedo of Earth and radiative budget (Kaufman and Koren 2006; Govaerts et al. 2002; Schafer et al. 2002).

The above-mentioned numbers show how the fire phenomenon is actual, and highlight the need to increase the knowledge of factors facilitating ignition and determining propagation.

Wildfire is a highly variable phenomenon in consideration of the environment, and each ecosystem is characterized by a different fire regime that can be defined as the summary of fire history characterizing an ecosystem (Heinselman 1981).

A natural fire regime is a classification of the role which fire would play across a landscape in the absence of modern human mechanical interventions. This situation is typical of ecosystems with little human influence such as rainforests, and thus ecosystems including the influence of aboriginal burning (Brown 1995; Agee 1993). As abovementioned, with the exception of the ecosystems described above, a fire regime must always be integrated with the human factor.

The description of fire regimes on a given area requires several ecological considerations about physical, meteorological, climatic and biological factors. Several features dominate forest fires of a given region and these can be described in terms of main temporal and spatial scales of variation (Carvalho et al. 2008).

In the past, the systems of classification of fire regimes were based on a very small number of features, which are described and used to explain the basic models of ecosystem changes. Unlike recent methods of classification that focus on the importance of multi-scale spatial and temporal variations of the phenomenon, the classifications of the past has offered a variety of information related to the simple description of a single feature.

It is important to recognize that any classification system is a simplification created for convenience to man and, as stated by Sugihara (2008), there is only one way "complete" or "right" to describe fire regimes. Kilgore (1981) suggests that it is more appropriate to speak of ecosystems with different fire regimes, which consist of factors such as the frequency and intensity of flame front (Heinselman 1981; Sando 1978), the season (Gill

1975), the model (Keeley 1977), and the severity of burnings (Methven 1978). A fire regime is defined by temporal, spatial, and magnitude characteristics (Sugihara 2006).
Seasonality, that represents the period in which wildfire occurs, and Fire Return Interval, that describes how often fires occur in the same territory over several years, are the temporal characteristics of the fire regime. Spatial characteristics are divided into Fire Size, which is given by the amount of surface area that falls within the perimeter of the burned area and Spatial Complexity that describes the types of the burned area at different levels of fire severity. Finally the last attribute is Magnitude, divided into three important characteristics:

- Fire Line Intensity, that is a description of fire in terms of energy released, more specifically the rate of heat released per unit time and per unit length of flame front; numerically, it is the product of heat, the amount of fuel consumed in flame front, and the rate of propagation.
- Fire Severity, that is the severity in the quantification of the alteration or destruction of the site by fire; numerically, it is given by the product of the intensity of fire and residence time, and by the description of the effects of these on the physical and biological components of the ecosystem.
- Fire Type, that is a description of the different types of flame fronts.

One of the main characteristics defining a fire regime is Fire Seasonality. Seasonality is expressed by an alternation of a fire-free and a fire occurrence season, and the main force of this alternation is climate (Le Page et al. 2010; Giglio et al. 2006; Dwyer et al. 2000).
Fires can occur in different periods of the year depending on climate, human activities, and vegetation types (Archibald et al. 2009; Cheney and Sullivan 2009; Korontzi et al. 2006; Nelson 2001). Seasonality is highly influenced by fuel moisture, which is directly correlated with weather conditions (La Page et al. 2010; Cheney and Sullivan 2009). In cultural landscapes, Seasonality is also a consequence of the combined effect of human activities and local bioclimatic conditions on the dynamics of fire (Cochrane & Laurance 2008; Dwyer et al., 2000). On the one hand, knowing the relationship between the period in which the majority of fires occurs and the different types of ground cover is of great ecological interest, because it allows to predict the spatial distribution of the

new fire regimes time in different shell soils; on the other hand, it is practically useful for the planning of firefighting (Bajocco et al., 2010).
Fire occurrence in the temperate hemisphere regions is principally located in summer, and the start and end of fire season are on average May and September, respectively (La Page 2010).
Figure 1.2 and 1.3 show the Fire Frequency and Burned Area in several European areas. Fires in the Mediterranean area are mainly located in summer, while in Northern Europe they are located in spring. In the Alpine area wildfires generally occur in winter.

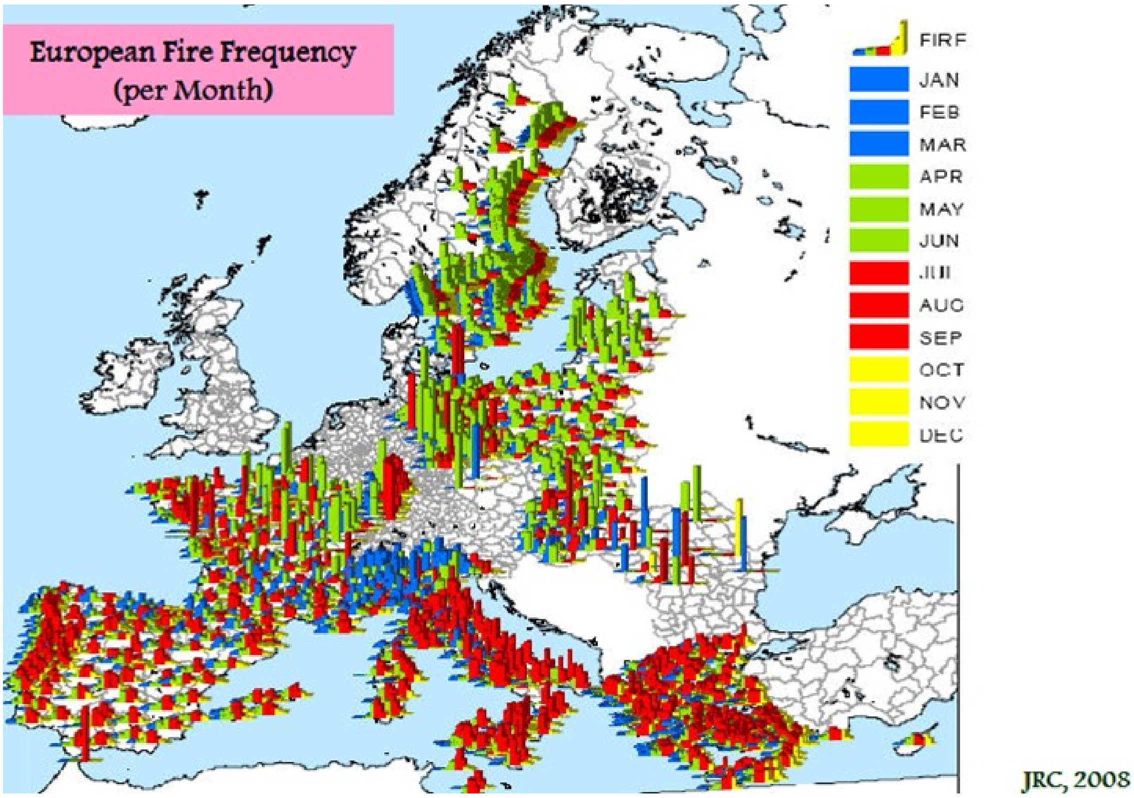

Figure 1.2 Fire frequency per season in Europe (Source: JRC).

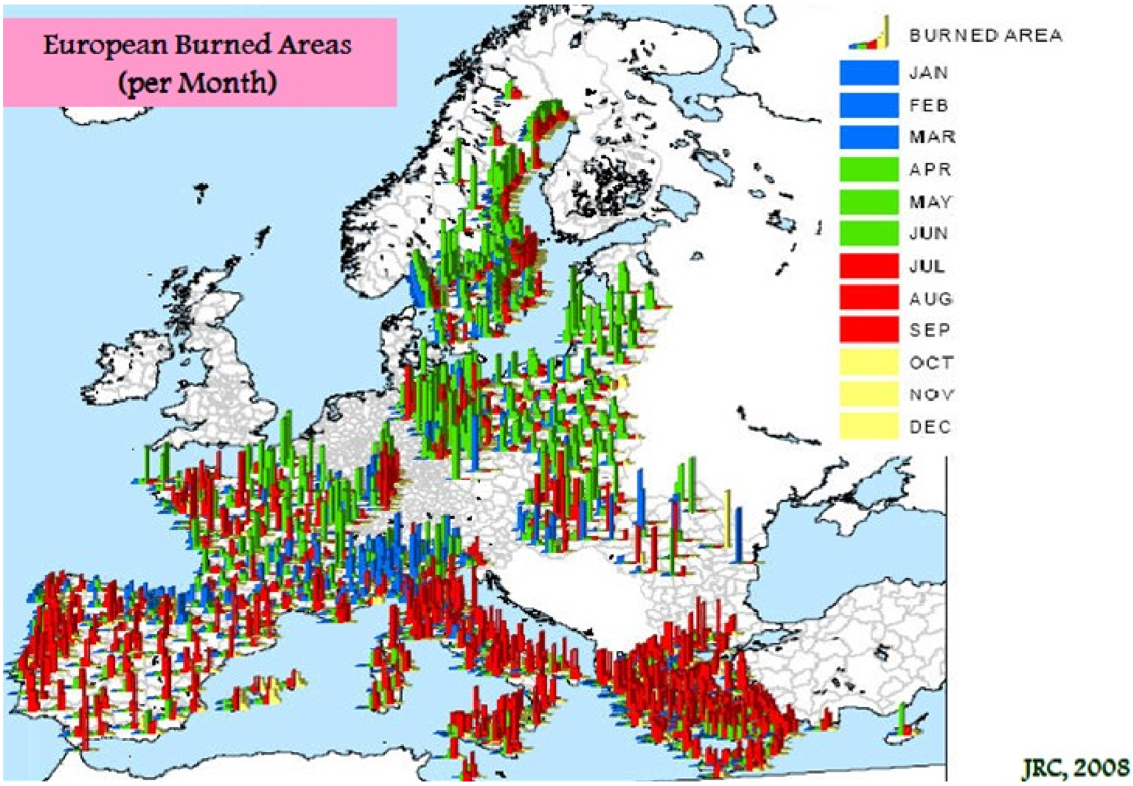

Figure 1.3 Burned Area per Season in Europe (Source: JRC).

The complexity of wildfires is associated with factors of different origin, such as climate and weather, human activities and vegetation conditions (Bowman et al. 2009), whose relative importance on different scales can be difficult to quantify (Bonan 2008). Figure 1.4 summarizes the main characteristics of temporal and spatial scales that are closely related to the forest fire dynamics. The characterization of fire regimes is important to define the impact of fire on ecosystems.

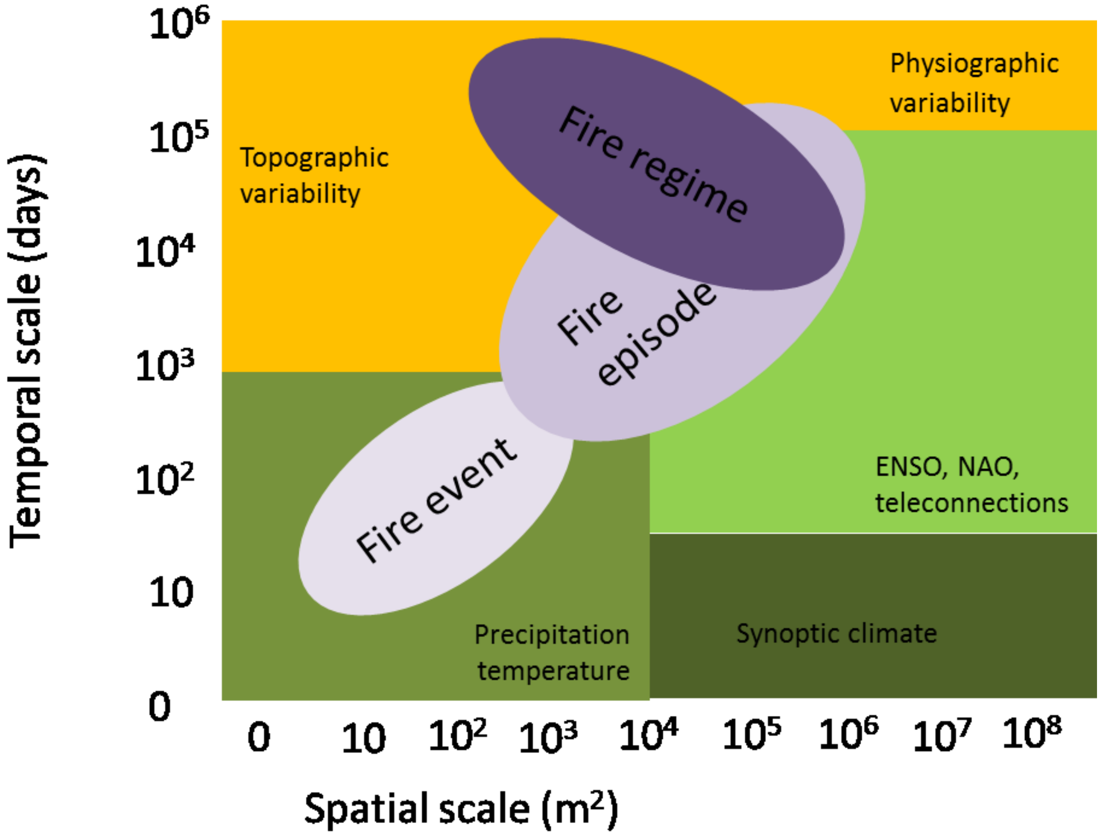

Figure 1.4. Scheme of the scaling responses and drivers of wildfires dynamics (modified from Carvalho, 2008).

On a local scale, fires need oxygen, fuel and ignition temperature (Oliveras et al. 2009; Dìaz-Delgado et al. 2004; Pyne et al. 1996). These three factors are the *conditio sine qua non* for fire ignition. On a landscape and short-term scale, the main drivers are synoptical weather conditions. Physiographic and topographic variability that characterize large temporal and spatial scales variations represents the broadest influence of these scales on fire regime definition (Carvalho 2008). Moreover, global and centennial scale is influenced by the variation of climate, human activities, as well as vegetation distribution and structure (Zumbrunnen 2010; Bowman et al. 2009; Pausas and Keeley 2009; Venevsky et al., 2002; Swetnam 1993; Swetnam and Betancourt 1990).

Weather is very important during the spread of fire. In particular, the intensity and direction of wind and the relative humidity have an effect on fuel moisture (Carvalho et al. 2008; Kunkel 2001; Pyne et al. 1996; Renkin and Despain 1992; Cesti 1990), and on the speed of flame front (Agee 1993). These variables are often used to model fire behaviour (Salis et al. 2012; Arca et al. 2007).

Worldwide, several studies have analyzed the relationship between weather and wildfires but only a few have analyzed this relationship in Mediterranean ecosystems.
The fire drivers above described have to be connected with the human factor. All over the world, wildfires show different patterns in relation to socio-economic conditions (Krawchuk et al. 2009). These patterns are different in relation to the spatial and temporal scale considered (Zumbrunnen 2010), and can be difficult to quantify (Bonan, 2008). Fires are used for many purposes in relation to land-use practices, and agricultural burning is applied worldwide to fertilize soil, to prepare fields for harvest work and to dispose of crop residues (La Page et al. 2010; Korontzi et al. 2006; Yevich and Logan 2003). In tropical forests, fire is used for deforestation, and during the dry season it is utilized to maximize fuel consumption (Morton et al. 2008; Thrupp et al. 1997). Fire is influenced by land use and its changes influence fuel load. An increasing number of studies (eg Carmo et al. 2011; Marlon et al. 2008; Viedma et al. 2006) show that these changes in fire regimes are to be linked with the sudden changes of land-use and socio-economic factors. The strong industrialization, which has characterized the Mediterranean Basin in the last decades, has actually led to a strong rural exodus to cities and coastal areas with a consequent increase in the so called wildland urban interface (WUI) (Calcerrada-Romero et al. 2010; Castellnou et al. 2010; Catry et al. 2009; Martinez et al. 2009; Bajocco and Ricotta 2008; Nunes et al. 2005). As a direct consequence of the countryside, the increase in plant fuel and changes in the structure and continuity of plant communities have helped to change the landscape and the conditions, as well as the potential fire behaviour (Moreira et al. 2011; Pausas 2004); the increase in the WUIs, particularly in coastal areas, has led to a distinct change in risk exposure of these areas (Salis et al. 2012; Badia-Perpinyà and Pallares-Barbera, 2006; Koutsias et al. 2002).
As far as human effects are concerned, fire activity can be influenced by climate change (Pausas 2009; Keeley et al. 2009). The climate change impacts, according to the temperature increase projections (IPCC 2007), may lead to raise fuel dryness, and has different effects according to the area considered, with effects in fuel and fire behaviour (Howden et al. 1999).

Although forest fire occurrence is closely linked to socio-economic factors, the potential fire danger, spread, and intensity of an event depend on factors such as topography, vegetation, and weather patterns. In particular, the importance of weather-climatic conditions on fire behaviour is well-documented (eg Flannigan and Wotton; 2001; Burgan et al., 1997). The spatio-temporal variability of fire behaviour is often linked to short-term weather conditions (e.g., wind speed and direction, relative humidity, temperature), which are the components of environmental variables (Ark et al. 2007; Pyne et al. 1996). The possibility of ignition is generally linked to a number of factors in the medium and long term, such as drought, the quantity and spatio-temporal distribution of precipitations, fuel load and the ratio of living material to died material (Mouillot et al., 2002).

In view of the ongoing climate changes and future scenarios, which increase more extreme weather events in the Mediterranean Basin (hotter and longer, frequent heat waves, drought) (Scoccimarro et al., 2011; Lindner et al. 2010; Alcamo et al., 2007), it is crucial to assess the impact of these changes in terms of hazard, risk, onset and propagation (Arca et al. 2012), as well as emissions of greenhouse gases and pollutants.

Several researches confirm an increasing trend of the burned area and the extension of fire season during recent decades, for example in Spain and in the western United States (Westerling et al. 2006; McKenzie et al. 2004; Moreno et al. 1998). In the Mediterranean Basin, fire activity was lower during the pre-fire statistics periods (<60's) because of lower fuel, but the depopulation of rural areas changed the landscape structure, with the consequence of increasing fuel load, thus increasing fire activity (Pausas and Fernàndez-Muñoz 2011).

Knowledge about wildfire drivers can help to understand the causes of these changes. As above-mentioned, it is essential to consider climate and weather because they are two of the main key factors influencing fire regimes and they have different effects on fire.

The indexes of fire danger, which is defined as the probability of fire occurrence and its consequences according to conditions variables of different nature (Bovio 1993; Bachmann and Allgöwer 1998; 2001), can be used to conveniently express the relationship between climate, weather and fire occurrence. Fire danger should not be confused with fire risk, which is the danger in relation to the vulnerability of a certain territory, determined by the value of goods and the possible loss of life (Bachman and Allgower 1998).

The estimation of fire danger is the basis of all the most advanced firefighting services, and the integration of scientific knowledge with operational experience in practical applications of fire management helps to give a measure of the dangerousness of an area on a particular day (Taylor and Alexander 2006).

The assessment of fire danger can be made by starting both from static indicators (long-term or structural) and dynamic indicators (short-term). The meteorological danger indices can be grouped according to the approach used for the selection and integration of variables, as described by Chuvieco et al. (1999), and are calculated by daily meteorological parameters. In literature, these indices are often simply called Fire Danger Indices (San Miguel-Ayanz 2002).

Estimating fire danger has always played a special scientific role throughout the years and many nations have been at the forefront in this sector. Nowadays in the United States operates the National Fire Danger Rating System (NFDRS), a system based on the use of fuel models able to predict the risk of fire (Deeming et al. 1974). One of the most world diffuse indices is the Fire Weather Index (FWI), developed in Canada by Van Wagner e Pickett (1987) and explained by Van Wagner (1987). In Europe, fire danger is calculated on a national and local scale using different methods and types of data. To make indices comparable with one another, in 1997 the European Union commissioned the Joint Research Centre (JRC) to develop the European Forest Fires Information System (EFFIS) (Camia et al.2006; San Miguel-Ayanz et al. 2003) and to provide the member states and the Commission on this issue with an open interface. The new fire danger system was named European Forest Fire Risk Forecasting System (EFFRFS) and provides danger forecast during the season of maximum occurrence (from May to October). In 2007, the FWI was chosen for the hazard assessment within the daily network EFFIS, thus slightly modifying the algorithms to compensate for differences in daylength of the European Union Countries.

Although the Canadian Fire Weather Index was born as a model to calculate risk in predominantly boreal forests, it shows features that make it the currently most used system worldwide: simplicity, adaptability, and it is relatively easy to get the input data (Lawson and Armitage 2008; De Groot et al. 2006; Dymond et al. 2005).

The analysis of the correlations between some of weather variables such as temperature, precipitation, relative humidity and wind with wildfire is important to define the climate change effect. Furthermore, the potential increase of fire may have a positive feedback on climate change, because forest fires influence the net carbon balance of the forest (Flanningan and Wotton 2001; Kurz et al. 1995).

In order to analyze the impact of climate change of fire regime, climate projection data are used as input variables of fire danger indices; the results of these simulations have confirmed the expected increase in fire risk, burned areas and frequency of fires (Liu et al. 2010; Justin and Wotton 2010; Mokhov and Chernokulsky 2010; Moriondo et. al. 2006; Brown et al. 2004; Mouillot et al. 2002; Williams et al. 2001; Flanningan et al. 2000; Stocks et al. 1998; Torn and Fried 1992). The use of fire danger for the quantification of the climate change effect on fire is then an important methodology that finds its solidity in the relationship between danger and fire occurrence; this shows the importance of the continuation of the research on the relationship between fire and the factors that influence initiation and propagation.

Despite the studies made so far and presented in the introduction, it is still required to specifically analyze the forces which drive a fire regime to better understand this system on a national level and also to allow projections of future fire regimes in terms of climate change, socio-economic and land use. In Italy for example, there is a lack of literature on this subject: the studies reported in literature are limited because they analyze mainly socio-economic differences, the characteristics of vegetation and fuel, but not the relationships between weather and fire on a national scale (i.e. Lovreglio et al. 2012, Bajocco et al. 2008). Furthermore, the country is strongly variable from north to south depending on the variation of socio-economic, climatic, vegetation and topographic conditions. This causes a strong variability even in fire activity, both in terms of fire number and fire occurrence period. It is then important to define the variability of fire in Italy, discriminating the homogeneous areas from a fire-weather-climate point of view.

This thesis is part of the project activities FUME (Forest fires under climate, socio-economic changes in Europe, Mediterranean and other fire-affected areas of the world), funded by the European Union under the Seventh Schedule framework. The objectives of the project are primarily to investigate and understand how the factors listed above interacted in the past, then to estimate the changes and define how and to what extent these have influenced fire regimes, to predict the developments in the decades to come (with a focus on future projections of extreme weather and climate extremes such as drought and heat waves).

2 OBJECTIVES

The main objective of the present work is to improve our knowledge on the complex relationships between fire occurrence and driving factors in a Southern Europe country (Italy). After a statistical characterization of fire regimes with respect to weather and time of occurrence, an analysis of the relationship between fires and weather conditions during the last decades has been carried out. Moreover, in the last part of the thesis, two fire danger models (the Canadian Fire Weather Index FWI and a modified version of the Keetch-Byram Drought Index KBDI) has been applied in the analysis to have a wider comprehension of fire dynamics related to weather conditions.

The thesis is presented in four main parts:

1) Identification of homogeneous areas in Italy with respect to fires and weather patterns;
2) Characterization of the Seasonality of fire occurrence within the previous homogeneous areas;
3) Fire-weather relationships on a global (national) and local scale;
4) Fire danger patterns.

3 MATERIALS AND METHODS

3.1 Study area

The study area is the whole Italian peninsula (Figure 3.1), a country located at 42° 50'N and 12° 50'E which comprises 301,340 km² and is 1,291 km long. The upper and lower limits of Italy are located in the Zillertal Alps, South Tyrol (47°05'30"N) and on the Island of Lampedusa (35°29'24"N), respectively. East and West limits reach Cape Otranto in Puglia (18°31'18"E) and Rock Bernauda in the Cozie Alps, Piemonte (06°37'32"E) (Figure 3.1).

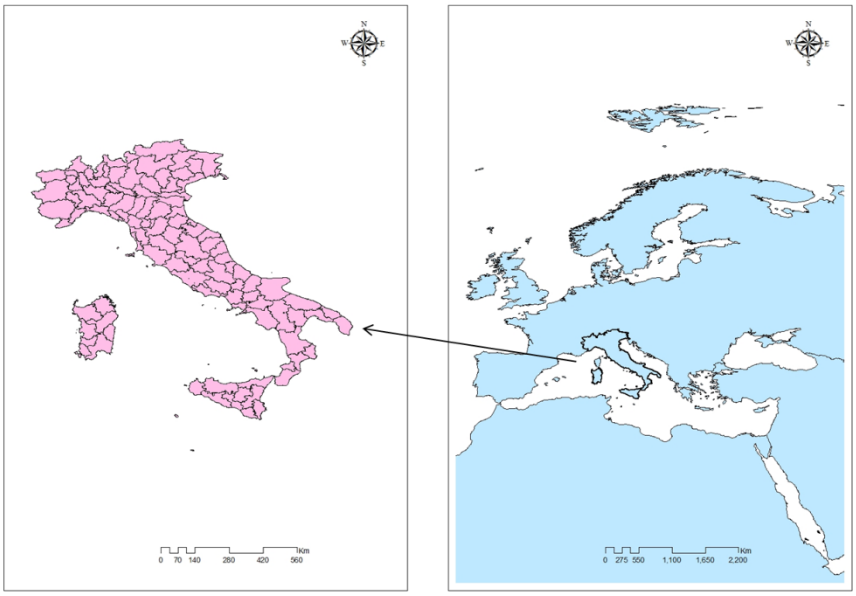

Figure 3.1 Location of Italy in Europe, and administrative boundaries of its provinces

The Italian population amounts to 60,626,442 people, with an average population density of 201 inhabitants per km^2 which varies remarkably according to the area considered, as shown in Figure 3.2. Northern Italy is highly populated than Southern Italy, although the region with the highest population density is Campania in the Southern area (429 inhabitants/km^2), followed by Lombardia (412 inhabitants/km^2) and Lazio (330 inhabitants/km^2). Valle d’Aosta and Sardinia are, by contrast, the regions with the lowest population density.

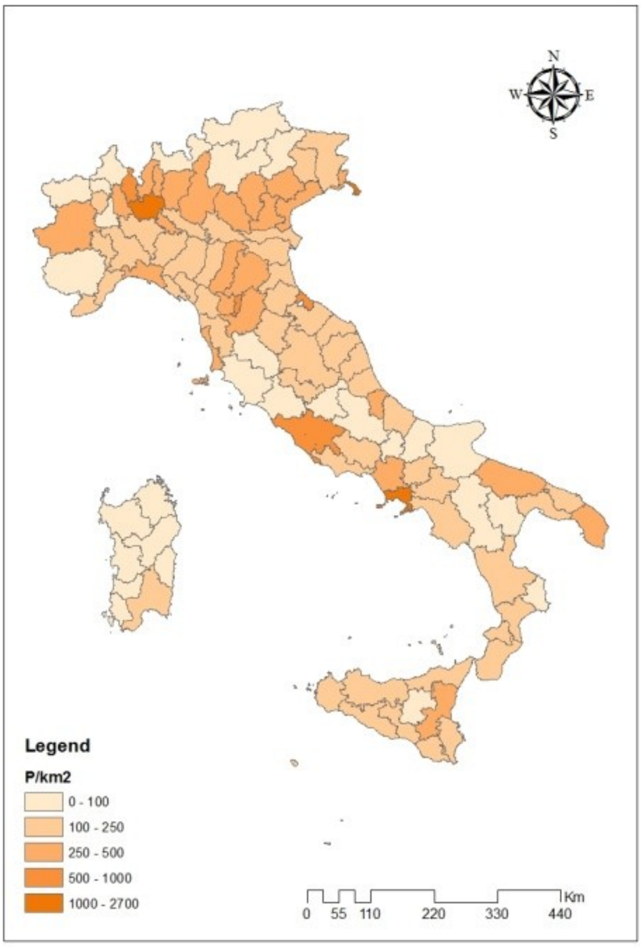

Figure 3.2 Italian population density (inhabitants/km^2) (data source: ISTAT)

As far as climate is concerned, and according to the Köppen classification, Italy is characterized by two main types of climate:

- Temperate ("mild wet"), characterized by the mean temperature of the coldest month ranging from -3 °C to +18 °C, unless arid.
- Cold-temperate ("boreal forest") and polar, characterized by the mean temperature of the coldest month below -3 °C and by the mean temperature of the warmest month lower than +10 °C.

The mean annual temperature is above 16 °C and the rainfall patterns are extremely variable, ranging from 3,500 mm per year in the wettest regions to 250 mm in the driest areas (De Agostini 2001).

As far as land use is concerned, and according to the Corine Land Cover classification (CLC 2006), agriculture is the main land use in Italy, covering 51.8% of the territory, closely followed by forest areas (40.2%). In terms of vegetation, forest areas are mainly composed of three main vegetation types: a) woodland (26.43%); b) shrubland (8.80%); c) natural grassland (4.85%). Man-made surfaces occupy 5% of the territory (Figure 3.3).

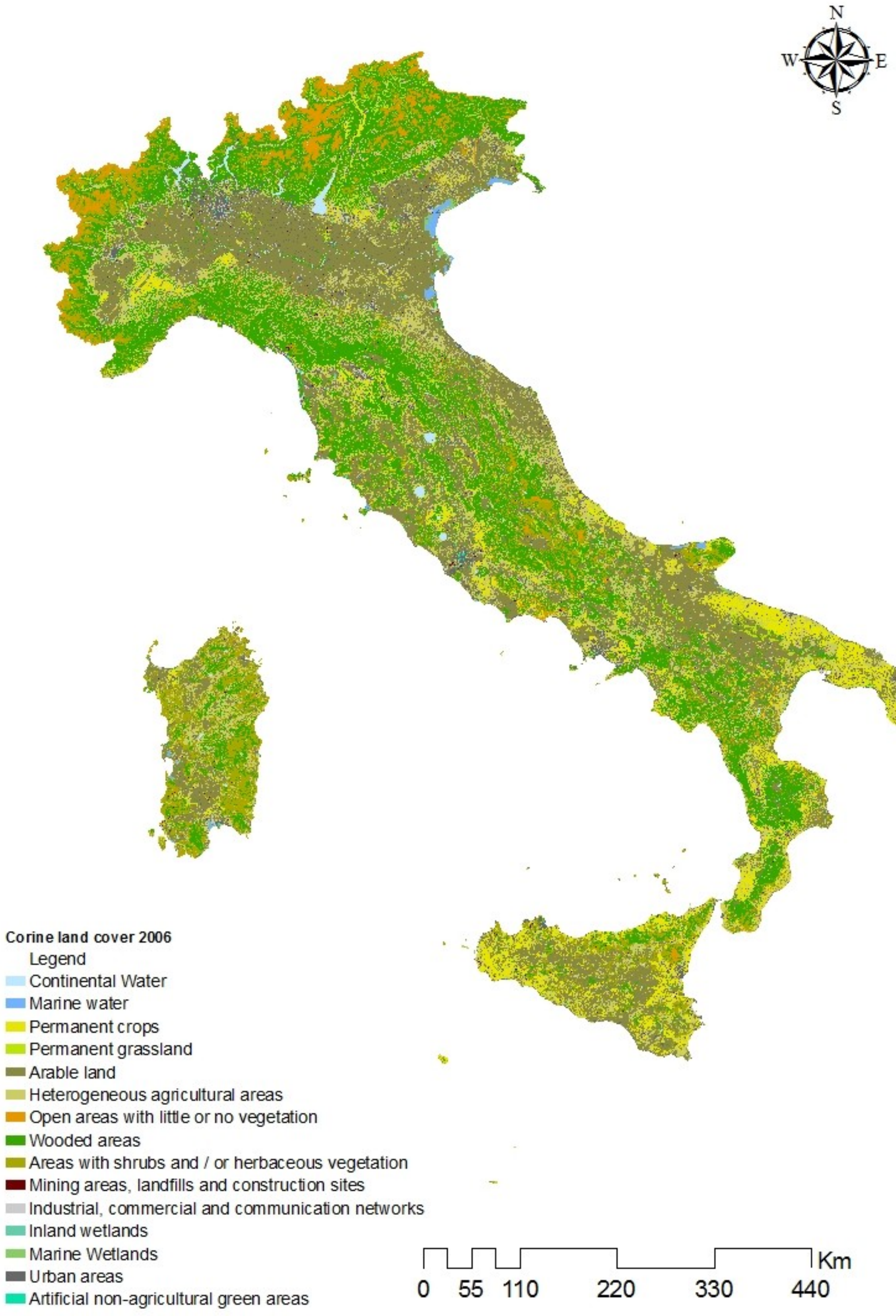

Figure 3.3 CORINE land cover 2006

3.2 Fire data

Accurate data on the amount of fires and burned areas for the Italian peninsula and Sicily have been obtained from the European Fire Database developed by European Union Joint Research Center (JRC), while for the region of Sardinia the dataset has been provided by the CFVA (Corpo Forestale e di Vigilanza Ambientale- Sardinian Forestry Corp). The JRC database is based on fire information collected by each member state of the European Union according to the directive EEC No 804/94, and provides forest fire information for EU and some neighbouring countries. From this database, forest fire information for the Italian peninsula between 1985 and 2008 has been extracted. Data include 184,000 fire occurrences, and about 2 million ha of burned surface.

For the Sardinia island, fire data have been analyzed on a daily basis and at municipal level. In order to make the datasets comparable, the daily data provided by the CFVA have been summarized into monthly data and aggregated at NUT03 (provincial) level.

In Italy, the majority of fire causes is intentional (almost 70%), and the remainder is negligent (about 18%) or uncertain (about 12%). Natural causes are less than 1% of total fire (Lovreglio et al. 2012). Fires in Italy have shown a highly variability over the years (Figure 3.4). Fire activity was very intense in the 1993, for both Fire Number (FN) and Burned Area (BA), and in 2007 only for BA (Figure 3.4). The most fire-affected regions are in the south (Fig. 1.6), even though fire activity is high in some Northern regions such as Liguria and other Alpine areas (Fig 3.5).

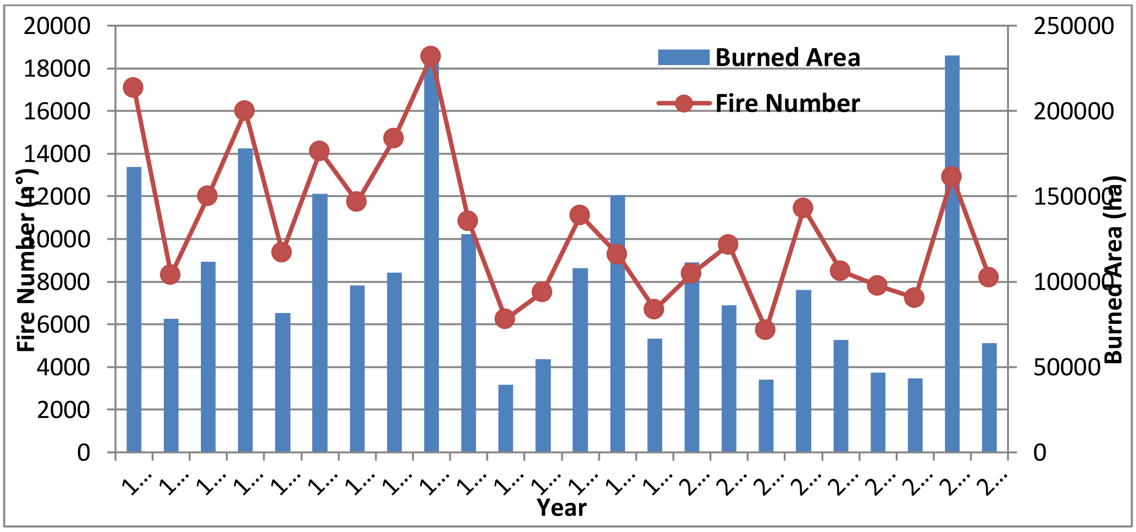

Figure 3.4 Fire Number between 1985-2008 in Italy (source: JRC and CFVA)

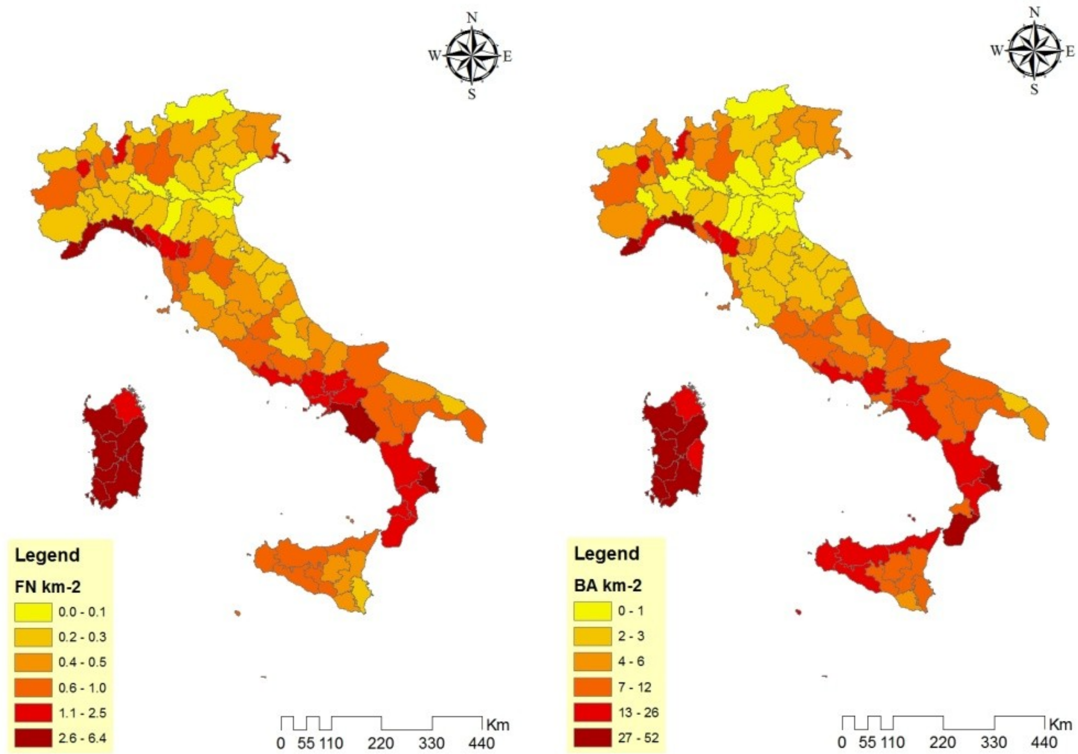

Figure 3.5 Fire number (FN) and burnt areas (BA) at provincial level in Italy, normalized by each provincial area.

3.3 Weather data

Meteorological data from 1985 to 2008 have been obtained from the MARS dataset at a 25 km resolution, and include the following variables: maximum and minimum daily temperature (°C), daily average vapour pressure (hPa), daily rainfall (mm) and daily average wind speed (m s^{-1}). The MARS project was setted up in 2007 and one of its components is the AGR4CAST, which represents the system for yield forecasting. The core of AGR4CAST is represented by the Crop Growth Monitoring System (CGMS). Among the main outputs of the CGMS are interpolated weather data, created by using different weather data sources such as direct observations from meteorological stations, products derived from ECMWF (European Centre for Medium-Range Weather Forecasts), modelling of weather and meteorological observations from remote sensing platforms. This database contains daily meteorological data from 1975 up to the most recent completed year for the EU member states, neighbouring and Mediterranean countries. MARS data are available for the scientific community through the web site http://www.marsop.info/ExtractGrid/RegistrationForm.php.

Figures 3.6, 3.7 and 3.8 show the variation of Tmax, Tmin and Rainfall averages, respectively, across Italy.

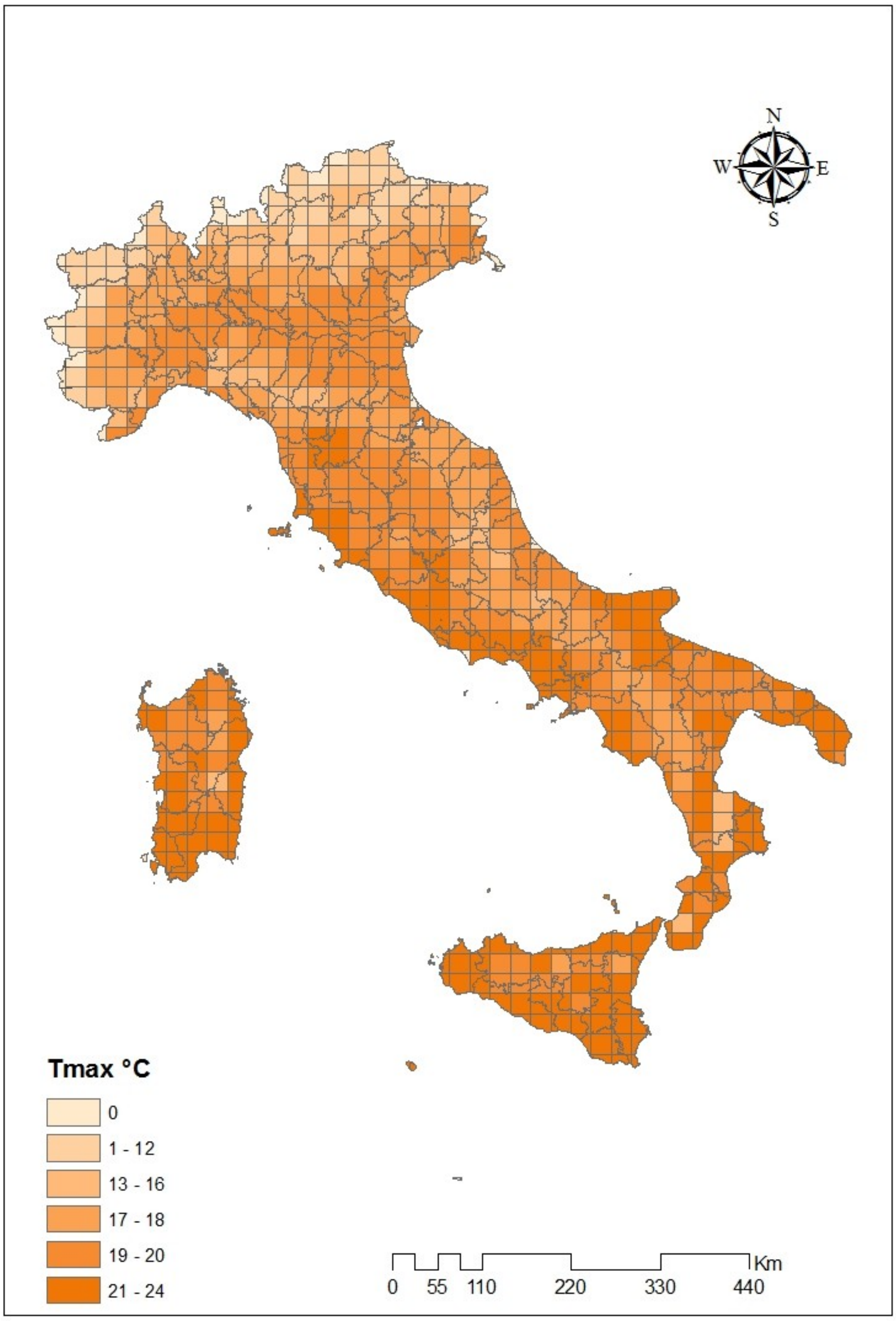

Figure 3.6 Distribution of maximum temperatures (Tmax) in Italy

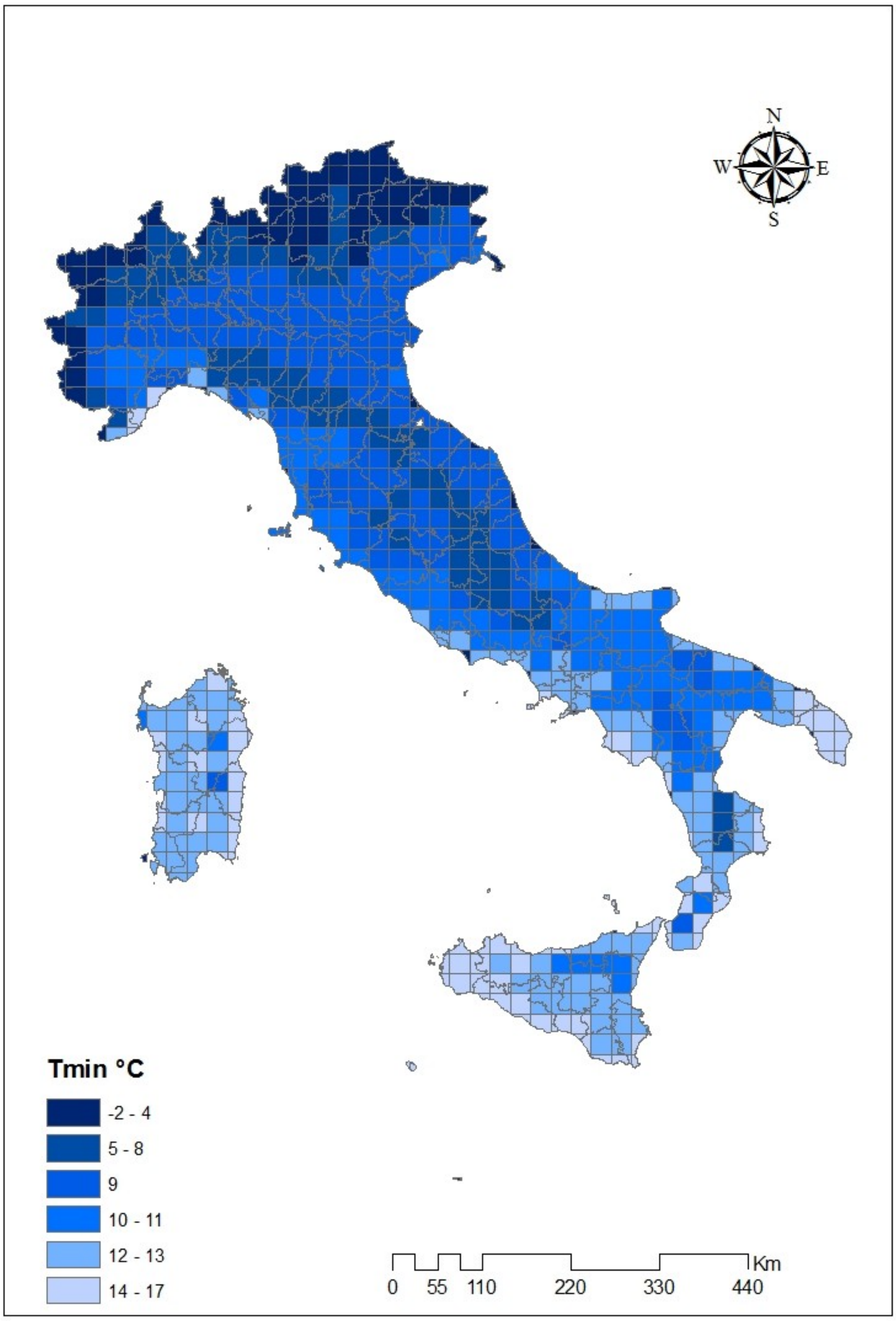

Figure 3.7 Distribution of minimum temperatures (Tmin) in Italy

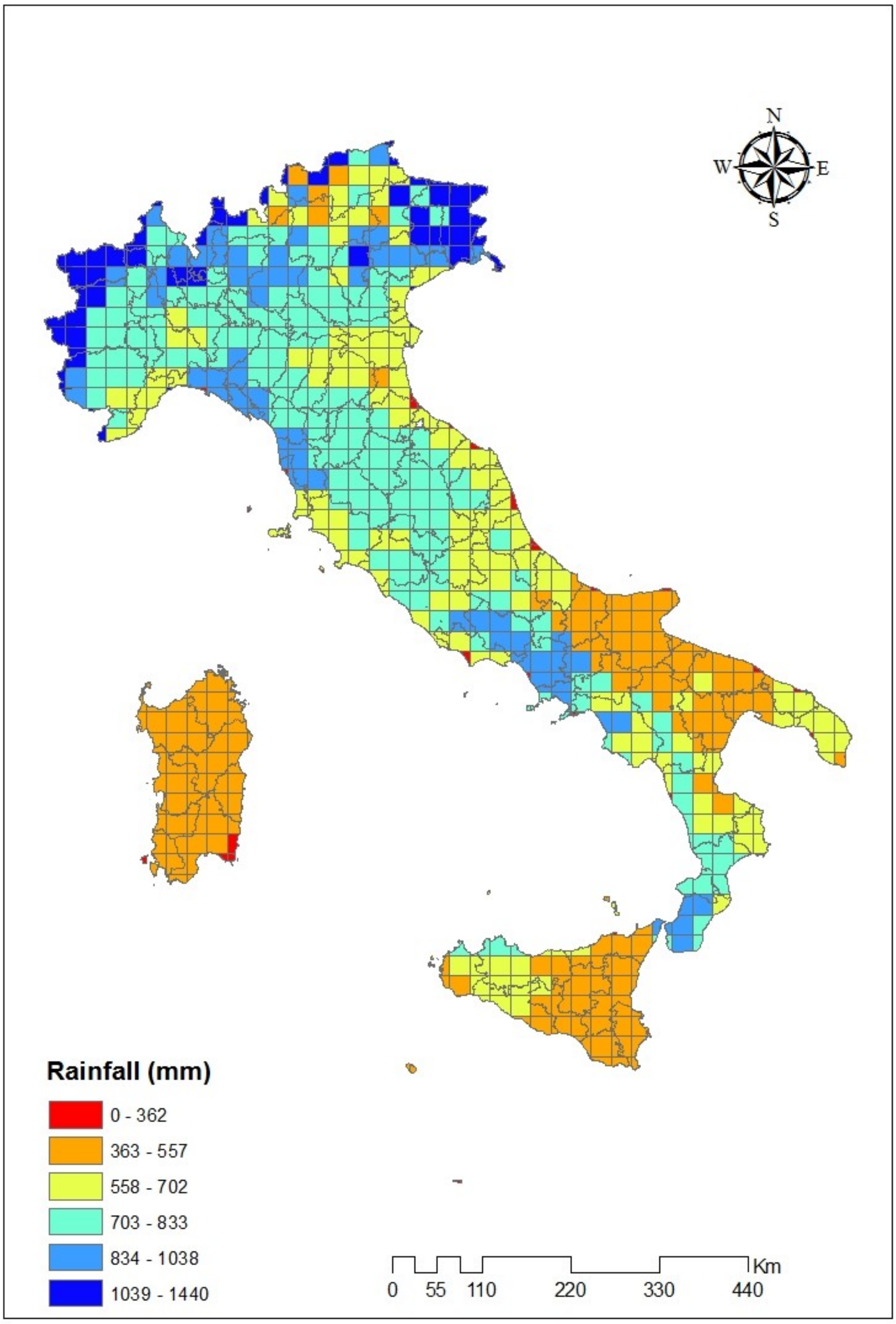

Figure 3.8 Rainfall distribution in Italy

3.4 Clustering

In the preliminary step of the analysis, Italy has been classified into homogeneous areas (called in this thesis as “piro-climatic” areas) through a cluster analysis based on meteorological and fire occurrence data. Cluster analysis is an efficient method to aggregate a set of objects into groups (clusters) and each cluster represents objects that are similar to one another, considering the parameters defined by the cluster data. “Cluster results” depend on the selected algorithm, and this may vary significantly in properties. The understanding of "cluster models" is therefore extremely important In this study, the method adopted for the cluster analysis has been the hierarchical clustering with an agglomerative strategy based on the squared Euclidean distance metric as a measure for dissimilarity. This is a "bottom up" approach in which each observation starts in its own cluster, and pairs of clusters are merged as one moves up the hierarchy (Fischer and Van Ness 1971).

The data used for clustering are maximum and minimum temperature, rainfall, and burned area. The average values of these variables have been calculated for each season between 1985 and 2008.

Before cluster analysis, the MARS dataset has been converted from daily to monthly data in order to match with time scale of fire occurrence dataset. Then, the fire database has been converted into gridded data format (ArcGIS 9.1 environment) to allow a better and easier data manipulation.

After the clustering, three specific chapters describe the specific analysis related to seasonality, fire-weather, and fire danger parts. In each chapter, after a state of the art reporting, the Materials and Methods section describes the steps of the analysis.

4 FIRE SEASONALITY ACROSS ITALY

This chapter focuses on the characterisation of the fire seasonality. Fire season length, begin and end, and seasonality changes among the piro-climatic areas have been analysed.

Wildfires occur at different times of the year, and fire season regimes have a great diversity depending on the regional climate, vegetation, land use, and anthropogenic environment (Le Page et al. 2010). In Italy, fire seasonality is typically concentrated in summer, but the fire occurrence is highly variable across the country (Lovreglio et al. 2012). The characterization of fire seasonality variability in Italy is complex, especially in the Northern area. This is due to the extreme heterogeneity of topography, climate, and vegetation of the Northern part, together with the fire information deficit for this area. For this reason fire regime reconstruction is still absent (Conedera et al. 2006, Tinner et al. 2005).
In Central-Southern Italy, fire occurs generally at the end of spring and in summer periods (Italian Forest Corps 2009). In the Greater Alpine Region, wildfires occur mainly in winter, between December and April, when the light fuels are dry (Reinhard et al. 2005). Considering these differences across Italy, it is important to study fire seasonality in each piro-climatic area (ref. clustering) to analyze the spatial variability of the seasonal patterns.
In the literature, at global scale, seasonality analysis has been addressed mainly using remote sensing data (Oom and Pereira 2012; La Page at al. 2010), which has limitations at smaller spatial scales.
This part or the work aims to analyse the seasonal distribution of fires in Italy. A method to characterize the patterns of seasonality in terms of season(s), start, end, length, and day of peak of fire occurrence has been specifically developed also to investigate possible changes during the study period within the piro-climatic areas.

4.1 Material and Methods

To define the observed seasonality of fires, in each cluster (piro-climatic area), the monthly fire data for the period 1985-2008 has been calculated. The Probability Density

Function (PDF) used for this study, has had the necessity of some adjustment using the observed data.

The linear probability distributions are not very useful, because fires occurring in January and December are closer in time than fires occurring in January and April, for instance. To overcome this problem, the use of circular distributions is more useful. The most commonly distribution function used is the von Mises one. This kind of distribution is analogous to the normal distribution for linear data (Fisher, 1995). The von Mises has probability density (Equation 4.1):

$$vM_j(\theta; k_j; \mu_j) = \frac{1}{2\pi I_0(k_j)} exp[k_j cos(\theta - \mu_j)] \qquad 0 \leq \theta < 2\pi \qquad (4.1)$$

where, kj ≥ 0, and 0 ≤ θ < 2π are the concentration and the mean parameters, respectively.

The previous equation is useful when the yearly fire distribution has a single peak. However, the yearly distribution of fires can have more than one season and, in this case, a mixture of N von Mises distributions be more suitable (Equation 4.2):

$$\mathrm{mvM}(\theta) = \sum_{j=1}^{N} \omega_j \mathrm{vM}_j(\theta) \qquad (4.2)$$

where N varied from 1 to 2, corresponding to uni or bimodal distributions, respectively, $0.05 \leq \omega \geq 0.95$ is the mixture proportion of each component (Mardia and Jupp, 2000; Jones, 2006).

For each cluster, and for both fire number and burned area, the two equations above were used, and the type of seasonality was defined by choosing one of them. When the trend was unimodal, the first equation was used; otherwise, if the trend is bimodal, the second one was used.

The PDF's were optimized by adjusting using the observed data. The optimization algorithm used was the Generalized Reduced Gradient (GRG2) for nonlinear optimization code aiming at maximizing the r^2 obtained between the observations and estimations.

To determine the type of function that better described fire seasonality, the following assumptions have been made:

1. The minimum chosen value of R^2 to accept the equation was 80%; if both unimodal and bimodal functions were lower no function was assigned;
2. To accept the bimodal over the unimodal function, the increase of R^2 with respect to the unimodal function must be a minimum of 2.5%, otherwise the distribution was considered unimodal. This threshold was chosen considering that the bimodal function with an increase of R^2 lower than 2.5% showed similar patterns to the unimodal function with more degree of freedom;
3. In the bimodal distribution, the distance in days between the first and the second peak should be at least 90 days, otherwise they were not considered as two different seasons, thus there was only one season;
4. If the increase of R^2 using the bimodal function was lower than 2.5%, but the r^2 of unimodal function was lower than 80%, the bimodal function was used, if the point 3 was fulfilled.

The second step was to extract the parameters that describe the fire seasonality using the Cumulative Density Function (CDF) of the PDF, based on three different chosen confidence intervals: from 5% to 95%, from 10% to 90%, and from 20% to 80%. Through the use of the CDF it was possible to calculate the begin, end, and the length of the fire season(s), for both FN and BA. The day of the peak(s) was the same for each interval. When the distribution of fires during the year was bimodal, the relative area (a) of the PDF to determine the most important season was used.

The CDF representes the integral of the PDF, and in this case there was no analytic solution. To overcome this using the PDF, it was calculated a discrete curve by approximating the CDF.

With the cumulative distribution (CD) it was possible to calculate the beginning, the end, the length, and the peak of fire season(s) for each cluster, for both FN and BA.

To analyze the possible changes in the fire seasonality over time the fire data was divided in several temporal intervals.

The choice of the intervals was based on the overall trend of the fires in Italy and on some changes in the law on firefighting strategy during the period considered. Across the last three decades the phenomenon of wildfires in Italy has been characterized by a tendency to oscillate in the number of events. In the 80s and 90s it has had a remarkable

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resurgence, followed by a decrease as follows (Lovreglio at al. 2012): 1971-1980 (6.964), 1981-1990 (11348 of fire number), 1991-2000 (10576 of fire number), and 2001-2010 (6857 of fire number). Regarding the regulatory changes, in the 1990 the law of (21 November 1990) "Framework Law on forest fires" was promulgated, and intended to completely define all active strategies to fight wildfires.

The study period was divided in four time intervals: 1985-1990; 1991-1996; 1997-2002; 2003-2008; the observed BA and FN were independently aggregated in this interval. For each interval, the equations 4.1 and 4.2 were fitted independently, and the possible changes in the start, end, length and in the peak of fires were analyzed, both for FN and BA. The objective was identify the presence of trends over time.

5 IMPACTS OF RECENT TEMPERATURE AND PRECIPITATION TRENDS ON FIRES IN ITALY: FROM LOCAL TO NATIONAL SCALE

An analysis of the relationships between fire occurrence and the main weather variables has been carried out. The results highlighted differences in fire-weather relationships for the different piro-climatic areas.

5.1 State of the art

The increased number of wildfires and burned area reported in several parts of the world (e.g. Brown et al. 2004; Flannigan et al. 2005; Stocks et al. 1998), and especially high variability of fire occurrence in the last decades (e.g Founda and Giannokopoulos 2009; Trigo et al. 2006; Pereira et al. 2005), has drawn once again much attention to the understanding of the interactions among abiotic and biotic factors influencing fire behaviour and patterns in the last decades.

Climate and weather area are two of the major drivers of fire regimes and they have a many-sided effect on fire activity. Weather is important especially in the short term, mainly determining the dangerousness of a fire. On the one hand, weather can be a predisposing agent which causes water stress and changes in fuel flammability and fuel moisture content (Chuvieco et al. 2004; Viegas et al 1991;), or it can act directly by igniting fires through lightning (Vázquez and Moreno 1993), or modulating fire behaviour through wind (Rothermel 1972). On the other hand, climate influences fuel type distributions, vegetation productivity and fuel accumulation (Carvalho et al. 2008; Kunkel 2001; Pyne et al. 1996; Renkin and Despain 1992; Cesti 1990). Moreover, climate contributes to control the frequency of weather conducive to fire ignition and spread (Mouillot et al. 2002).

A number of authors argue that spatial variation in fire patterns may be controlled by the dynamics of fuel (amount, accumulation, distribution, decomposition, etc.) (Nunes et al. 2005; Cumming 2001). Conversely, the so-called “weather hypothesis” sustains that climate and weather are the most important factors driving fires (Moritz et al. 2004; Moritz 2003). In Mediterranean climate areas, socio-economic context has to be added to the previous framework. Socio-economic conditions affect land use/land cover patterns, ignition causes, fire-prevention and firefighting capacity (Viedma et al. 2006; Romero-Calcerrada and Perry 2004; Moreira et al. 2001).

Recently, two authors (Koutsias et al. 2012; Pausas and Fernández-Muñoz 2012) have pointed out the synergistic effect of fuel (influenced also by socio-economic changes) and weather. Koutsias et al. (2012) has shown an increased proportion of non-fire prone burned areas, as well as humid and sub-humid areas by comparing 2007 burning patterns with those of the previous period (2000–2006) in Southern Greece. Pausas and Fernández-Muñoz (2012) have identified a fire pattern shift around the early 1970s in the province of Valencia (Spain), suggesting fuel amount and climatic conditions as the main drivers of fire regimes during the pre-1970s and post-1970s period, respectively. The two authors have pointed out that, both at short-term and long-term level, fire patterns are subject to a shift from "fuel-limited" to "drought-driven" (Pausas and Fernández-Muñoz 2012). This means that fire patterns, highly promoted by fuel accumulation in the past, are now subject to climatically driven changes.

As above-mentioned, and as highlighted by Zumbrunnen et al (2009), it is clear that region-specific analyses are required to understand local fire regimes and their driving forces. Furthermore, in the context of changing climate, a better understanding of these interactions is the key to define suitable management programmes of both fire and ecosystems. An altered fire regime could have more immediate and significant impacts on extant ecosystems (Rambal and Hof 1998).

Worldwide, a number of studies have analyzed the relationship between weather and forest fires, focusing both on influences and patterns. In Spain, Vázquez and Moreno (1993) have shown strong relationships between temperature and precipitation variables, particularly of extreme values of these variables, and burned area. However, these relationshipsvary among areas with different climate. In Portugal, Viegas and Viegas (1994) have indicated a non-linear relationship between burned area and rainfall, so that, depending on the time of rainfall, this could promote or deter burned areas. Pausas (2004) has shown how summer rainfall is significantly related to interannual variability in burned area, showing also a significant cross-correlation for a time lag of two years in the province of Valencia (Spain). Turco et al. (2012) have focused on the relationships between summer maximum temperature, precipitation and fire occurrence in Catalonia (Spain) by finding results similar to those of Pausas (2004) in terms of fire occurrence delay in response to drought periods. In addition, Turco et al. (2012) have

assumed that winter minimum temperature and spring minimum temperature play an important role in increasing fuel load.
In Italy, apart from few studies at administrative regional level (Bajocco et al., 2010; Locci and Delitala, 2005) where the issue of fire is particularly experienced, a complete understanding of the relationships between fire occurrence and weather variables is still largely lacking. Conversely, a number of studies on firefighting planning (e.g., Bovio 1992) and fire prevention (Bovio 1996). Recently, Lovreglio et al. (2012) have focused on the analysis of fire ignition causes, but principally at provincial level.
Italy has an interesting environmental and climatic variability, due to its territory extent. In addition, the long fire history as a means able to change and adapt the landscape to the anthropogenic needshas made the study of fire regime characteristics a challenge.
This paper investigates the relationship between weather conditions and wildfires statistics (number of fires and burned area) in Italy during the recent past (1985-2008). The work will be carried out from local to national level, in order to achieve a detailed knowledge of the relationships within the bigger picture.

5.2 Material and Methods

In addition to the weather variables used in Chapter 1 to perform cluster analysis (maximum and minimum temperature and rainfall), in this part of the work daily average of vapour pressure (hPa) from MARS database has been utilized to calculate relative humidity by using the following equation:

$$RH = \frac{\mathrm{VP}}{\mathrm{SVP}}\,100 \tag{5.1}$$

where RH is relative humidity, VP is vapour pressure and SVP is saturated vapor pressure.
Saturated vapor pressure has been calculated by using the equation:

$$SVP = 0.6108\mathrm{EXP}\,\frac{17.27\mathrm{Tm}}{\mathrm{Tm}+237.3}10 \tag{5.2}$$

where Tm is mean temperature.

For each identified area found with cluster analysis, descriptive statistics have been initially calculated, with the aim of determining the differences between fire and weather conditions.

Linear models and non-parametric models have been used to assess, at seasonal and annual level, if interannual variability in weather patterns and fire events has had a significant trend. As highlighted by several authors (Yu and Neil, 1993; Suppiah and Hennessy, 1996), more information can be obtained from a combination of such techniques. Following Del Rio et al. (2007), the magnitude of trends has been obtained from the slope of the regression line by using the least squares method. Statistical significance has been determined by the Mann-Kendall test (Sneyers, 1990). The Mann-Kendall test is a non-parametric test to identify trends in time series data. The test compares the relative magnitude of sample data rather than data values themselves (Gilbert, 1987). One benefit of this test is that data do not need to conform to any particular distribution. The Mann–Kendall test is applicable when the data values xi of a time series can be assumed to obey the model:

$$xi = f(ti)+\varepsilon i \quad (5.3)$$

where f(t) is a continuous monotonic increasing or decreasing function of time and the residuals εi can be assumed to come from the same distribution with zero mean. It is therefore assumed that the variance of distribution is constant in time.
In order to test the null hypothesis of no trend, H0, the observations xi are randomly ordered in time, against the alternative hypothesis, H1, where there is an increasing or decreasing monotonic trend.
The Mann-Kendall test has been applied by using MAKESENS, an Excel Template Application (Salmi et al. 2002) that estimates also the slope of a linear trend with the non-parametric Sen's method (Gilbert 1987). In the computation of the Mann-Kendall test, normal approximation (Z statistics) has been used because applied for time series with more of 10 data.
The presence of a statistically significant trend has been evaluated by using the Z standardized values. A positive (negative) value of Z indicates an upward (downward) trend. To test for either an upward or downward monotone trend (a two-tailed test) at α

level of significance, H0 is rejected if the absolute value of Z is greater than $Z1\text{-}\alpha/2$, where the $Z1\text{-}\alpha/2$ is obtained from the standard normal cumulative distribution tables. In this application, the tested significance levels α are 0.001 (***), 0.01 (**), 0.05 (*) and 0.1 (+).

The correlation between meteorological variables and fire occurrence has been evaluated through a non-parametric correlation test (Spearman coefficient) at monthly, seasonal and annual level, with the aim of screening the variables that most correlate with fire occurrence.

Then, these variables have been introduced, as well as the natural logarithm of fire statistics, in forward stepwise regression and the terms have been accepted only in case of reaching the 0.05 significance level. The natural logarithm has been used to normalize fire statistics, because raw data distribution is non-normal. A unit has been added to the observed area burned and number of fires in order to avoid the zero values in logarithmic calculation (Carvalho et al. 2008). Multiple regressions have been calculated at annual, seasonal, and monthly level.

Finally, monthly multiple regressions obtained have been validated by using the analysis of residues. The square of the difference between data observed and data predicted has been calculated to analyze the performance of all models.

6 FIRE DANGER IN ITALY

Two diffuse fire danger indices have been used to characterise the fire danger pattern in Italy. The analysis have revealed the good skills of the tested indices to model the fire regime, in particular in the areas with a summer fire regime.

6.1 State of the art

There are several and heterogeneous definitions of fire danger. Fire danger can be defined as the probability of fire occurrence in case of favourable conditions for ignition and propagation (Chuvieco et al. 2003), while fire risk is the danger with respect to the vulnerability of the area (Hardy 2005). The fire risk also depends from the value of goods and from the possibility of casualties (Bachmann and Allgower 1998; 2001). Currently, despite major advances in fire danger estimation, the need to improve computational systems that allow its estimation is still a main research topic. In fact, defining fire danger for a location is often difficult, since fire is a complex phenomenon. Moreover, fire danger measurements are very valuable for all firefighting services, since they allow to minimize the level of uncertainty combined with scientific knowledge and operational experience (Valese 2008; Taylor and Alexander 2006).

The main determinants for fire danger are climate and weather conditions, as shown in several studies (Turco et al. 2012; Carvalho 2008; Pausas et al. 2004). Higher temperature and lower relative humidity usually correspond to a higher fire danger and a large burned area, but not necessarily to an increase in the amount of fires (Carvalho 2008). Weather conditions influence fuel moisture content, and fire behaviour also through the wind action (Carvalho 2008).

The relationship between weather and fire danger has led to the development of models to estimate fire danger. Besides the fire danger models, fire rating systems have become an instrument widely used in many regions of the globe. Fire danger can be measured by using both static (long-term or structural) and dynamic (short-term) indicators. The most common fire danger systems use daily meteorological variables as input data and are simply denominated as Fire Danger Indexes (San Miguel-Ayanz 2002). These meteorological fire danger indexes can be distinguished according to the approach used for variables selection and integration, as described by Chuvieco et al. (1999).

One of the most commonly used fire danger rating systems across the world is the Canadian Fire Weather Index System (FWI), developed by Van Wagner and Pickett (1987). FWI has been very effective not only in Canada, the place where it was developed, but also in the Mediterranean area, as demonstrated in literature (Viegas et al. 1999, Viegas et al. 2001). An important comparative study assessing the performance of different danger indexes in Southern Europe has revealed that FWI is the fire danger index best correlated with fire occurrence in Spain, France, Italy and Southern Portugal (Viegas et al. 1999). Therefore, FWI is a reliable fire danger system also in dry Mediterranean vegetation and climate conditions, which are very different from Canadian conditions for which FWI has been designed. However, despite its successful application in recent studies in Mediterranean regions (Valese 2008; Carvalho et al. 2008; Moriondo et al. 2006), it is noticeable that the performance of FWI and its relationship with fire danger, and hence with fire occurrence, show different response patterns according to the area considered (Carvalho 2008).

In Italy, where a relatively few papers on fire danger are available, this variation of fire danger indexes performance with respect to the location is even more reasonable, considering the variability of the Italian peninsula. Moreover, in Italy a detailed analysis on the differentiation of fire danger according to the location, as well as on the relationship between fire danger indexes and fire occurrence, is still missing. Furthermore, fire danger analysis has almost always relied on FWI, while other existing fire danger indexes (e.g., Keetch-Byram Index KBDI) (Keetch and Byram 1968) may be also effective for fire danger issues.

Here, to contribute for a better understanding on the links between potential fire danger and fire occurrence in Italy, the FWI and Keetch-Byram Index (KBDI) danger indexes have been estimated for the piro-climatic clusters obtained in Chapter 2. The main goal of this analysis has been to evaluate the performance of these fire danger indexes on a annual and seasonal scale across Italy and, more specifically to:

- characterize the fire danger patterns in Italy;
- establish significant trends of fire danger in Italy in the recent past;
- investigate the relationships between fire occurrence and fire danger.

6.2 Material and Methods

Two weather fire danger indexes have been considered to represent fire danger in Italy: FWI and KBDI. The former has been widely used across Europe when assessing fire danger, while the latter has been used in this thesis to verify the reliability of this index in the Italian context. Detailed meteorological data have been obtained from the MARS database (previously described in the Chapter 1). The following weather variables have been used to make calculations:

- maximum temperature, Tx (°C)
- minimum temperature, Tn (°C)
- daily average vapour pressure, e_a (hPa)
- daily rainfall, R (mm)
- daily average wind speed, WS (m s^{-1})

Since relative humidity data are not available in the MARS database, the following procedure to estimate RH has been implemented.

a) calculation of dew point temperature T_d frome_a:

$$T_d = \frac{b}{1-b} \tag{6.1}$$

where e_a is the vapore pressure and b is:

$$b = \ln \frac{\frac{e_a}{0.6108}}{17.27} \tag{6.2}$$

b) then, T_d has been calculated by changing the amplitude of arbitrary values of RHx and RHn until the difference between T_d estimated from points (a) and (b) is equal to 0. This procedure provides the values of RHx and RHn that give the same T_d obtained from the MARS data.

6.3 Fire Danger Indexes calculation

Fire Weather Index (FWI)

FWI is composed of 6 adimensional subindexes (Figure 6.1): Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), Drought Code (DC), Initial Spread Index (ISI), Buildup Index (BUI) and Fire Weather Index (FWI) (Van Wagner 1987). The first three subindexes characterize daily changes in water content for three classes of forest fuels with different drying rates:

- FFMC is related to the litter water content and other cured fine fuels present in a forest stand for 0.25 kg m^{-2} dry weight layer (Van Wagner 1987); for this reason, it can be used as a proxy for fire ignition potential and spread in the area (Carvalho 2010).
- DMC is related to the moisture content of loosely compacted, decomposing organic matter weighing about 5 kg m^{-2}, when dried. This is an indicator of fuel consumption in moderate duff layers and medium-sized woody material (Carvalho 2010).
- DC is related to the deep layer of compact organic matter weighing about 25 kg m^{-2}, when dried.
- ISI is obtained by the combination of wind and the FFMC component. It represents the rate of fire spread without the influence of variable quantities of fuel.

BUI combines DMC and DC components to represent the total fuel available for spreading fire; FWI is the combination of ISI and BUI components to represent the intensity of fire spreading as a rate of energy output per unit of fire front length.

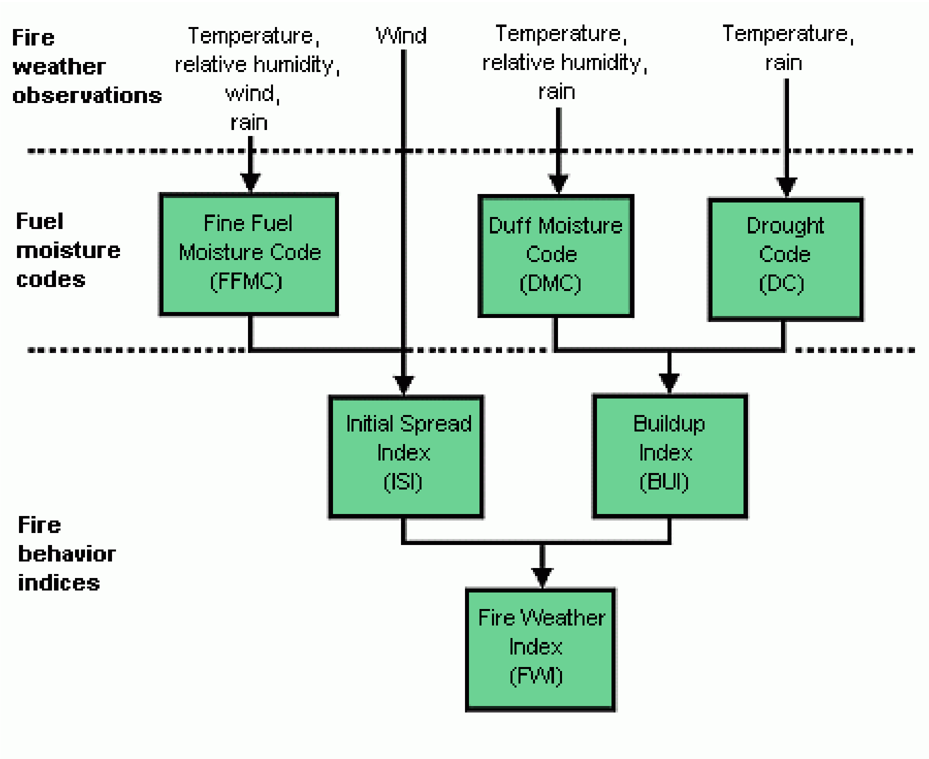


Figure 6.1 Canadian Fire Weather Index (FWI) System components (Van Wagner 1987).

The calculation of FWI is usually limited by the lack of instantaneous noon data for temperature and relative humidity, as already reported in other studies assessing the relationship between weather, climate and fire. In this work, maximum temperature and minimum relative humidity values were used as proxies of temperature and relative humidity values at noon, respectively. In addition, the FWI code was adjusted to account for differences in the daylenght of Italy with respect to the original code related to Canada.

Keetch-Byram Index (KBDI)

KBDI is a drought index expressing fire potential estimating the effect of evapotranspiration and precipitation in deep duff and upper soil layers. Higher values express greater inflammability of organic fuels (Deeming, 1995), which may kindle the burning of heavier fuels and contribute to fire intensity. The KBDI model is based on three assumptions:

1. Moisture release in a forest area depends on the transpiration capacity of vegetation cover;
2. Moisture release from soil depends on the capacity and soil moisture content ;

3. Soil layer depth affected by drought, which influences the flammability of forest and soil organic matter, has a maximum field capacity of 8 inches (203 mm) of water, and this is the amount available for evaporation (Deeming, 1995).

In this study, a modified version of KBDI has been used, as better detailed in Snyder et al. 2006. The Hargreaves-Samani (1982) equation, substituted for the Ep in Eq. (A.1), has also been computed. The reference evapotranspiration value is an estimate of the maximum evapotranspiration rate for a 0.12 m tall, cool-season grass. The Hargreaves-Samani equation calculates the reference evapotranspiration values from daily maximum (Tx) and minimum (Tn).

6.4 Evaluation of fire danger Indexes performance

With the aim to evaluate the performance of fire danger indexes with respect to fire occurrence, all data for fire occurrence (FN ad BA) and fire danger index values have been converted into a GIS (Geographic Information System) format. To allow the comparison with fire data (available at monthly level), FWI and KBDI values have been converted from daily to monthly data.

To evaluate the differences between fire occurrence and fire danger, descriptive statistics have been initially calculated in each area (i.e., clustering). The maximum index value for each month has been calculated; the number of the days in which indexes exceed a defined threshold has also been calculated (see below for the FWI threshold) (Valese 2008; Lawson e Armintage 2008; Abbott 2007: Otway 2007; Camia and Bovio 2000; Stocks et al. 1989; Turner 1972):

- FFMC > 92 trigger conditions highly probable (FFMC92);
- DMC > 40 intense surface fires (DMC40);
- DC > 500 extreme drought conditions and high intensity of fire, out of extinguishing capability and the difficulty of cleaning due to the persistence of outbreaks underground (DC50);
- ISI > 16 extremely rapid rates of spread (ISI16);
- BUI >60 extreme behaviour; (BUI60)
- FWI > 19.9 high risk (FWI19.9).

The KBDI thresholds have been arbitrarily defined because such a threshold of risk is not available, according to our best knowledge on the available literature. Therefore, the 75th percentile of distribution has been adopted as threshold, corresponding to a value of 150.

In order to identify annual variations of fire danger during the study period, parametric (linear regression) and non-parametric (Mann-Kendall test) statistics have been applied. The relationship between fire occurrence and burned area with fire danger indexes have been analysed with the Spearman correlation and stepwise multiple regression. In the multiple linear regression analysis, burned area (ha) and fire number values have been normalized (by expressing them in a natural logarithm scale) to avoid effects induced by the non-normal distribution of raw data (Carvalho et al. 2008; Flanningan et al. 2005). All the analyses have been made at seasonal and annual level for each cluster and at national scale.

7 RESULTS AND DISCUSSION

In this chapter the experimental results obtained during this study are showed. They can be summarized in four parts:

1) Cluster analysis results;
2) difference of fire seasonality across Italy
3) Impact of recent trends of temperatures and precipitation on fires in Italy: from local to national scale;
4) fire danger in Italy

7.1 Cluster analysis results

The results obtained from cluster analysis showed, for Italy, six different piro-climatic areas with different fire regimes (Figure 7.1).

Cluster 1 represents the Alpine zone, where fires occur typically in winter (figure 7.2) and fire occurrence is very low (on average, 259 of FN and the 2582 ha of BA per year) (Table 7.1). The climate is characterized by a severe winter, with very low minimum temperatures, and high rainfall (Table 7.2). Cluster 2 represents the sub-alpine zone, and fire occurrence is similar to Cluster 1 (Figure 7.3). The FN and BA are higher than Cluster 1, respectively 577 and 6144 ha per year (Table 7.1). Maximum and minimum temperatures are higher than Cluster 1, while rainfall is lower (Table 7.2).

Cluster 3 consists in the main plain of the Northern Italy and of the middle of the peninsula. This cluster is the biggest in terms of km^2. Fire occurrence is divided into two peaks, the first one is located during late winter and early spring, while the second during summer, with the fire occurrence higher than the first peak (Figure 7.4). On average, for this area, the fire occurrence is relatively low (Table 7.1). From a climate point of view this area is milder than the first two clusters (Table 7.2). The Cluster 4, mainly constituted by the Liguria region, is peculiar. Although the climate is typically Mediterranean, the fire regime is not exclusively on summer, but also fires occur in winter-early spring (Figure 7.5). The winter peak has a higher fire number and a higher burned area than summer peak. In this cluster, fire occurrence is higher than the previous cluster (Table 7.1).

Cluster 5 and 6 show the same fire activity. Fire occurrence is located in summer (Figure 7.6; 7.7), these clusters are in the south Italy and the two largest islands. The year FN is 4605 and 2683 for Cluster 5 and 6, respectively, while BA is 49620 ha for Cluster 5 and 27890 ha $year^{-1}$ for Cluster 6 (Table 7.1). Climate in these Clusters is typically Mediterranean (Table 7.2). Cluster 6 represents the area where fire occurrence is the highest in Italy.

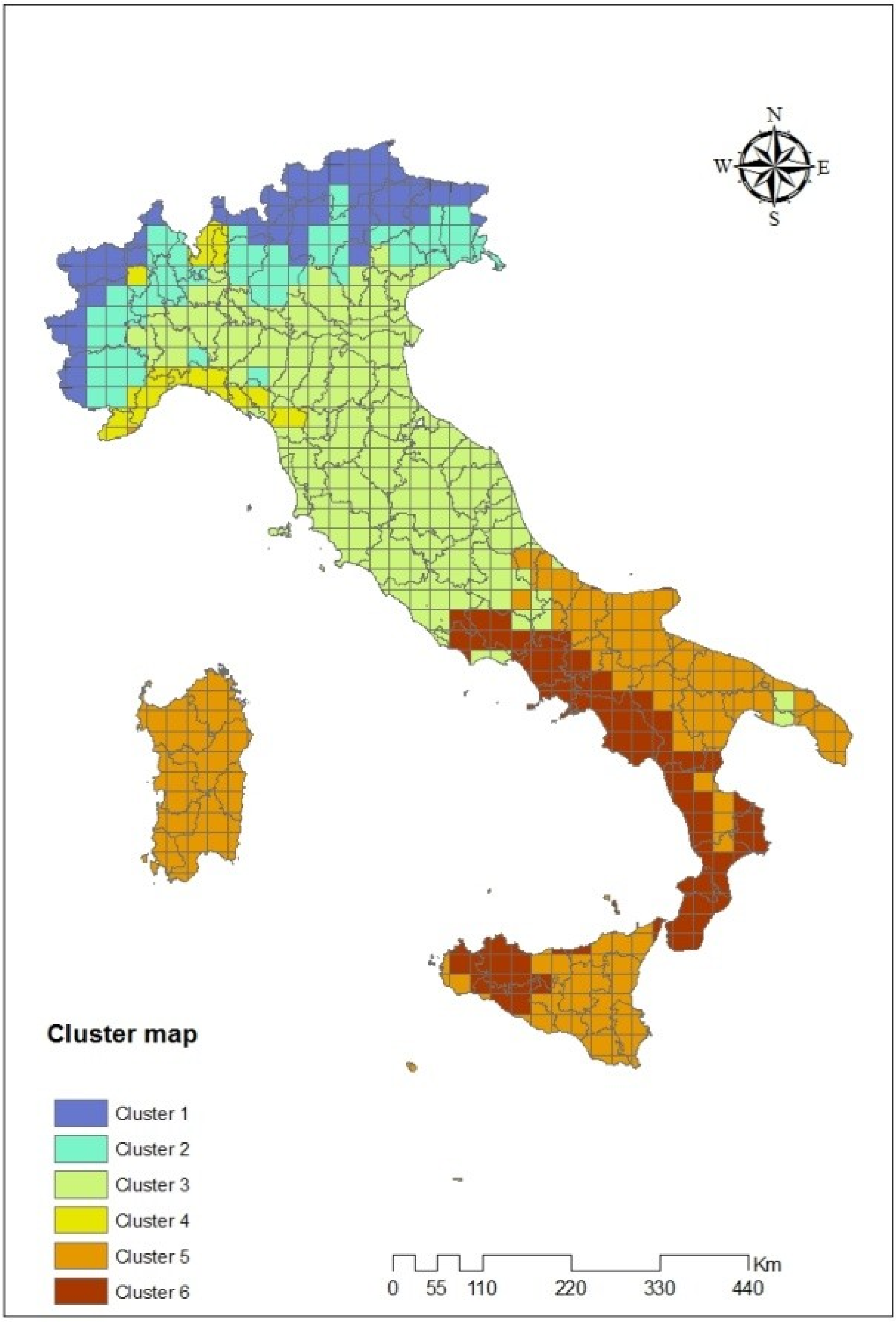


Figure 7.1 Piro-climatic areas identified in Italy by the cluster analysis

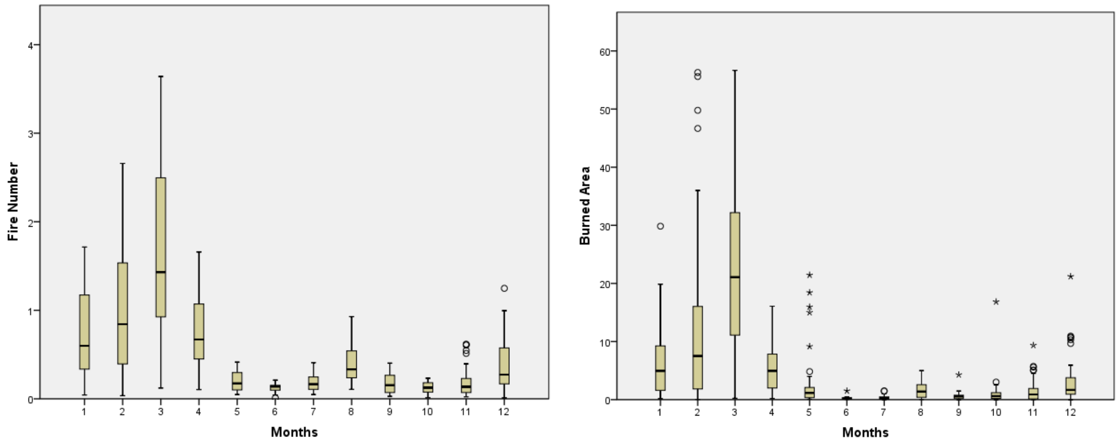


Figure 7.2 Fire Number and Burned Area occurrence during the year in Cluster 1.

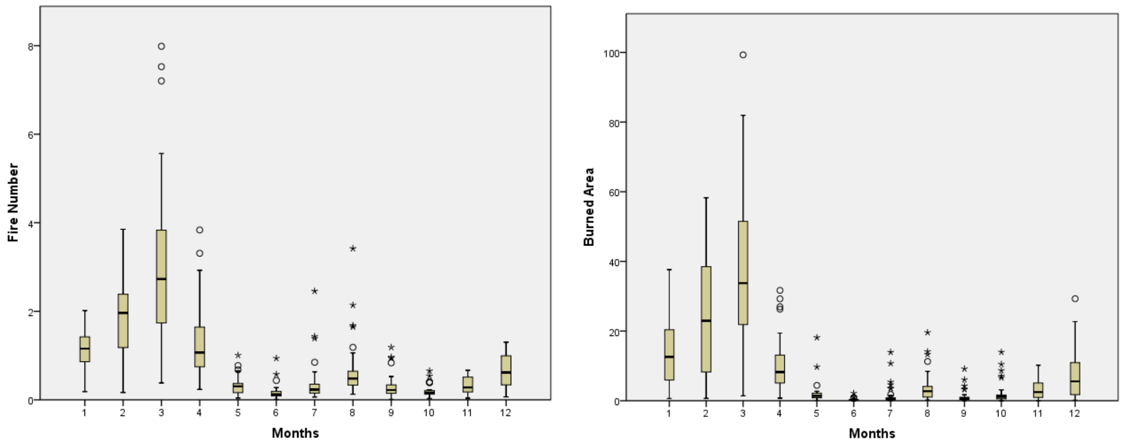


Figure 7.3 Fire Number and Burned Area occurrence during the year in Cluster 2.

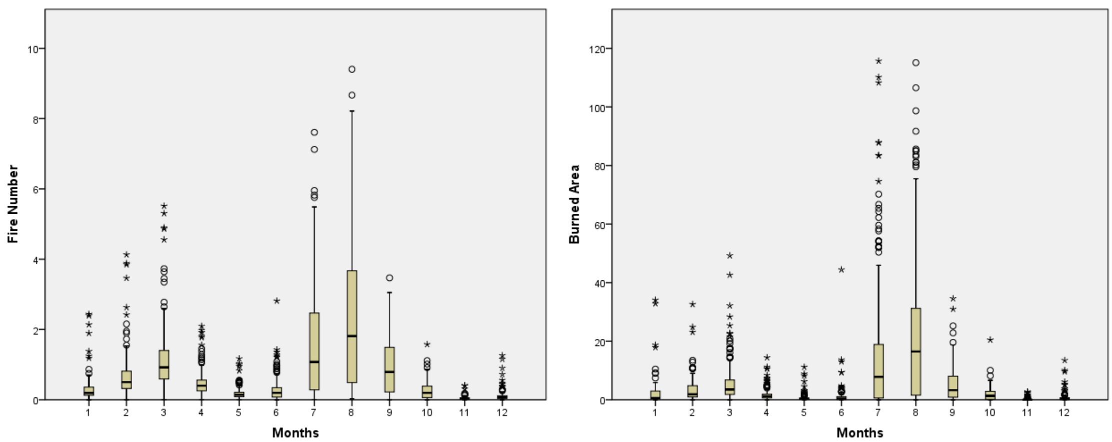


Figure 7.4 Fire Number and Burned Area occurrence during the year in Cluster 3.

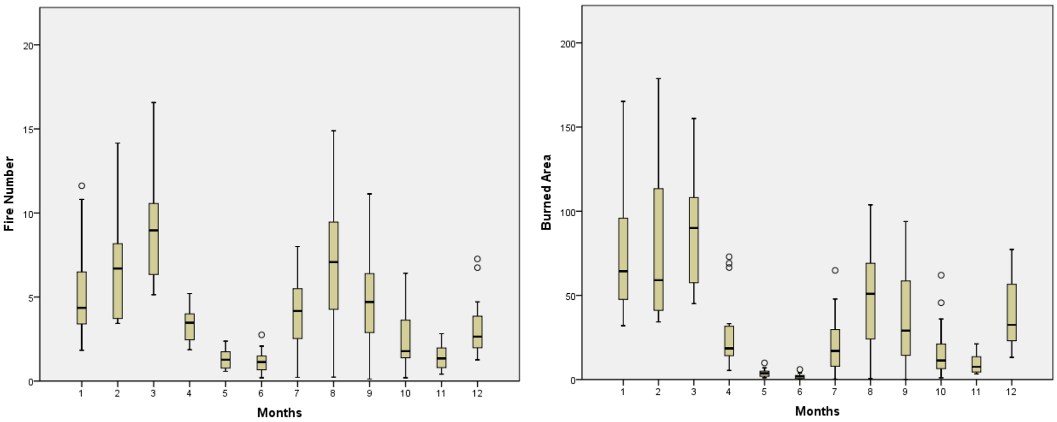


Figure 7.5 Fire Number and Burned Area occurrence during the year in Cluster 4.

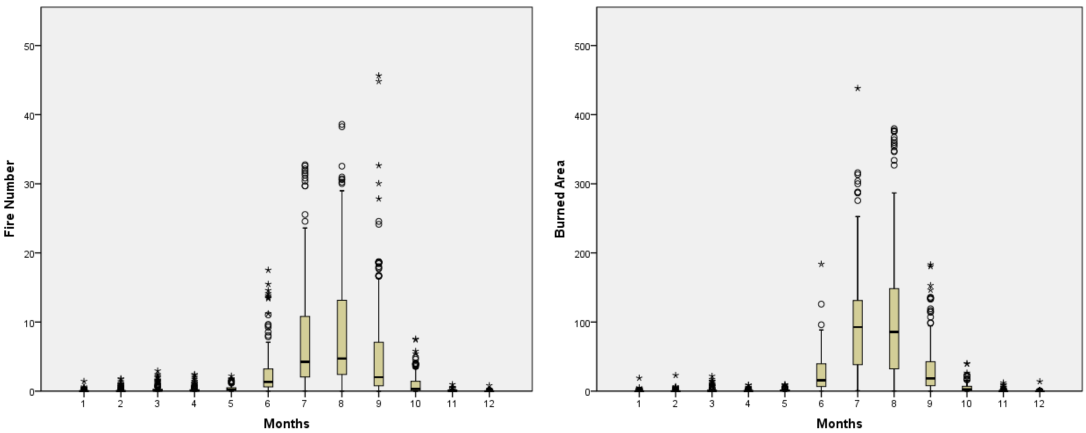


Figure 7.6 Fire Number and Burned Area occurrence during the year in Cluster 5.

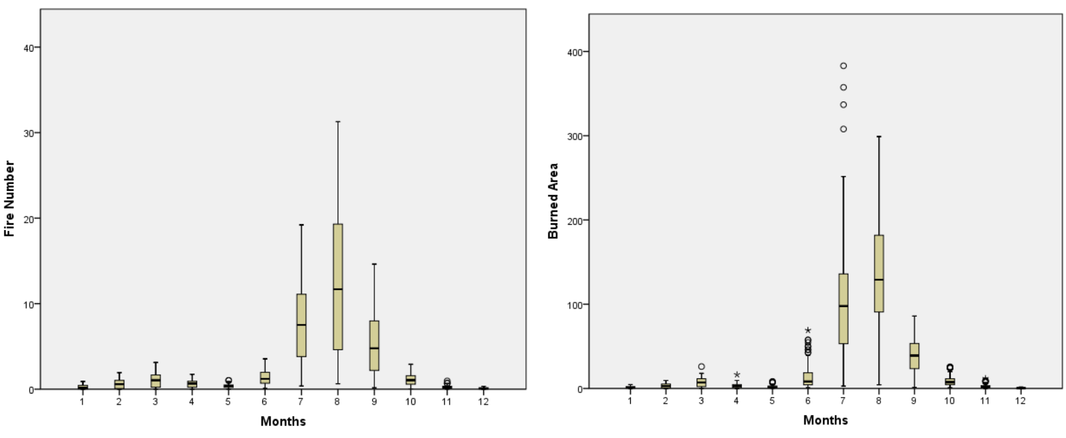


Figure 7.7 Fire Number and Burned Area occurrence during the year in Cluster 6.

Table 7.1 Fire occurrence for the different clusters

Region	Number of Fires	Burned area (ha)	Fire season
Cluster 1	259	2582	Jan-Apr
Cluster 2	577	6144	Jan-Apr
Cluster 3	1551.	11630.	Jan-Apr, Jul-Setp
Cluster 4	892	8080	Dec-Apr, Jul-Oct
Cluster 5	4605	49620	Jun-Sept
Cluster 6	2683	27890	Jun-Sept

Table 7.2 Categorization of Italy in the six cluster recognized by the cluster analysis.

Region	Tmax (°C)	Tmin (°C)	Rainfall (mm)	RH (%)
Cluster 1	10.09	1.39	922.48	71.97
Cluster 2	16.95	7.33	851.42	70.85
Cluster 3	18.69	8.59	720.45	73.92
Cluster 4	17.27	9.24	799.84	72.16
Cluster 5	20.38	11.79	485.04	74.67
Cluster 6	20.41	12.22	760.49	73.87

7.2 Fire Seasonality across Italy

The results of this part will be showed in two part:

- Long term seasonality characterisation;
- Seasonality changes over time.

7.2.1 Long term seasonality analysis

The comparison between the unimodal and bimodal distribution, and the Cumulative Distribution (CD) of each cluster for each confident interval are presented in Appendix A. The confidence interval showed in the results is 5-95%.

The seasonality analysis for the Cluster 1 showed that the best distribution for this area was the unimodal (Figures 7.8 and 7.8). Fire tipically occurs during the winter season. The distribution of FN showed a little peak during the summer, but the difference of R^2 between unimodal and bimodal distribution was lower than 2.5% (i.e. Cap 4.2).

The parameters of von Mises probability density are shown in Table 7.3 for both FN and BA. Considering the FN, the R^2 between the observed and predicted data was 0.92. The start of the fire season was on the beginning of January and the end at the begining of April. The length of season was above 3 months and one week, and the peak (θ) was located in the end of February.

Regarding the BA, the R^2 (Table 7.3) was 0.94. The start and end of season for BA was slightly shifted forward, but was very similar, and the duration was about 2 months and 2 week. The peak was located in the same period of FN.

Cluster 2 showed a similar trend of the Cluster 1; the best distribution to explain the occurrence of fires was the unimodal, and the fires were located principally at the beginning of the year (Fig. 7.8, Table 7.3). For the FN the R^2 was 0.95. The start, end and length of the fire season were the same as Cluster 1 with only a small difference of two or three days. The peak was also located in the end of February.

Regarding the distribution of BA, the R^2 obtained was 0.94 and the beginning of the fire season was similar to FN, however the end of season was anticipated by several days, so the length was lower. The peak of Burned Area was located in the middle of February.

The analysis done for Cluster 3 showed that the seasonality had a bimodal distribution (Fig. 7.8, Tab 7.4). For FN the best model had a R^2 of 0.92. The first season was located during the winter period, starting on the first week of January and ending in the first week of April. The duration of this season was three months and the peak was in the middle of February. The second season occurred in the summer between the middle of June and the beginning of September .The length of the season was three and half months. The peak of this season was located at the end of July. The relative areas of the von Mises distributions (a) of both seasons showed the most important season was the second, but the difference was not very high. The analysis of the distribution of BA showed that the first season started during the first three weeks of January. The end of season was anticipated, when compared to the FN, and was in the second half of March. The duration was two and an half months, and the peak was in the middle of February.

The start of the second season was in the beginning of June and end was in the end of August. The length of this season was two and half months, and the peak was located during the last week of July. For BA, the areas of the von Mises distributions (a) showed that the summer season was the more relevant and the winter season was even less important than it was for the FN distribution.

Cluster 4 showed a similar distribution to Cluster 3 and the distribution of both FN and BA was bimodal (Fig. 7.8, Tab 7.4). The FN distribution showed an R^2 of 0.91. The first season was located in the winter, starting in the middle of December ending in mid April. The length of this season was four months and the peak was in the middle of February. The second season was located during the summer, starting in the second half of June and ending in the middle of September. The length was three months and the peak of this season was located in the beginning of August. The areas of the von Mises distributions (a) of both seasons showed that the most important season was the first. BA showed that the first season started in the middle of November and ended at the end of May. The length of this season was six months. The second season started in the second week of June and ended in the first week of September. The length of this season was two and half months, and the peak was during the second week of August. The most important season was the first.

The analysis of Cluster 5 showed a unimodal distribution (Fig. 7.8, Tab 7.3) with fire occurring during summer. Considering the FN distribution, the $R^2$was 0.99. The day of the start of fire season was during last week of May and ending was in the last week of September. The length of the season was four months. The peak was located during the last week of July. Regarding BA, the R^2 was 1. The start of the season was in the

beginning of June, and the end in the beginning of September. The peak was located after the middle of July.
The seasonality of Cluster 6 was very similar to Cluster 5. The distribution was unimodal and the fires occurred during summer (Fig. 7.8, Tab 7.3). The best distribution of FN had an R^2 of 0.99. The start of fire season was in the middle of June and the end in the second week of September. The length was about three months and the peak was located in the end of July. The R^2 for the BA distribution was 1. The start of season was on the second week of June and end in the last week of August. The length of the season was less than three months and the peak was located after the middle of July.

In summary, the seasonality analysis results showed that in Italy there are three different patterns. In Clusters 1 and 2 it was unimodal with fire occuring generally during the winter. Clusters 3 and 4 showed a bimodal seasonality, the first season was located during winter and the second was located in summer. In Cluster 3, the second season was more important than the first one, the opposite occurred in Cluster 4. The length of the two seasons in Cluster 4 was very large and the end of the first season was close to the beginning of the second season. For Clusters 5 and 6 the seasonality study showed a very clear trend since this is a typical Mediterranean area with wildfires occurring during the summer. Thus, the distribution of fires was unimodal for both Clusters 5 and 6.
WE argue that a combination of several factors is responsible of the high observed variability in the fire seasonality across Italy. Latitude gradient, topography, and the influence of the Mediterranean Sea influence climate, and then the type of fuel (Cheney and Sullivan 2009; Carvalho et al. 2008; Kunkel 2001; Pyne et al. 1996; Renkin and Despain 1992; Cesti 1990) and the fuel moisture (La Page et al. 2010;). In addition, human activities can also influence the fire distribution, with actions related to fuel load, fuel structure and, in particular, with increasing or suppressing fire fighting actions (Archibald et al. 2009; Cheney and Sullivan 2009; Korontzi et al. 2006; Nelson 2001).

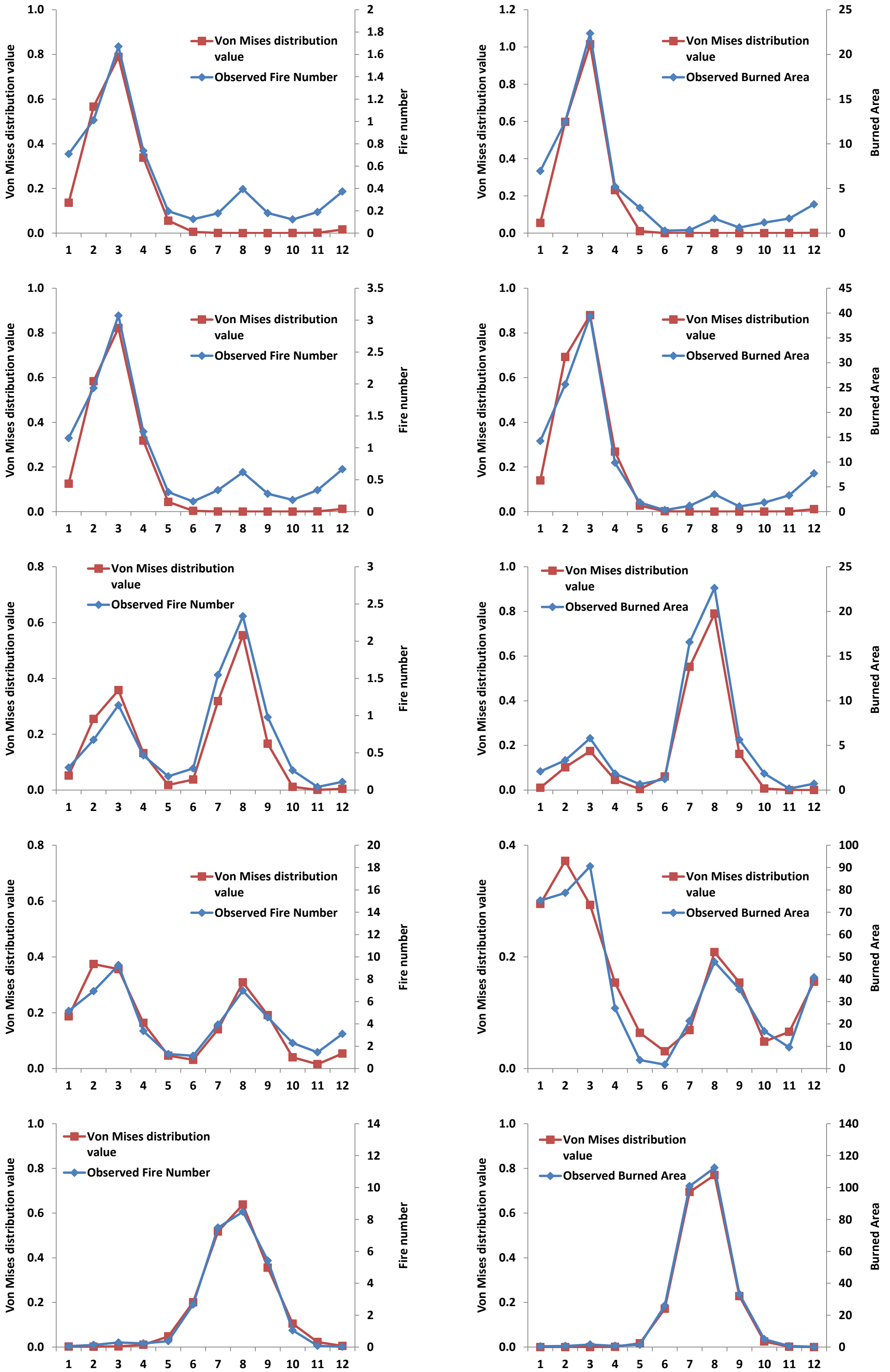


Figure 7.8 Trends of observed and predicted Fire Seasonality for each Cluster.

Table 7.3 Seasonality analysis characterisation (Clusters 1, 2, 5, 6; unimodal distribution). θ ***= peak, k = concentration (dimensionless)***

Cluster	Fire Data	R^2	θ (DOY)	k	Start (DOY)	End (DOY)	Length (days)
1	FN	0.93	54	4.44	5	102	97
	BA	0.92	54	7.55	17	89	72
2	FN	0.94	54	4.86	7	99	92
	BA	0.93	51	5.41	6	93	87
5	FN	0.99	206	2.99	142	266	124
	BA	1.00	200	5.05	157	251	94
6	FN	0.99	209	5.24	164	252	88
	BA	1.00	202	6.00	160	242	82

Table 7.4 Seasonality analysis characterisation for Clusters 3 and 4 (bimodal distribution). a = relative area; θ ***= peak; k = concentration (dimensionless)***

Cluster	Fire Data	R^2	Season	a (%)	θ (DOY)	k	Start (DOY)	End (DOY)	Length (days)
3	FN	0.92	I	43	53	5.02	7	97	90
			II	57	207	6.61	167	245	78
	BA	0.99	I	18	42	7.04	16	91	75
			II	82	203	7.37	166	239	73
4	FN	0.91	I	63	44	2.85	346	109	128
			II	37	217	4.80	170	262	92
	BA	0.91	I	78	14	1.76	318	146	193
			II	22	222	6.13	178	251	81

7.2.2 Seasonality changes over time

With respect to the length of the season for the four intervals considered is shown in the Fig. 7.9. Cluster 1, 2, 5, and 6 did not show any particular variation of the length of the fire season, while Cluster 3 showed that the season for FN was increasing. On the other side, the length of the fire season for BA was decreasing, in particular for the last three intervals. The length of Cluster 4 showed a clear decrease.

The parameters obtained for each time interval considered are shown in appendix A, while the main results of seasonality changes are shown in the Figures 7.9, 7.10, 7.11, 7.12, 7.13 and Tables 7.5 - 7.6. The Figures 7.10, 7.11, 7.12, 7.13 and the Tables 7.5 - 7.6 reports the principal variation of the pattern seasonality of fire during the four time intervals considered.

Because the Cluster 1 and 2 showed the same pattern, only the distributions of Cluster 2 is showed (Fig. 7.10). The seasonality of FN showed an alternation between the unimodal and bimodal distribution. On the other side, the BA analysis showed a unimodal distribution for the first three intervals, while the last was bimodal. When the fire distribution was bimodal, the first season was more important than the second. This was confirmed by the areas of von Mises distribution (a) (Tables 7.5 and 7.6).

The Cluster 3 (Fig. 7.11) showed that the fire seasonality had bimodal distribution for each interval. This was always true for FN, while for BA the last analyzed interval showed only one season. The most important season was always the second, and for BA it can be see a decreasing trend for the winter season (Tab. 7.5 and 7.6).

With respect to the Cluster 4 (Fig. 7.12) the seasonality of fire in the four analyzed intervals was more complicated, because for the first interval it was not possible to adjust a suitable distribution for this Cluster for both FN and BA (Appendix A). On average, the fire seasonality had a bimodal distribution. The most important season was the first, but the second peak, located in the summer periods, showed an increasing trend (Tab. 7.5 and 7.6). The fire seasonality of Cluster 5 and 6 during the study intervals showed the same patterns. For this reason, only the results of Cluster 6 (Fig. 7.13) are showed because it had the best adjustment. From the analysis it was not detected any relevant change in the seasonality pattern during the study periods.

The seasonality change analysis showed that for each cluster there were some changing, in particularly in the Clusters with a bimodal distribution of fire. In these Clusters the FN distributions was highly variable, and both FN and BA highlighting an increase of summer season when it was marginal. On the other side, in the Clusters where the most important season was the second, the winter season showed a decreasing trend.

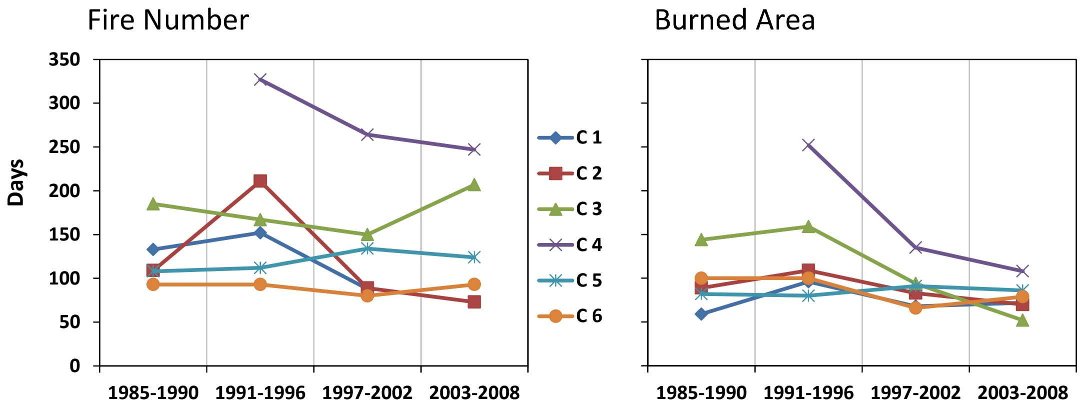


Figure 7.9 Changing of the length of fire season during 1985-2008 for each Cluster for Fire Numberand Burned Area. *In the Cluster with bimodal distribution the total length was equal to the sum of the length of the two seasons. The missing point in the graphic represent the intervals where the* R^2 *obtained with the adjustment was lower than 80%.*

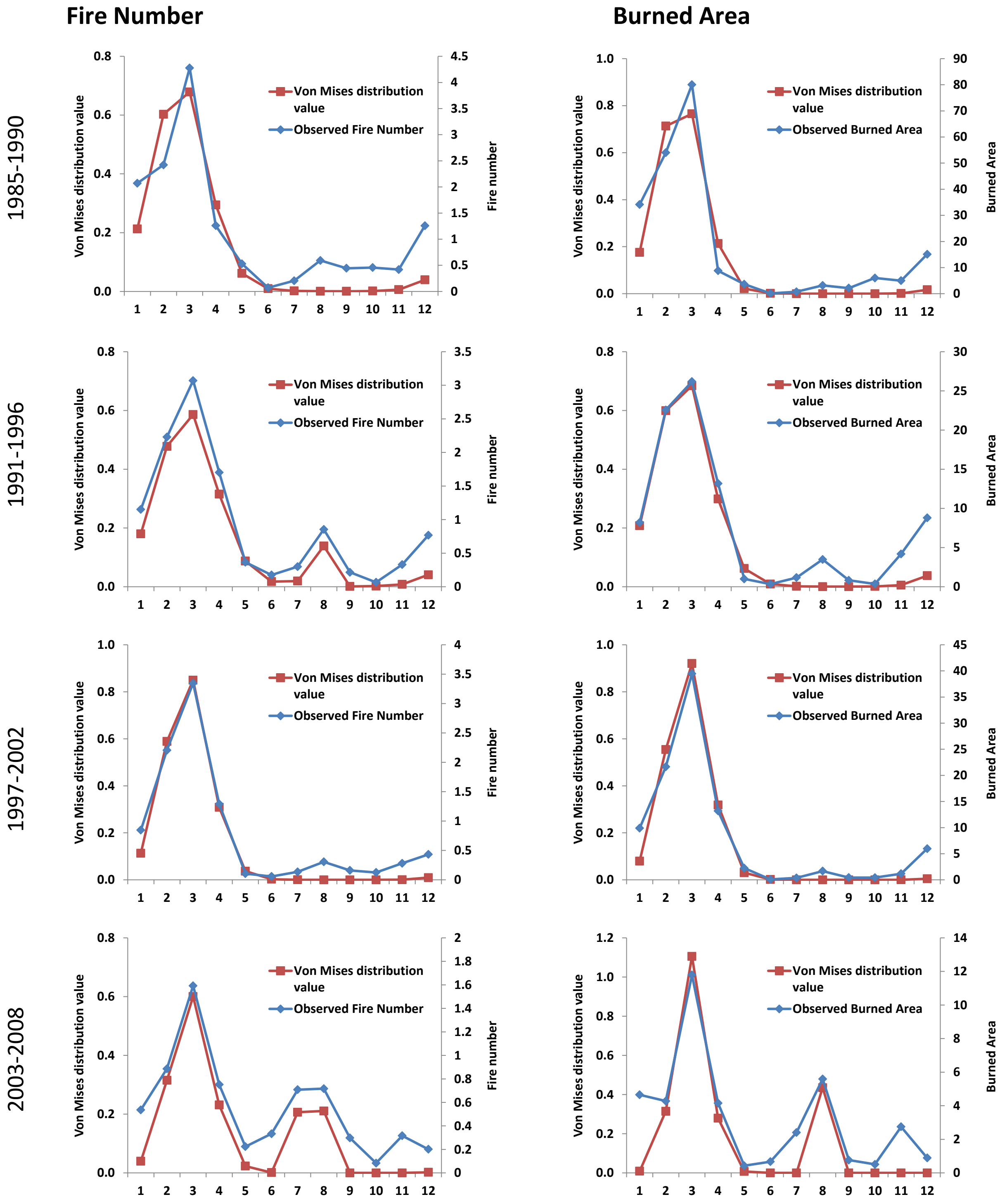


Figure 7.10 Observed and predicted Fire Seasonality for Cluster 2 for each chosen interval

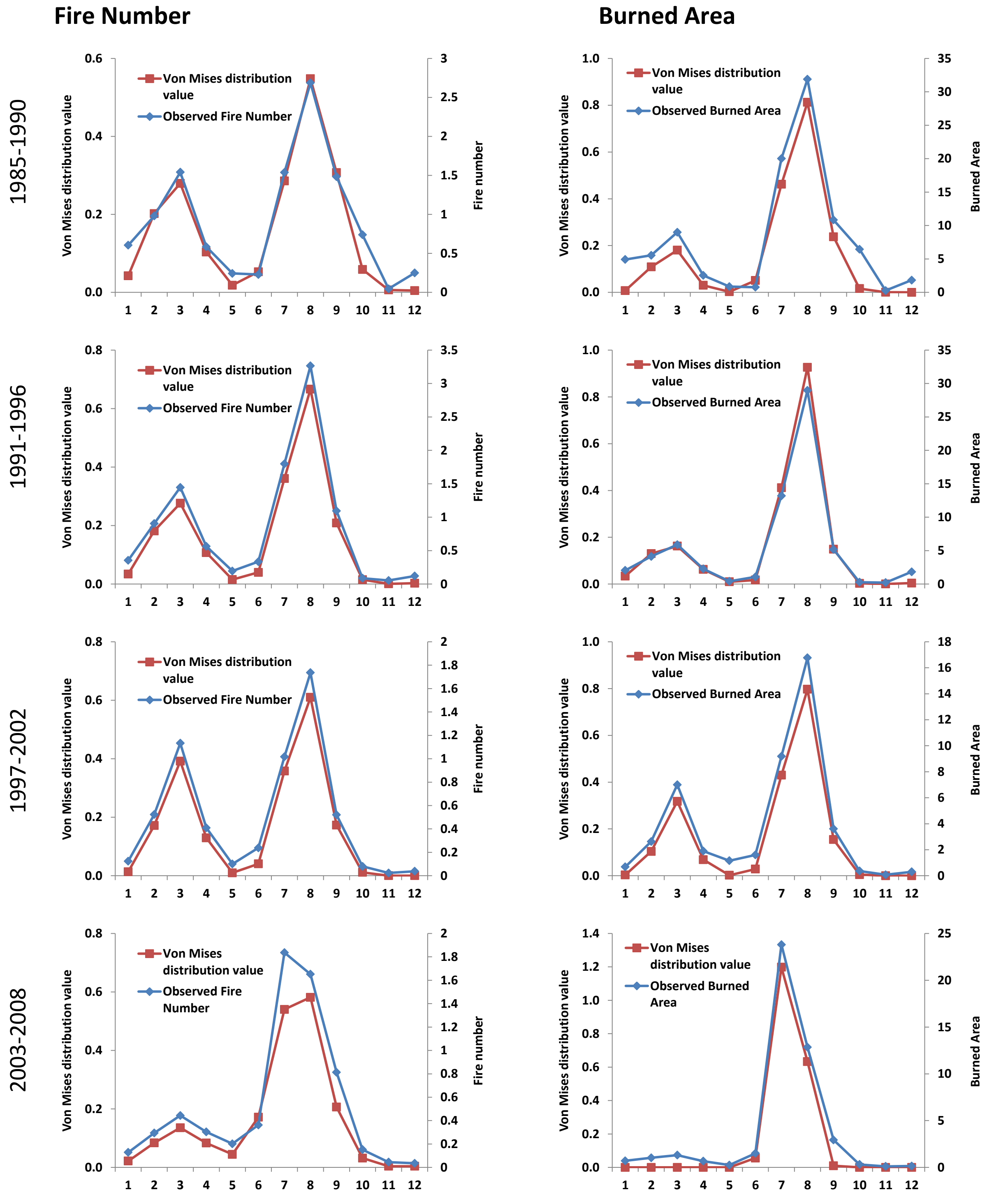


Figure 7.11 Observed and predicted Fire Seasonality for Cluster 3 for each chosen interval

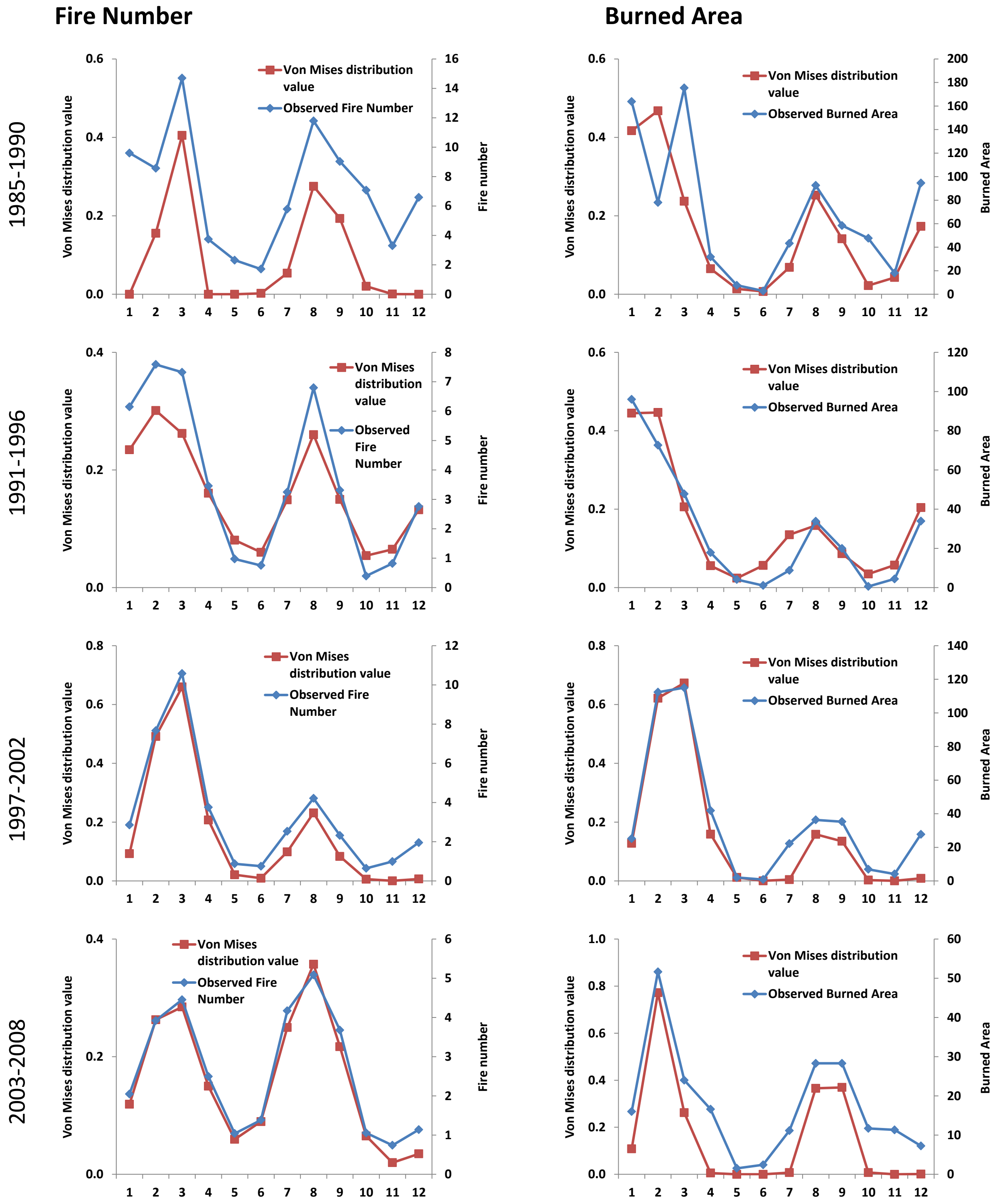


Figure 7.12 Observed and predicted Fire Seasonality for Cluster 4 for each chosen interval

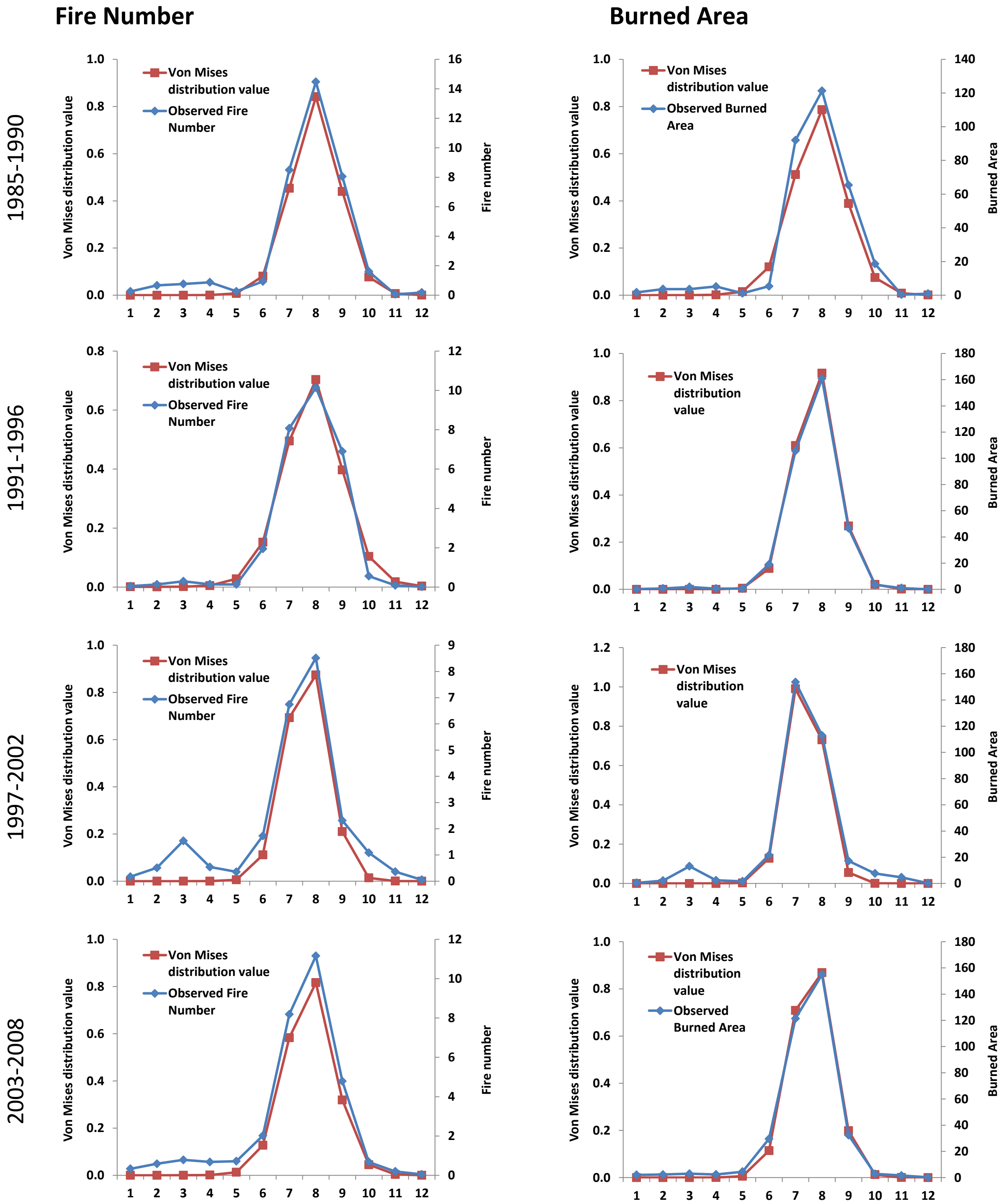


Figure 7.13 Observed and predicted Fire Seasonality for Cluster 6 for each chosen interval

Table 7.5 Relative area variation (a) calculated in the Fire Number seasonality analysis for the Clusters that showed two fire seasons (a1, a2 = proportion of the total area of bimodal distribution)

Time interval	Cluster 1		Cluster 2		Cluster 3		Cluster 4	
	a_1	a_2	a_1	a_2	a_1	a_2	a_1	a_2
	%		%		%		%	
1985-1990					34	66		
1991-1996	90	10	32	68	71	29		
1997-2002					37	63	78	22
2003-2008	64	36	18	82	48	52		

Table 7.6 Relative area variation (a) calculated in the Fire Number seasonality analysis for the Clusters that showed two fire seasons (a1, a2 = proportion of the total area of bimodal distribution)

Time interval	Cluster 1		Cluster 2		Cluster 3		Cluster 4	
	a_1	a_2	a_1	a_2	a_1	a_2	a_1	a_2
	%		%		%		%	
1985-1990					17	83		
1991-1996					21	79	75	25
1997-2002					26	74	84	16
2003-2008	90	10	90	10			60	40

The analysis of seasonality change for the first Cluster showed, in the last time step (2003-2008) a insurcence of a summer season. In the Cluster 3 the first fire season showed a decreasing trend, suggesting that the winter season is tending to disappear. This trend was also confirmed in the Cluster 4, although this cluster showed the most variable patterns. Clusters with summer fire seasonality did not show any trend.

The dynamics of fire seasonality changes can have several causes, due to climate changes and anthropogenic. The climate change can influenced the climate drivers that affect the patterns of fire seasonality, going to move the fires period from winter to summer even in those areas where you have only winter fires. In areas with winter fires, as discussed later in this work, an inverse relationship between minimum temperatures and fires was found. It could be argue that, during the winter season, milder temperatures causes less damages to the vegetation, reducing the available dead fuel for ignitions. Moreover the in Northern Italy, 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. This on the one hand decreases the human ignition and on other increases the availability of dry fuel in summer. The analysis with von Mises distribution has showed one big limitation, in particular for the clusters with bimodal patterns. When one season was too bigger than the other, the smaller season wasn't considered from the analysis. Therefore, when a fire season increases, this increase may be due simply to a decrease in the main season.

7.3 Impact of Recent Trends of Temperatures and Precipitation on Fires in Italy: From Local to National Scale

The results of this part have been divided into the following parts:

- Trend analysis;
- Spearman correlations;
- Linear multiple regression.

7.3.1 Trend analysis

Fire data trends have been analyzed both for Italy and each cluster in order to have some inferences on the evolution of fires through the years. Tables 7.7 and 7.8 show the slope of the regression line, the standard error, and the Mann-Kendall test for fire data for Burned Area (BA) and Fire Number (FN), respectively.

Considering all Italy, the BA annual trend has not shown significance for both tests from a statistical point of view. By analyzing the BA trend of each cluster (Table 7.7), it is evident that Clusters 1 and 6 do not show any significant trend for both tests, while Clusters 2 and 5 are significant only for the Mann-Kendall test, with $p<0.05$ and $p<0.001$, respectively; in these clusters, trends are negative. Finally, BA in Clusters 3 and 4 is significant for both tests, and shows a negative trend.

In regard to FN, it shows a negative significant trend for all Italy (Table 7.8) and for both tests ($p < 0.05$). Cluster 6 is the only that does not show any statistically significant trend for both tests, while Cluster 5 is significant only for the Mann-Kendall test ($p < 0.001$). The other clusters are significant for both tests.

The trends show that for the period 1985-2008 FN and BA are decreasing. This can be seen especially in Clusters 4 and 5 for both FN and BA.

As far as weather variable trends are concerned, minimum temperature (Tn) and maximum temperature (Tx) show a significant trend of increase (Tables 7.9 and 7.10), confirmed by the Mann-Kendall test in each cluster, with the exception of Cluster 1 for the trend of maximum temperature.

During the periods of study, temperature trends have showed an increase. On the other hand, results obtained from the Mann-Kendall test do not show a clear trend for rainfall (R) (Table 7.11), although only Cluster 1 has statistically significant values. In this cluster R is increasing.

Table 7.7 Least square linear fitting and Mann-Kendall results for BA trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-135.18	90.54	2.23	0.15	n.s	-1.96	+	-1.352
Cluster 2	-395.66	205.93	3.69	0.07	+	-2.46	*	-3.607
Cluster 3	-517.53	246.71	4.40	0.05	*	-2.85	**	-2.753
Cluster 4	-508.17	148.94	11.64	0.00	**	-3.55	***	-23.659
Cluster 5	-61.34	46.97	1.71	0.21	n.s	-4.14	***	-2.656
Cluster 6	-51.05	31.47	2.63	0.12	n.s	-1.31	n.s	-0.511
Italy	-2265.36	1614.32	1.97	0.17	n.s	-1.96	+	-5.554

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

Table 7.8 Least square linear fitting and Mann-Kendall results for FN trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-8.52	3.34	6.50	0.02	*	-2.55	*	-0.152
Cluster 2	-21.03	6.71	9.83	0.00	**	-2.70	**	-0.306
Cluster 3	-58.35	18.20	10.28	0.00	**	-2.85	**	-0.322
Cluster 4	-50.75	8.84	32.94	0.00	***	-4.14	***	-2.656
Cluster 5	-847.61	920.64	0.85	0.37	n.s	-3.55	***	-23.659
Cluster 6	138.80	555.97	0.06	0.81	n.s	-0.22	n.s	-1.309
Italy	-251.03	91.62	7.51	0.01	*	-2.26	*	-0.453

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

Table 7.9 Least square linear fitting and Mann-Kendall results for minimum temperature trend for Italy and for each cluster

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	0.08	0.04	4.43	0.05	*	2.65	**	0.05
Cluster 2	0.08	0.03	7.31	0.01	*	4.09	***	0.06
Cluster 3	0.11	0.03	10.75	0.00	**	3.89	***	0.09
Cluster 4	0.09	0.02	13.66	0.00		3.99	***	0.08
Cluster 5	0.08	0.03	7.53	0.01		3.99	***	0.08
Cluster 6	0.06	0.02	6.54	0.02		2.55	*	0.05
Italy	0.07	0.04	3.55	0.07	+	3.89	***	0.07

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

Table 7.10 Least square linear fitting and Mann-Kendall results for maximum temperature trend for Italy and for each cluster

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	0.02	0.02	1.53	0.23		1.17		0.02
Cluster 2	0.06	0.01	15.33	0.00	***	2.95	**	0.06
Cluster 3	0.05	0.01	15.81	0.00	***	3.25	**	0.06
Cluster 4	0.04	0.01	9.04	0.01		2.11	*	0.04
Cluster 5	0.04	0.01	10.80	0.00		2.11	*	0.04
Cluster 6	0.03	0.01	11.57	0.00		3.15	**	0.04
Italy	0.01	0.02	0.07	0.79		3.20	**	0.05

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

Table 7.11 Least square linear fitting and Mann-Kendall results for Rainfall trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	19.55	5.20	14.13	0.00	**	2.95	**	16.90
Cluster 2	8.53	5.12	2.78	0.11		1.51		4.21
Cluster 3	-1.01	3.23	0.10	0.76		-0.22		-0.83
Cluster 4	0.58	4.87	0.01	0.91		0.07		0.55
Cluster 5	-0.29	0.04	64.93	0.00		0.07		0.55
Cluster 6	-4.16	4.15	1.00	0.33		-1.36		-5.24
Italy	1.91	1.58	1.46	0.24		0.92		3.07

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

7.3.2 Spearman's correlations

In order to analyze the relationships between fire and weather, Spearman's correlations between meteorological variables and fire variables have been computed at national and cluster level by using monthly, seasonal and yearly periods. The procedure of correlation establishs that the best results have been obtained on a monthly basis.

All the correlations have been highly significant with $p<0.001$, with the exception of Cluster 4. In this cluster, only BA is significantly correlated with Tx with $p< 0.05$ (Table 7.12)

Considering all Italy, relative humidity (RH) is the most correlated variable for both FN and BA, which is followed by Tx, positively correlated with fire occurrence.

FN and BA in clusters with marked summer seasonality (especially Cluster 5) show better correlation with Tx (Spearman's Rho >0.83) and Tn (Spearman's Rho >0.81).

In addition, Clusters 5 and 6 show proportional negative correlation with rainfall and relative humidity.

The worst correlation has been found in Cluster 4, where no correlation is above 0.60.

Clusters 1 and 2 have a good correlation with rainfall and the correlations shown are inversely proportional to FN and BA especially for Cluster 1 with relative humidity .

The best correlation of Cluster 3 was between FN and relative humidity.

To better analyze the correlation between weather variables and fire, monthly Spearman's correlation has been calculated by setting the focus for each season.

Analyzing the correlation calculated for all Italy, in winter (Figure 7.14) R is highly significant correlated with both FN and BA (Spearman's Rho > 0.70). Tn shows a negatively significant correlation with both FN and BA.

During spring (Figure 7.14), for all Italy, the most important variable is Tn, that is proportionally inverse to fire occurrence. In summer (Fig. 7.14), this trend changes and Tn is directly correlated with FN, but the most important variable is Tx, for both FN and BA. A similar trend can be found in autumn (Figure 7.14).

At cluster level, during winter Tn shows a negatively significant correlation with fire occurrence, with the exception of Cluster 1, where the best Spearman's Rho is between RH and both FN and BA. The other clusters, with the exception of Cluster 5, show a good correlation with R (Rho of Spearman >0.60 for FN and also BA).

During spring (Figure 7.14), in Clusters 1 and 2, both Tx and Tn are negatively correlated with FN and BA, as well as R and RH, while the best correlation has been found between Tn and both FN and BA. In the other clusters, the main variable is R. Summer has shown a different trend (Figure 7.14). The best results have been indeed found in those clusters having a peak of fire activity during this period, particularly Clusters 5 and 6. The most correlated variable is Tx (Rho of Spearman > 0.90) for both clusters and for both FN and BA. In Clusters 1 and 2, good correlations with RH and R have been found. Regarding autumn (Figure 7.14), the correlations of clusters are very similar to those of summer, with a Rho of Spearman generally lower than that of summer.

The results show the importance of R for fire activity. Moreover, the temperatures show different correlations regarding the cluster and season considered. In particular, Tn shows an inverse correlation during spring in the clusters with winter fires, and a direct correlation during summer in the clusters with summer fires.

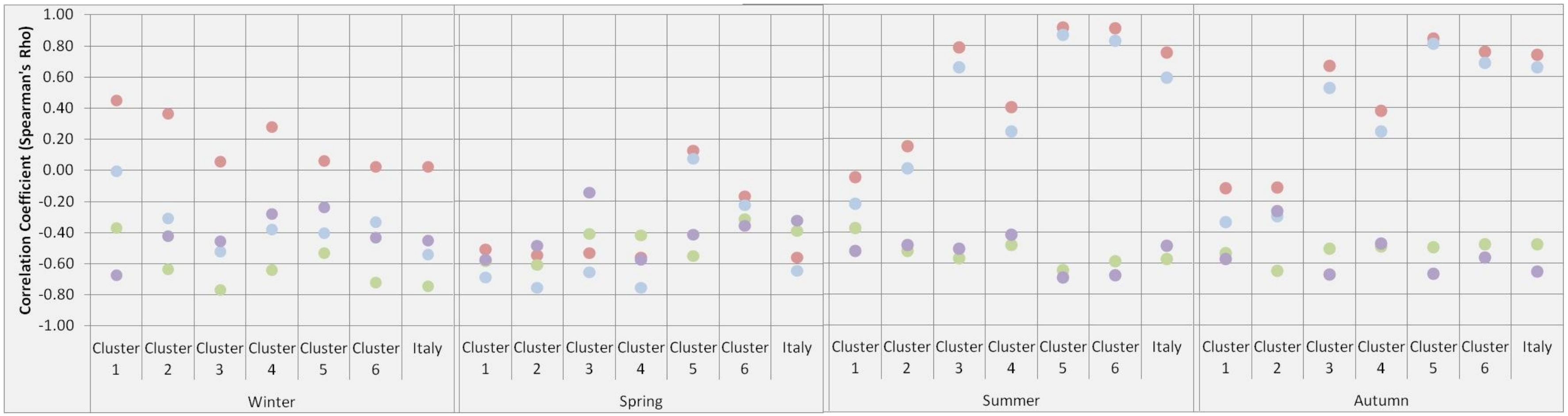
Table 7.12 Spearman's correlation between BA, FN and selected meteorological variables (monthly mean).

Area	Burned area				Fire Number			
	R	RH	Tx	Tn	R	RH	Tx	Tn
Cluster 1	-0.54***	-0.58***	-0.32***	-0.44***	-0.52***	-0.66***	-0.21***	-0.34***
Cluster 2	-0.62***	-0.33***	-0.30***	-0.43***	-0.60***	-0.46***	-0.23***	-0.36***
Cluster 3	-0.59***	-0.61***	0.44***	0.31***	-0.59***	-0.69***	0.49***	0.35***
Cluster 4	-0.48***	-0.44***	-0.13*	-0.24***	-0.57***	-0.48***	n-s.	n.s.
Cluster 5	-0.63***	-0.74***	0.83***	0.78***	-0.63***	-0.77***	0.86***	0.81***
Cluster 6	-0.65***	-0.65***	0.74***	0.68***	-0.66***	-0.67***	0.73***	0.67***
Italy	-0.58***	-0.64***	0.57***	0.48***	-0.59***	-0.69***	0.64***	0.54***

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

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

Burned Area



Fire Number

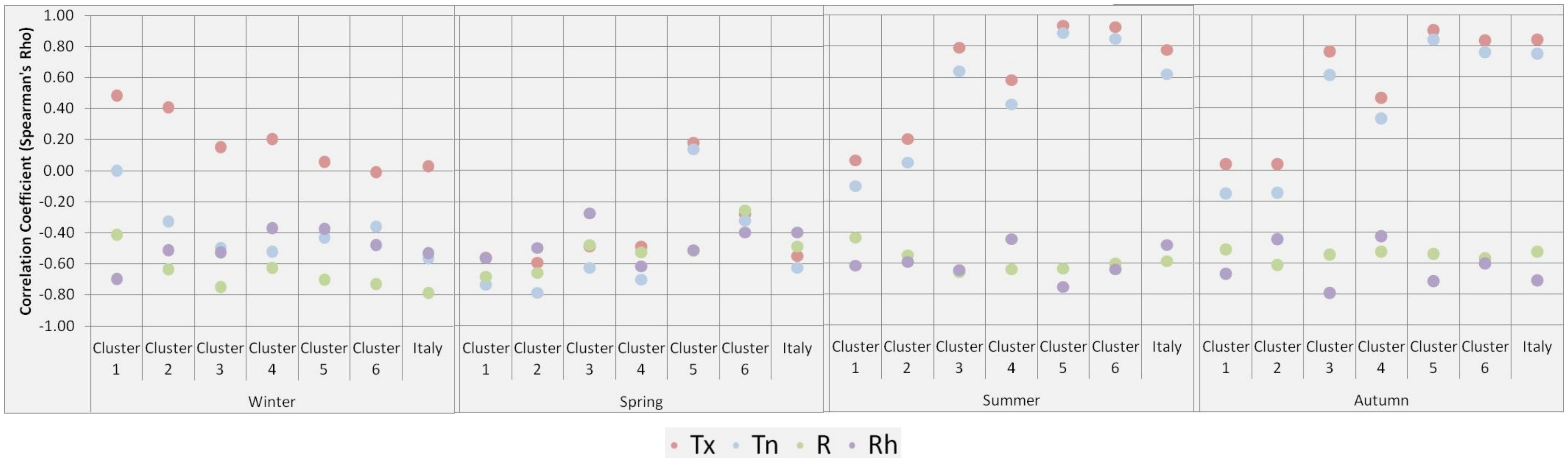


Fig 7.14 Spearman's correlation between fire occurrence (FN and BA) and weather variables for each season (monthly mean). *Notes: x axis represents the Rho of Spearman and the significant value is of 0.05, 0.01 and 0.001 for value of Rho above 0.25, 0.30 and 0.40 respectively.*

7.3.3 Multiple Linear Regression between weather and fire occurrence (monthly basis)

Tables 7.13 and 7.14 present results from multiple regressions of the monthly number of fires and the monthly area burned for the six Clusters across Italy. All variables listed in Table 7.12 are available for stepwise regression and only the significant terms are kept. As far as Italy is concerned, the obtained model shows that the most important predictor of FN and BA is RH. Explained variance by the equation is 64% for FN and 56% for BA. Tn is inversely proportional to fire occurrence.

The relevance of variables is different, considering clusters with winter or summer seasonality (Tables 7.13 and 7.14).

For instance, in Cluster 1, RH is the main variable affecting both FN and BA, while in Cluster 2 the variable that better explains variance is R; for both clusters, explained variance is over 50%. In Cluster 3 the explained variance is 62% for FN and 52% for BA. In this area the most impotrtant variable is RH for both FN and BA. The most influencing variable in Cluster 4 is R for FN and RH for BA, and explained variance is the lowest observed, 36% and 37% for FN and BA, respectively. In Cluster 5, stepwise regression shows that the first variable is Tx, with a r^2 of 81% and 77% for FN and BA, respectively. Cluster 6 shows a similar trend, with Tx as the most important variable, and explained variance over 65% for both FN and BA.

Model Error Analysis (MEA) is performed by using the equation obtained with multiple linear regressions. Residual analysis for all Italy (Figure 7.15 a, b) shows that the best prediction is in July, while the worst predictions are in May. The model of Cluster 1 (Figure 7.16 a, b) shows that for the whole year the square of the difference between data observed and data predicted is very high, and the best results have been found for FN in July and November. Cluster 2 shows better results than Cluster 1 (Figure 7.17 a, b) and the best results have been found in July, November and February, and the worst in December. The results of FN residual analysis are better than BA. Cluster 3 shows good results for the whole year (Figure 7.18 a, b) and the best are in July for FN analysis, and in February and April for BA analysis. Cluster 4 has a lower difference between data observed and data predicted in April and July, and only for FN analysis.

Clusters 5 and 6 (Figure 7.19 a, b, 7.20 a, b) show that residual analysis is very low in the summer period and the worst prediction is in May.

Each cluster generally shows that during the fire periods the regression model has a good performance, but in the pre-fire period, residual analysis shows a higher difference between data predicted and data observed.

To better analyze the influence of weather variables on fire, multiple linear regression has been calculated per season.

Table 7.13 Explained variance (R^2) and variables selected, in order of importance by multiple linear regression

Cluster	***Significan variables***	***R^2***	N	***P***
Cluster 1	RH, Tn, Tx	0.54	288	***
Cluster 2	R, RH, Tn, Tx	0.57	288	***
Cluster 3	RH, R, Tx, Tn	0.62	288	***
Cluster 4	R, RH	0.36	288	***
Cluster 5	Tx, R, RH	0.81	288	***
Cluster 6	Tx, RH, R	0.68	288	***
Italy	RH, Tx, R, Tn	0.64	288	***

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

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

Table 7.14 Explained variance (R^2) and variables selected, in order of importance by multiple linear regression

Cluster	Significan variables	***R^2***	N	***P***
Cluster 1	RH, Tn, Tx	0.54	288	***
Cluster 2	R, Tn, Tx, RH	0.54	288	***
Cluster 3	RH, R, Tx, Tn	0.52	288	***
Cluster 4	RH, R, Tn, Tx	0.37	288	***
Cluster 5	Tx,R, RH	0.77	288	***
Cluster 6	Tx, RH,R	0.67	288	***
Italy	RH, R, Tx,Tn	0.56	288	***

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

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

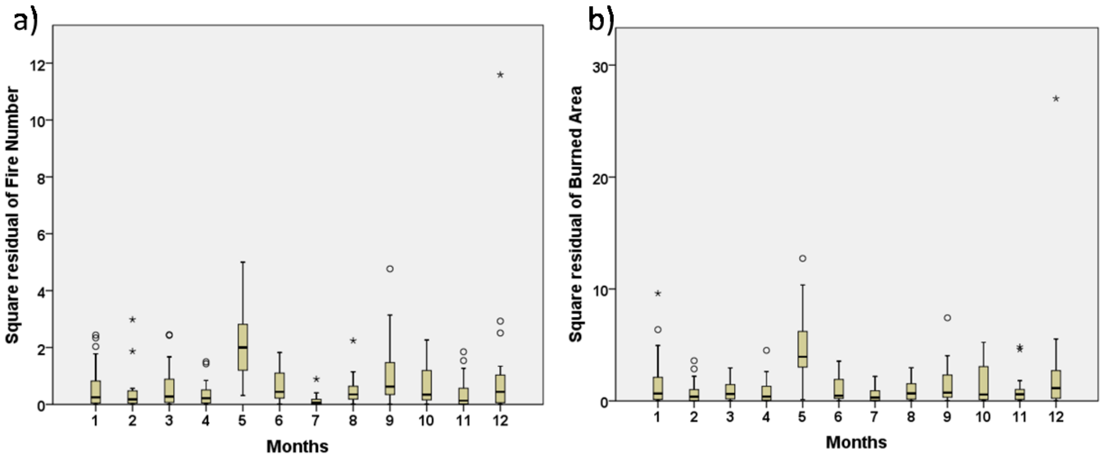


Figure 7.15 Model Error Analysis of Linear Multiple Regression for Italy a)FN b) BA.

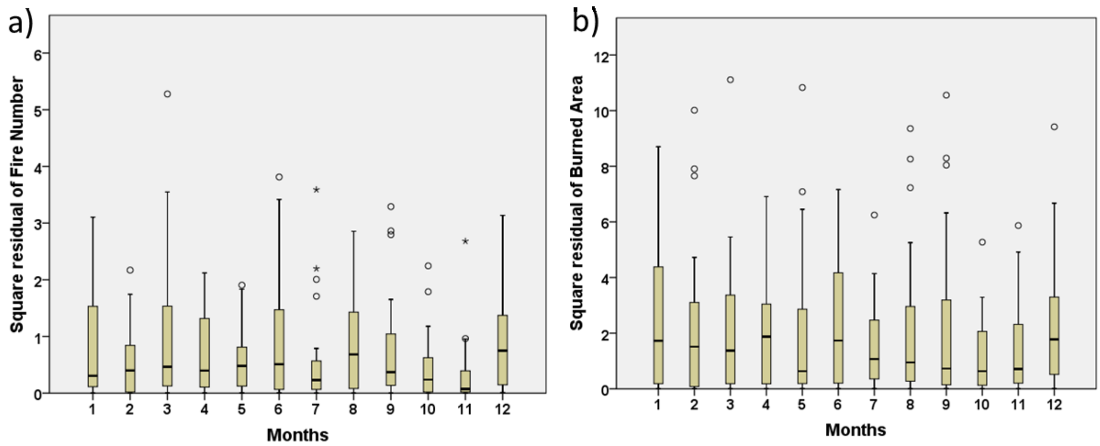


Figure 7.16 Model Error Analysis of Linear Multiple Regression for Cluster 1 a)FN b) BA.

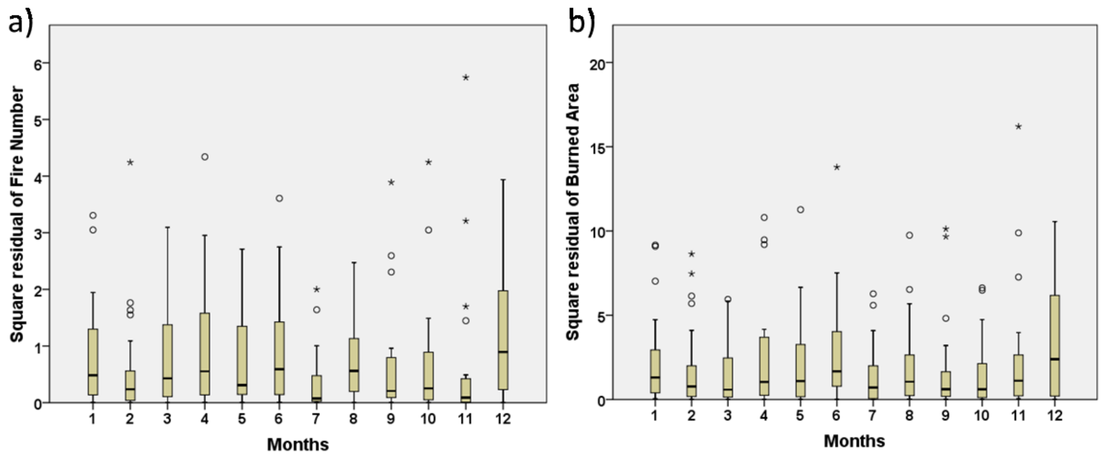


Figure 7.17 Model Error Analysis of Linear Multiple Regression for Cluster 2 a)FN b) BA.

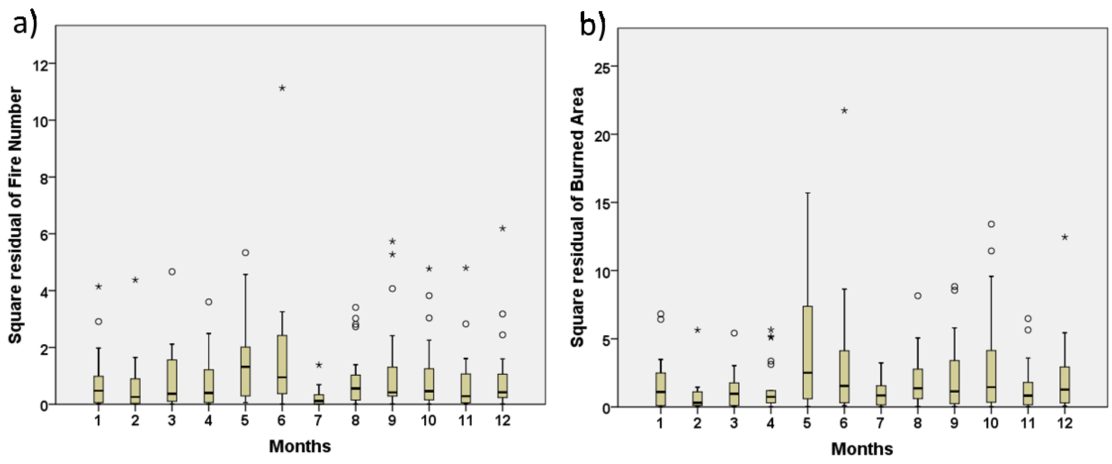


Figure 7.18 Model Error Analysis of Linear Multiple Regression for Cluster 3 a)FN b) BA.

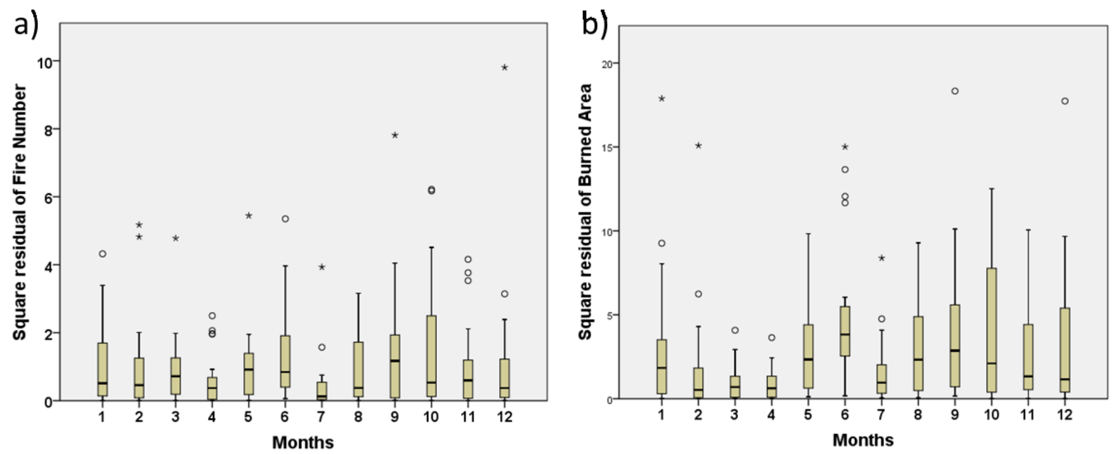


Figure 7.19 Model Error Analysis of Linear Multiple Regression for Cluster 4 a)FN b) BA.

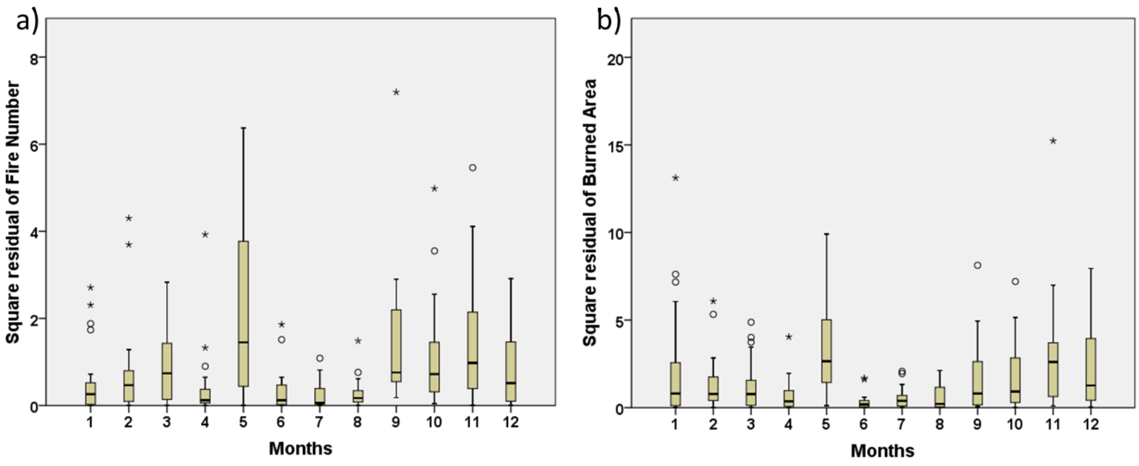
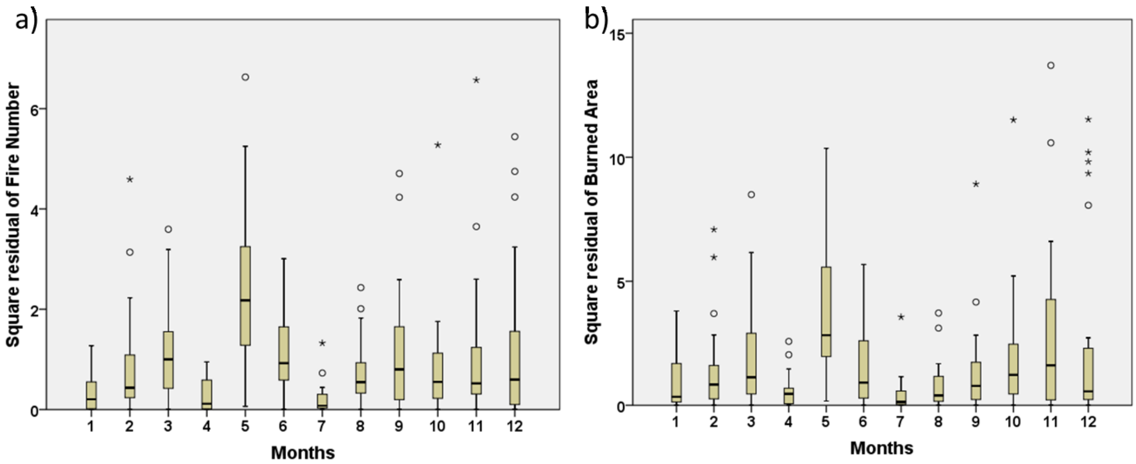


Figure 7.20 Model Error Analysis of Linear Multiple Regression for Cluster 5 a)FN b)



BA.Figure 7.21 Model Error Analysis of Linear Multiple Regression for Cluster 6 a)FN b) BA.

7.3.4 Multiple Linear Regression between weather and fire occurrence for each season (monthly mean)

Tables 7.15-7.22 shows linear multiple regressions calculated for all Italy and for each cluster by using monthly mean, per season. For all Italy, in winter (Tables 7.15, 7.16), the most important variable in the equation is R, followed by Tn and Tx. R and Tx have a negative angular coefficient; explained variance is 73% and 67% for FN and BA, respectively. In spring (Tables 7.17, 7.18), the first variable considered by multiple regression is Tn, for both FN and BA, with an inversely proportional relationship to fire occurrence. In summer (Tables 7.19, 7.20), the first parameter of equation is Tx, with a R^2 near to 70% for FN and over 60% for BA. Finally, in autumn (Tables 7.21, 7.22), analysis has found the best results of all Italy. The R^2 of FN is indeed 80%, and the first variables in the equation is Tx, the same result with BA as dependent variable, but this model presents a lower R^2 than the equation with fire number. In Clusters 1 and 2, the best results have been found in winter and spring. Explained variance by RH ranges from 61% to 72 % for BA and from 56% to 63% for FN, depending on the cluster and the season, and all regressions are highly significant (P <0.0001). Cluster 2 (Table 7.14) has a similar trend to that of Cluster 1. The best results have been found in winter (62% and 56% of explained variance for FN and BA, respectively) and spring (70% and 67% of explained variance for FN and BA, respectively). The analyis of the equations obtained for Cluster 3 show that for each season explanatory variables change (Table 7.14), but R^2 is generally good and explained variance ranges from 57% to 70%. Cluster 4 (Table 7.14) shows a similar trend to that of Clusters 1 and 2, with a good R^2 in winter and spring. The most important variables in winter is R, while Tn is in Spring.

Finally, in Clusters 5 and 6 (Table 7.14), the best results are found in summer and autumn. The most important variable during these periods is Tx and explained variance ranges from 64% to 88%.

Table 7.15 Winter fire number explained variance (R^2) and variables selected, in order of importance by multiple linear regression

Cluster	***Significan variables***	R^2	N	***P***
Cluster 1	RH, Tx, Tn	0.61	72	***
Cluster 2	R, RH, Tx, Tn	0.62	72	***
Cluster 3	RH, Tn, Tx	0.69	72	***
Cluster 4	R, Tn, Tx	0.62	72	***
Cluster 5	R, Tn, Tx, RH	0.62	72	***
Cluster 6	R, RH	0.58	72	***
Italy	R, Tn, Tx	0.73	72	***

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

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

Table 7.16 Winter burned area explained variance (R^2) and variables selected, in order of importance by multiple linear regression

Cluster	***Significan variables***	R^2	N	***P***
Cluster 1	RH, Tx, Tn	0.56	72	***
Cluster 2	R, Tx,Tn	0.56	72	***
Cluster 3	R, Tn, Tx	0.63	72	***
Cluster 4	R, Tn,Tx	0.49	72	***
Cluster 5	R, Tn, Tx	0.40	72	***
Cluster 6	R, RH	0.50	72	***
Italy	R, Tn, Tx	0.67	72	***

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

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

Table 7.17 Spring fire number explained variance (R^2) and variables selected, in order of importance by multiple linear regression

Cluster	***Significan variables***	R^2	N	***P***
Cluster 1	Tn, RH,R	0.719	72	***
Cluster 2	Tn, RH	0.699	72	***
Cluster 3	Tn, R	0.627	72	***
Cluster 4	Tn, RH, Tx	0.708	72	***
Cluster 5	RH, R, Tx	0.388	72	***
Cluster 6	RH, Tn, R	0.481	72	***
Italy	Tn, R, RH	0.672	72	***

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

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

Table 7.18 Spring burned area explained variance (R^2) and variables selected, in order of importance by multiple linear regression

Cluster	***Significan variables***	***R^2***	N	***P***
Cluster 1	Tn, RH	0.634	72	***
Cluster 2	Tn, Tx	0.675	72	***
Cluster 3	Tn, R	0.573	72	***
Cluster 4	Tn, RH, Tx	0.720	72	***
Cluster 5	R, RH, Tx	0.314	72	***
Cluster 6	RH, Tn, R	0.379	72	***
Italy	Tn, R, RH	0.612	72	***

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

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

Table 7.19 Summer fire number explained variance (R^2) and variables selected, in order of importance by multiple linear regression

Cluster	***Significan variables***	***R^2***	N	***P***
Cluster 1	RH, R	0.399	72	***
Cluster 2	RH, R	0.378	72	***
Cluster 3	Tx, Tn, R	0.624	72	***
Cluster 4	R, Tx, Tn, RH	0.464	72	***
Cluster 5	Tx, RH	0.880	72	***
Cluster 6	Tx, RH	0.873	72	***
Italy	Tx	0.690	72	***

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

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

Table 7.20 Summer burned area explained variance (R^2) and variables selected, in order of importance by multiple linear regression

Cluster	***Significan variables***	R^2	N	***P***
Cluster 1	RH, Tn	0.356	72	***
Cluster 2	R, RH	0.306	72	***
Cluster 3	Tx, Tn	0.578	72	***
Cluster 4	R, RH	0.251	72	***
Cluster 5	Tx, RH	0.869	72	***
Cluster 6	Tx, RH	0.863	72	***
Italy	Tx, R	0.642	72	***

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

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

Table 7.21 Autumn fire number explained variance (R^2) and variables selected, in order of importance by multiple linear regression

Cluster	***Significan variables***	R^2	N	***P***
Cluster 1	RH	0.466	72	***
Cluster 2	RH, Tn	0.459	72	***
Cluster 3	RH, Tx, R	0.761	72	***
Cluster 4	R, Tx, RH, Tn	0.477	72	***
Cluster 5	Tx, RH	0.837	72	***
Cluster 6	Tx, RH	0.787	72	***
Italy	Tx, RH, R	0.801	72	***

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

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

Table 7.22 Autumn burned area explained variance (R^2) and variables selected, in order of importance by multiple linear regression

Cluster	***Significan variables***	R^2	N	***P***
Cluster 1	RH, Tn	0.452	72	***
Cluster 2	R, Tn	0.451	72	***
Cluster 3	Tx, R	0.576	72	***
Cluster 4	R, Tx, RH	0.370	72	***
Cluster 5	Tx, RH	0.720	72	***
Cluster 6	Tx, RH	0.640	72	***
Italy	Tx, RH, R	0.616	72	***

7.3.5 Discussion

The main objective of the present study is to analyze the relationship between fire occurrence (number of fires and burned area) and weather conditions during the last decades (1985-2008). To achieve this aim, firstly we have focused our analysis on establishing weather significant trends for all main weather variables and fire occurrence; secondly, we have determined the relationships between fire occurrence and weather conditions by using correlation and multiple linear regressions. The analysis has been performed at annual, seasonal, and monthly level and from national to local scale.

Several studies on fire occurrence in Southern Europe, especially in the Mediterranean Basin, show that fire activity has increased (Pausas 2004; Moreno et al. 1998) during the last decades. Our study shows different results for Italy, highlighting an opposite trend, especially for burned area. Similar results have been found by Lovreglio et al. (2012), by evidencing that during last two decades (1981-2010) the phenomenon of wildfires in Italy has been characterized by a decreasing tendency. Our study has also showed that different areas (namely the piro-climatic regions illustrated in paragraph 5.1) have been undergoing different trends. While in northern areas a marked decreasing trend in both number of fires and burned area has been detected, southern regions (Clusters 5 and 6) have not exhibited a unique pattern, unless similar climatic conditions.

Temperatures have clearly increased during the study period. At regional level, the increase is about 0.01°C/year for maximum temperature, and 0.07°C for minimum temperature. Maximum temperature trend results are similar to the change observed in the province of Castilla y León (Spain) (0.02°C/year, Del Rio et al., 2007). Annual increases have been found in Italy by Brunetti et al. (2000) and Ventura et al. (2002).

As far as rainfall is concerned, our results have shown an increasing pattern for Cluster 1. Similar finding has been found in the French Alps by Durand et al. (2007). The others areas have not shown a clear pattern even though southern areas records have revealed a negative trend (not significant). Other studies have highlithed a decreasing trend in Central and Southern Italy at the end of the 20th century (Polemio and Casarano 2004; Brunetti et al., 2002; Delitala et al. 2000).

Concerning the analysis of the relationships between weather and fire, promising results have been obtained at local and seasonal level. Considering all Italy, both fire number and burned area are highly correlated with rainfall on an annual basis, as expected.

At seasonal level, it is also interesting to notice that minimum temperature is inversely proportional to fire occurrence in clusters showing winter-early spring seasonality. This could be explained by two main factors: firstly, low temperature and especially frost may increase fuel load, as suggested by Turco et al. (2012); secondly, the occurrence of foehn wind (a typical dry down-slope wind that occurs in the lee of the Alps) at low and moderate altitudes (Zumbrunnen et al. 2009). Recent studies have highlighted that low temperatures can damage vegetation and make it particularly dry, especially in conditions with low rainfall (Zumbrunnen et al. 2009) and with dry winds (Reinhard et al., 2005). This situation can be particularly dangerous in early spring, during the vegetative resumption. Considering the complexity and variability found in areas with winter seasonality, the dynamics of fire in these areas need more specific surveys to improve the knowledge of drivers.

In this study, we have developed several models in order to estimate fire occurrence on a seasonal basis and at cluster level. Maximum temperature and relative humidity appear to be the best predictors of fire activity. In particular, as far as summer seasonality clusters are concerned, our regression models have explained up to 85% of the variance of both fire number and burned area. Similarly, Carvalho et al. (2008) have revealed that relative humidity and maximum temperature explain the majority of numbers of fires in Portugal.

7.4 Fire danger in Italy

The results of this section are presented in the following parts:

- Variability of fire danger across Italy;
- Trend analysis of fire danger in Italy;
- Spearman correlation;
- Multiple linear regressions.

7.4.1 Description of fire danger across Italy

Mean and maximum values of the FWI and KBDI are shown in Tables 7.23 and 7.24. . With respect to the mean values, the cluster with the highest FWI value is Cluster 5, the lowest is Cluster 1. Analysing the submodules, the highest and lowest values have always been found in the Cluster 5 and Cluster 1, respectively. The KBDI has shown the same patterns of FWI subindexes.

In Table 7.16, the maximum indexes values during the study period are shown. The highest FWI value is in Cluster 5, and the lowest is in Cluster 1, followed by Cluster 4. In the FWI submodules, there are the same patterns of the FWI, with the exception of the BUI and DC, where Cluster 6 is the one with the highest value of these submodules.

Table 7.17 shows the number of days above the chosen threshold. The classification of clusters as a result of fire danger is generally the same with mean values, but considering the DMC, the Clusters 5 and 6 have had high dangerous conditions for more than four months; this pattern has been confirmed for Cluster 5 even with DC, while FFMC and ISI have not shown considerable differences.

Figures 7.21, 7.22, 7.23 and 7.24 show the mean values of FWI and KBDI across Italy and the number of days above the chosen thresholds. The areas with the high fire danger are localized in Southern Italy (particularly in the two main islands), and in the southeast part of the Italian peninsula.

The results show that the clusters with the highest fire danger are Clusters 5 and 6, localized in Southern Italy. Moreover, the clusters with the lowest fire danger are Clusters 1 and 2, localized in the Alpine area.

Table 7.23 Mean annual values of FWI and its submodules, and KBDI for each piro-climatic area.

Cluster	FFMC	DMC	DC	ISI	BUI	FWI	KBDI
1	70	15	135	3	21	3	70
2	76	30	192	4	40	5	77
3	76	38	263	4	51	5	95
4	76	37	238	4	49	5	78
5	79	61	459	4	83	6	126
6	77	48	316	4	63	5	95

Table 7.24 Maximum annual values FWI and its submodules, and KBDI for each piro-climatic area.

Cluster	FFMC	DMC	DC	ISI	BUI	FWI	KBDI
1	96	2301	1077	46	249	24	197
2	97	2668	1417	72	699	29	199
3	98	4412	2008	63	703	34	203
4	97	6953	2170	70	680	28	202
5	100	10656	2083	87	967	40	203
6	99	9785	2937	76	1015	36	203

Table 7.25 Annual numbers of days above of the thresholds value of FWI and its submodules, and KBDI for each piro-climatic area.

Cluster	FFMC92	DMC40	DC500	ISI16	BUI60	FWI19.9	KBDI150
1	0	30	10	3	25	0	22
2	2	95	27	7	82	1	27
3	4	113	59	7	106	2	66
4	3	112	55	6	102	1	44
5	5	157	144	7	160	4	144
6	3	126	93	5	123	2	84

Notes: To homogenize the difference in the surface between clusters the numbers of days has been divided for the numbers of grid of each cluster.

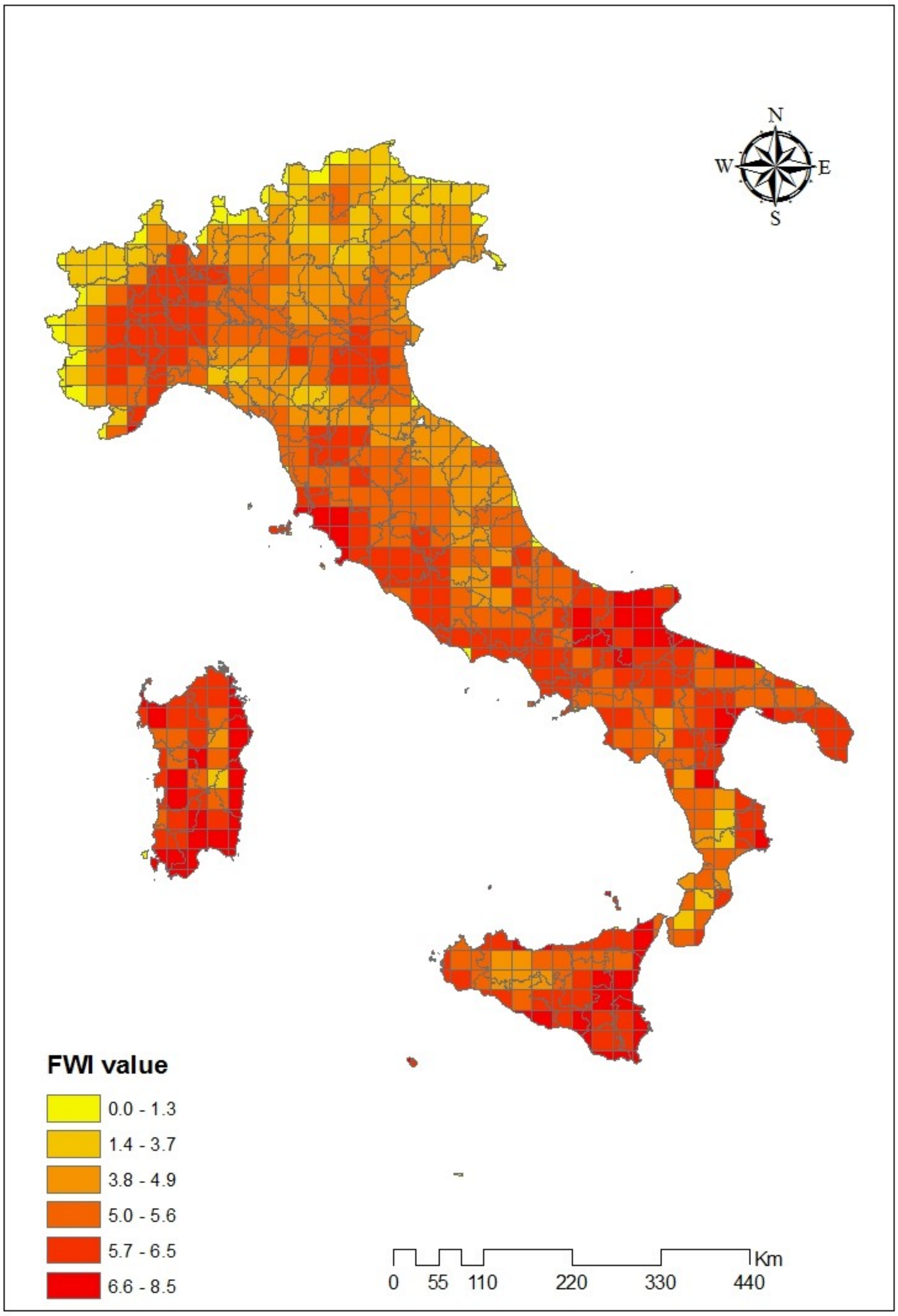


Figure 7.21 Mean annual values of FWI across Italy (1985-2008).

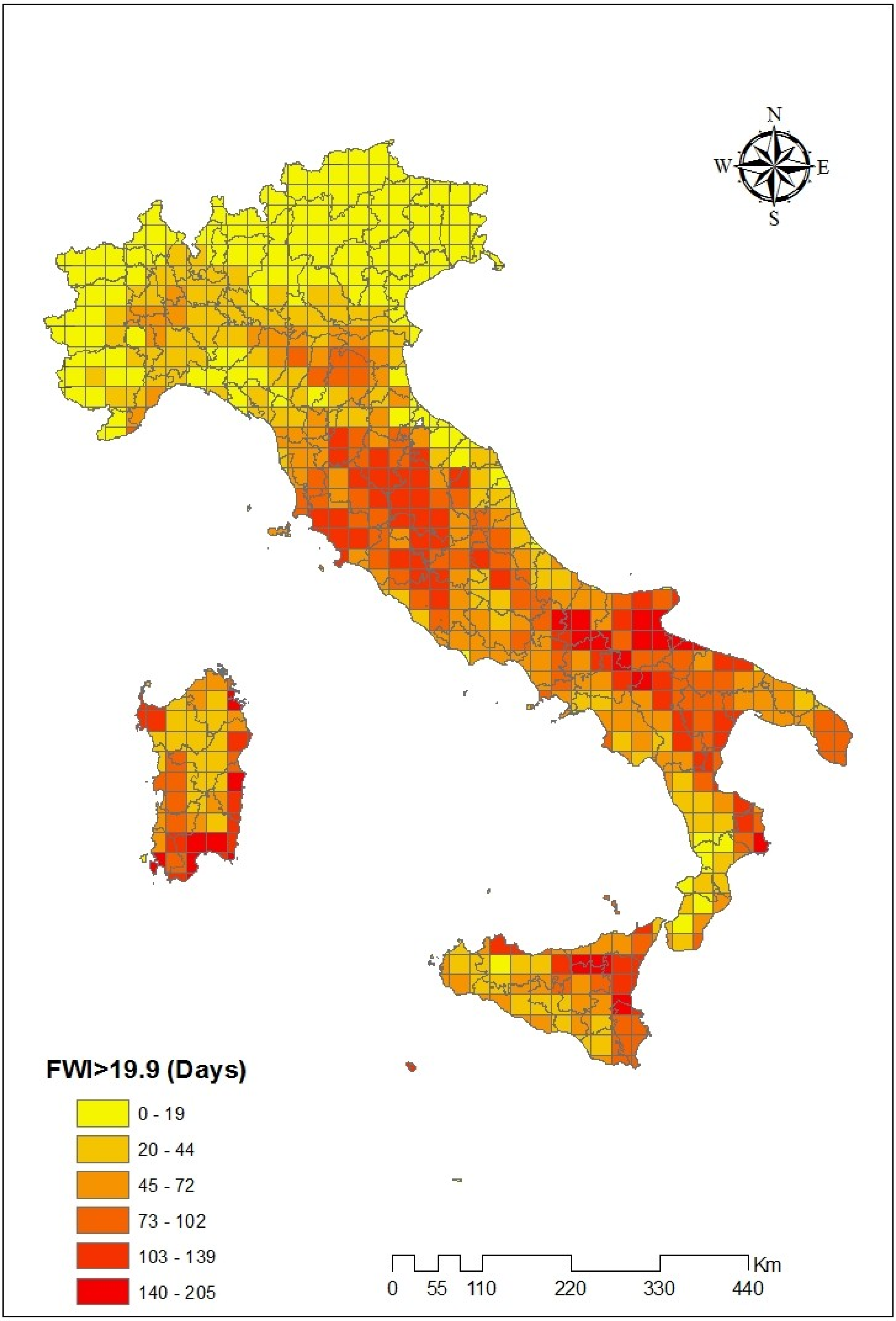


Figure 7.22 Number of days above 19.9 value of FWI across Italy (1985-2008).

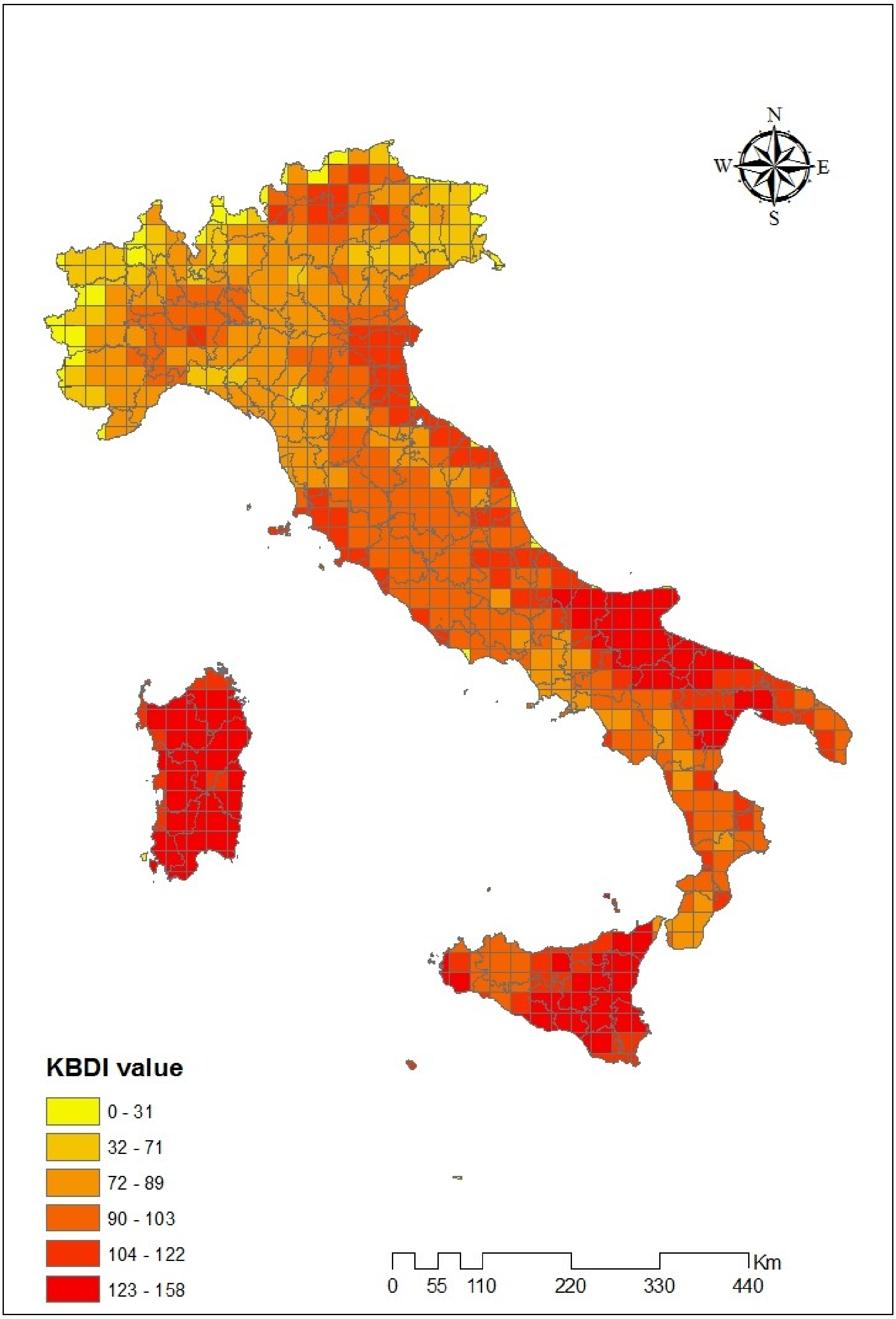


Figure 7.23 Mean annual values of KBDI across Italy (1985-2008).

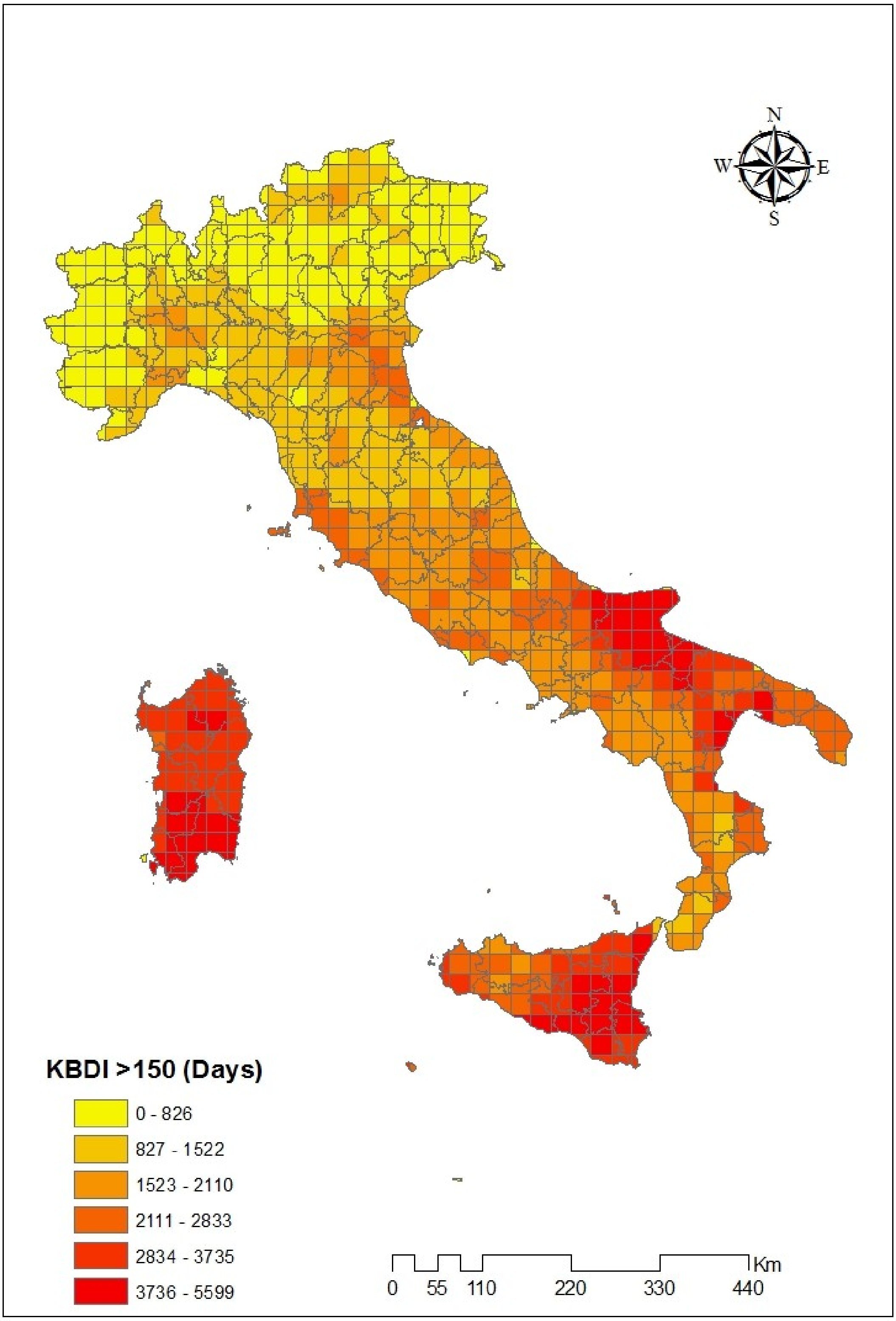


Figure 7.24 Number of days above 150 value of KBDI across Italy (1985-2008).

7.4.2 Trend analysis of fire danger in Italy

In this paragraph the trend analysis results are shown. For each index and indicator (mean and maximum value, and number of days above the threshold), only the most significant results are shown. Results are summarized in Tables 7.26-7.38.

The analysis generally revealed a positive trend, in particular for maximum values of the tested indexes and submodules. The trend of maximum value of FFMC is significant and positive for each cluster and for all Italy, with the exception of Clusters 1 and 6. DMC trend does not show a significant trend, because it shows the mean value trend in Cluster 4 only for parametric test, and the maximum value trend in Cluster 5 for all Italy only for non-parametric tests. DC shows a significant trend for mean and maximum values only for Cluster 1. ISI shows a significant positive trend with the exception of Cluster 1. The BUI trend is significant only for maximum values: the trend is the same of the maximum value of FFMC. FWI shows a significant trend for maximum values and for the number of days above the threshold of 19.9. Finally, KBDI has a trend only for the mean value and only for Cluster 1: this trend shows that fire danger is decreasing.

Trend analysis has shown that fire danger has, on average, increased during the study period, in particular for Clusters 5 and 3. The only cluster where the trend is decreasing is Cluster 1.

Table. 7.26 Least square linear fittin and Mann-Kendall results for maximum value of Fine Fuel Moisture Content (maxFFMC) trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-0.06	0.03	4.40	0.05	n.s.	-1.86	+	-0.04
Cluster 2	0.13	0.03	22.60	0.00	***	3.05	**	0.13
Cluster 3	0.16	0.03	28.98	0.00	***	3.89	***	0.16
Cluster 4	0.14	0.02	34.74	0.00	***	4.24	***	0.15
Cluster 5	0.10	0.03	8.97	0.01	**	2.55	*	0.10
Cluster 6	0.05	0.04	1.55	0.23	n.s.	1.22	n.s.	0.07
Italy	0.10	0.03	8.34	0.01	**	2.31	*	0.10

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

Table 7.27 Least square linear fittina and Mann-Kendall results for number of day above the value of 92 of Fine Fuel Moisture Content (FFMC92) trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-0.09	0.76	0.01	0.91	n.s.	-1.29	n.s.	-0.47
Cluster 2	12.74	2.55	25.03	0.00	***	4.39	***	8.55
Cluster 3	89.48	21.91	16.67	0.00	***	3.75	***	58.38
Cluster 4	3.36	1.46	5.34	0.03	*	3.46	***	2.00
Cluster 5	65.72	15.56	17.84	0.00	***	3.15	**	54.33
Cluster 6	14.95	6.44	5.39	0.03	*	1.71	+	8.93
Italy	186.16	43.17	18.59	0.00	***	3.80	***	121.79

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

Table 7.28 Least square linear fittin and Mann-Kendall results for Duff Moisture Code (DMC) trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-0.20	0.12	2.66	0.12	n.s.	-1.76	+	-0.21
Cluster 2	0.10	0.19	0.31	0.59	n.s.	0.32	n.s.	0.07
Cluster 3	0.42	0.26	2.61	0.12	n.s.	1.31	n.s.	0.45
Cluster 4	0.69	0.30	5.29	0.03	*	1.17	n.s.	0.26
Cluster 5	0.36	0.32	1.27	0.27	n.s.	0.87	n.s.	0.32
Cluster 6	0.04	0.37	0.01	0.90	n.s.	-0.17	n.s.	-0.06
Italy	0.27	0.24	1.34	0.26	n.s.	1.12	n.s.	0.30

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

Table 7.29 Least square linear fittin and Mann-Kendall results for Drought Code (DC) trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-4.72	1.22	14.98	0.00	***	-3.10	**	-4.69
Cluster 2	-2.89	1.68	2.96	0.10	+	-1.81	+	-3.29
Cluster 3	1.22	1.86	0.43	0.52	n.s.	0.00	n.s.	0.02
Cluster 4	2.48	2.19	1.28	0.27	n.s.	0.77	n.s.	2.24
Cluster 5	-3.63	2.15	2.85	0.11	n.s.	-1.56	n.s.	-3.83
Cluster 6	0.16	1.80	0.01	0.93	n.s.	-0.37	n.s.	-0.85
Italy	-1.28	1.42	0.81	0.38	n.s.	-1.56	n.s.	-2.04

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

Table 7.30 Least square linear fittin and Mann-Kendall results for maximum value of Drought Code (MaxDC) trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-8.96	4.96	3.26	0.08	+	-2.26	*	-8.45
Cluster 2	13.98	5.54	6.36	0.02	*	1.61	n.s.	10.66
Cluster 3	10.01	9.55	1.10	0.31	n.s.	0.72	n.s.	8.79
Cluster 4	21.70	9.15	5.63	0.03	*	1.12	n.s.	5.41
Cluster 5	4.88	6.79	0.52	0.48	n.s.	0.57	n.s.	4.83
Cluster 6	14.26	11.84	1.45	0.24	n.s.	0.27	n.s.	4.08
Italy	14.58	10.09	2.09	0.16	n.s.	0.62	n.s.	6.43

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

Table 7.31 Least square linear fittin and Mann-Kendall results for Initial Spred Index (ISI) trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-0.01	0.01	0.33	0.57	n.s.	-0.32	n.s.	0.00
Cluster 2	0.04	0.01	9.74	0.00	**	2.80	**	0.04
Cluster 3	0.04	0.01	11.59	0.00	**	2.85	**	0.04
Cluster 4	0.03	0.01	6.29	0.02	*	2.16	*	0.02
Cluster 5	0.04	0.01	15.26	0.00	***	2.75	**	0.04
Cluster 6	0.02	0.01	4.36	0.05	*	1.27	n.s.	0.01
Italy	0.03	0.01	12.41	0.00	**	2.75	**	0.03

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

Table 7.32 Least square linear fittin and Mann-Kendall results for maximum value of Initial Spread Index (MaxISI) trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-0.31	0.20	2.32	0.14	n.s.	-1.61	n.s.	-0.30
Cluster 2	0.49	0.27	3.32	0.08	+	1.91	+	0.40
Cluster 3	0.86	0.24	12.51	0.00	**	2.85	**	0.88
Cluster 4	0.49	0.25	4.00	0.06	+	2.16	*	0.32
Cluster 5	1.36	0.30	20.65	0.00	***	3.60	***	1.07
Cluster 6	0.56	0.25	4.99	0.04	*	1.81	+	0.30
Italy	1.36	0.30	20.36	0.00	***	3.35	***	0.96

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

Table 7.33 Least square linear fittin and Mann-Kendall results for number of day above the value of 16 of Initial Spread Index (ISI16) trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	0.03	1.76	0.00	0.99	n.s.	-0.02		-0.03
Cluster 2	14.93	3.82	15.28	0.00	***	3.15	**	14.92
Cluster 3	59.89	14.24	17.70	0.00	***	2.75	**	54.90
Cluster 4	3.80	1.42	7.11	0.01	*	2.55	*	3.23
Cluster 5	49.96	11.52	18.82	0.00	***	3.35	***	44.86
Cluster 6	13.37	5.35	6.25	0.02	*	1.51	n.s.	9.20
Italy	141.98	31.95	19.75	0.00	***	3.25	**	115.43

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

Table 7.34 Least square linear fittin and Mann-Kendall results for Build Up Index (BUI) trend for Italy and for each cluster.

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

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-0.38	0.17	4.83	0.04	*	-1.86	+	-0.39
Cluster 2	-0.04	0.27	0.02	0.88	n.s.	-0.22	n.s.	-0.08
Cluster 3	0.44	0.34	1.68	0.21	n.s.	1.17	n.s.	0.49
Cluster 4	0.77	0.39	4.01	0.06	+	1.02	n.s.	0.43
Cluster 5	0.10	0.40	0.07	0.80	n.s.	0.00	n.s.	0.00
Cluster 6	0.03	0.41	0.01	0.94	n.s.	-0.17	n.s.	-0.11
Italy	0.17	0.29	0.35	0.56	n.s.	0.82	n.s.	0.21

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

Table 7.35 Least square linear fittin and Mann-Kendall results for maximum value of Build Up Index (MaxBui) trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-1.21	1.29	0.89	0.36	n.s.	-0.87	n.s.	-1.00
Cluster 2	7.11	3.23	4.86	0.04	*	1.41	n.s.	4.08
Cluster 3	9.07	3.60	6.35	0.02	*	1.81	+	7.68
Cluster 4	7.69	3.37	5.21	0.03	*	0.87	n.s.	1.30
Cluster 5	10.27	3.23	10.13	0.00	**	2.60	**	6.75
Cluster 6	4.76	4.45	1.14	0.30	n.s.	0.12	n.s.	0.25
Italy	10.82	3.18	11.55	0.00	**	2.85	**	8.23

Table 7.36 Least square linear fittin and Mann-Kendall results for Fire Weather Index (MaxFWI) trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-0.06	0.08	0.56	0.46		-0.12		-0.01
Cluster 2	0.14	0.08	3.22	0.09	+	1.76	+	0.15
Cluster 3	0.26	0.09	8.29	0.01	**	2.16	*	0.24
Cluster 4	0.13	0.08	2.99	0.10	+	1.27		0.14
Cluster 5	0.34	0.08	16.80	0.00	***	2.95	**	0.26
Cluster 6	0.12	0.08	2.68	0.12		1.17		0.07
Italy	0.34	0.08	17.23	0.00	***	3.10	**	0.28

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

Table 7.37 Least square linear fittin and Mann-Kendall results for number of day above the value of 19.9 of Fire Weather Index (FWI19.9) trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	0.08	0.13	0.45	0.51	n.s.	0.39	n.s.	0.00
Cluster 2	4.26	1.23	12.02	0.00	**	2.81	**	2.04
Cluster 3	41.52	10.64	15.24	0.00	***	2.90	**	29.41
Cluster 4	1.68	0.54	9.58	0.01	**	2.78	**	1.00
Cluster 5	40.07	10.05	15.89	0.00	***	3.40	***	39.69
Cluster 6	11.08	4.37	6.43	0.02	*	1.94	+	8.63
Italy	98.70	23.69	17.35	0.00	***	3.18	**	91.61

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

Table 7.38 Least square linear fittin and Mann-Kendall results of Keetch-Byram Index Hargreaves Samani (KBDI HS) trend for Italy and for each cluster.

Area	Slope	Standard error	F	p	Sign.	Test Z	Sig.	Q
Cluster 1	-1.97	0.46	18.39	0.00	***	-3.35	***	-1.82
Cluster 2	-0.88	0.50	3.04	0.09	+	-1.66	+	-1.08
Cluster 3	0.13	0.47	0.07	0.79	n.s.	-0.07	n.s.	-0.05
Cluster 4	0.23	0.52	0.19	0.66	n.s.	0.42	n.s.	0.31
Cluster 5	-0.78	0.39	4.14	0.05	+	-1.76	+	-0.83
Cluster 6	0.22	0.43	0.25	0.62	n.s.	0.17	n.s.	0.06
Italy	-0.40	0.33	1.44	0.24	n.s.	-1.76	+	-0.57

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

7.4.3 Spearman correlation analysis

To analyze the relationships between fire danger and fire occurrence, the Spearman correlation coefficients between each index and fire variables have been computed at national and cluster levels by using fire danger monthly mean values and the days above the thresholds. The analysis has been performed considering all years (Figure 5.25, 7.26), and per season (Figure 7.27). The analysis with maximum values has also been performed but it shows no good results; we have therefore decided to do not show it here.

Considering the whole year (Figure 7.25, 7.26), the best correlations for all Italy have been found between either Fire Number and Burned Area with ISI.

Clusters 1, 2, 3 and 4 show the best correlations between the BUI60 and ISI both for Fire Number and Burned Area. This is evident mainly for Clusters 1, 2 and 4 while Cluster 3 shows that even the mean value of FWI has a good correlation. Clusters 5 and 6 generally show good correlations with all indexes, but the best mean value is that of the FWI. KBDI does not show any remarkable correlations.

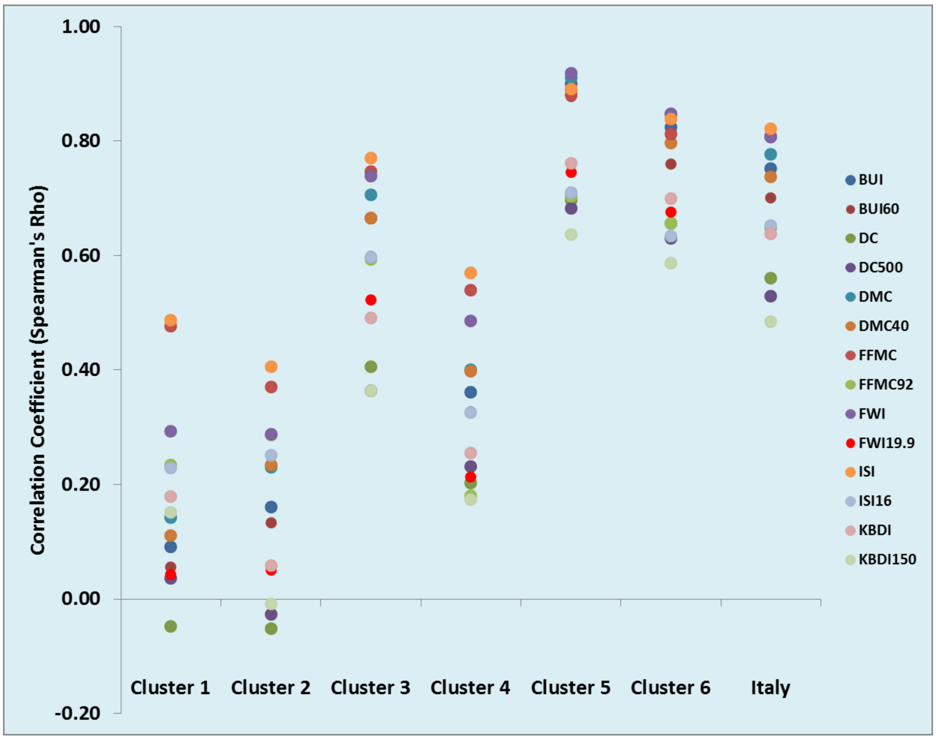
Considering each season (Figure 7.27 a, b), it is possible to see the variation of the weight of each index and modules. At national scale, during winter and spring, the best correlations have been found with the FFMC and the BUI60, for both Fire Number and Burned Area; winter correlations are higher than spring correlations.

In Clusters 1 and 2, the best correlation has been found for the BUI60, considering Fire Number, but only for winter and spring. This trend is confirmed in the others clusters as well, but in spring the first 4 clusters show better correlations. Burned Area correlations have a similar trend, but in some cases the FFMC shows better correlations than BUI60, especially in Clusters 1, 4 and 5, only for winter.

In summer and autumn, the FWI and the BUI show the best results for both Fire Number and Burned Area. The best correlations found are in Clusters 5 and 6 during summer and are those with the BUI and the FWI.

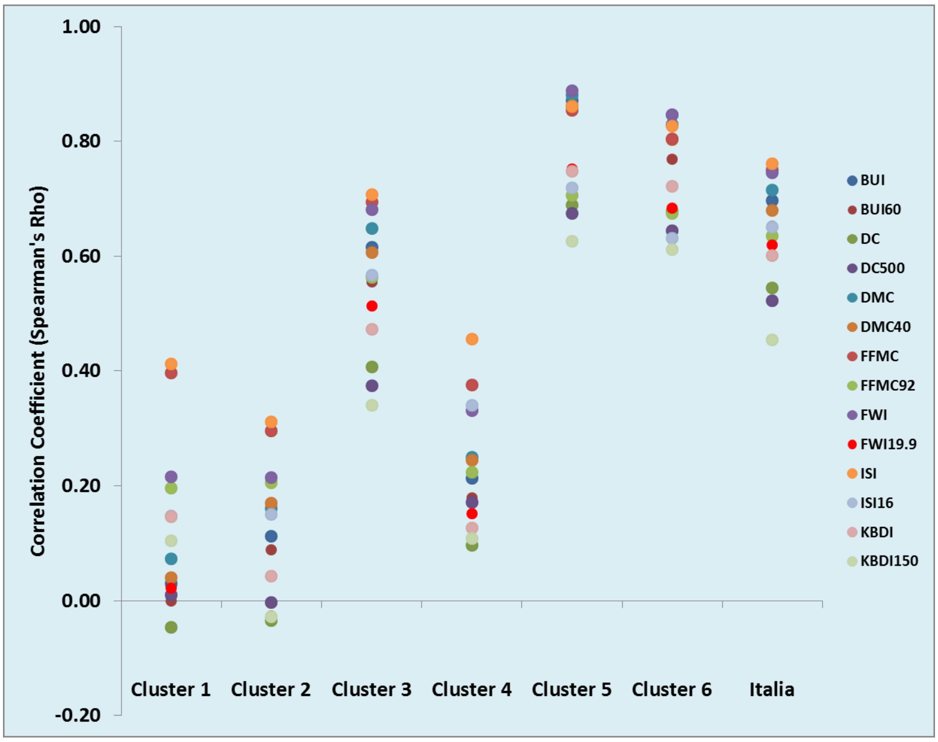
KBDI generally shows good correlations considering the mean value for each season and for each cluster, but usually lower than FWI correlations.

In summary, these results showed that the best correlations have been obtained for the FWI index and its submodules; mean values usually have better correlations than the number of days above the threshold. Correlations are highly variable depending on the cluster and the season considered.



Notes: x axis represents the Rho of Spearman and the significant value is of 0.05, 0.01 and 0.001 for value of Rho above 0.25, 0.30 and 0.40 respectively.

Figure 7.25 Spearman's correlation between Fire Danger Indexes and Fire Number (monthly mean).



Notes: x axis represents the Rho of Spearman and the significant value is of 0.05, 0.01 and 0.001 for value of Rho above 0.25, 0.30 and 0.40 respectively.

Figure 7.26 Spearman's correlation between Fire Danger Indexes and Burned Area (monthly mean).

Notes: x axis represents the Rho of Spearman and the significant value is of 0.05, 0.01 and 0.001 for value of Rho above 0.25, 0.30 and 0.40 respectively.

Figure 7.27 a)Spearman's correlation coefficients between Fire Danger Indexes and Fire Number for each season (monthly mean). b) Spearman's correlation between Fire Danger Indexes and Burned Area for each season (monthly mean).

7.4.4 Multiple Linear Regression between FWI and KBDI mean values and fire occurrence

In order to analyze the indexes that better explain fire occurrence in Italy, multiple linear regression has been calculated for all Italy and for all clusters, firstly for each year between FWI and KBDI mean values and fire occurrence (Table 7.39), and then for each season (Table 7.40a, b, c). Regressions with R^2 lower than 0.4 is not shown.

Considering the whole year (Table 7.39) and all Italy, the FFMC and the BUI explain over 70% and 60% of variance for Fire Number and Burned Area, respectively.

Clusters 1 and 2 show that, for each year, any index is able to explain the variance of fire. In Cluster 3, it is possible to find a combination of indexes that explain 58% of variance for Fire Number and 50% for Burned Area; the modules in question are the FFMC and the DMC. In Cluster 4, linear multiple regression does not reveales any relationship. Finally, Clusters 5 and 6 show the best results, with the FFMC and BUI for both Fire Number and Burned Area. In Cluster 5, the explained variance is 83% and 78% for Fire Number and Burned Area, respectively; in Cluster 6, it is 75% and 74% for Fire Number and Burned Area, respectively.

Seasonal analysis (Table 7.40 a, b, c) shows that as far as Italy is concerned, spring is not included because it does not show any good regressions.

Regarding all Italy in winter, the index that explain better the variance are the FFMC and the FWI for both Fire Number and Burned Area, with 63% and 53% of explained variance for Fire Number and Burned Area, respectively. Summer and autumn have shown better results, with 80% and 73% of explained variance for Fire Number and Burned Area in summer, respectively, and 87% and 74% of explained variance for Fire Number and Burned Area in autumn, respectively. The indexes used for regression are the FWI and the DC for Fire Number for both summer and autumn, the BUI and the FWI for summer Burned Area and the DC and the FWI for winter Burned Area.

Cluster 1 shows the best equation in winter with explained variance near 60% for both Fire Number and Burned Area. The indexes considered are the ISI, KBDI and the FFMC for Fire Number and KBDI and FFMC for Burned Area. In summer and autumn, explained variance is lower than 50% and in some cases it is lower than 40% (Summer Burned Area).

In Cluster 2, the best regression has been found in summer with explained variance of 80% for Fire Number and 70% for Burned Area. The indexes shown are the BUI and the DC for Fire Number and the BUI for Burned Area. In winter, regression analysis has found R^2 above 60% for both Fire Number and Burned Area with the FFMC and the FWI for Burned Area and with FFMC and KBDI for Fire Number. In autumn, regression analysis has not found any good equations.

Cluster 3 shows the best regression in autumn with explained variance of 84% for Fire Number and 70% for Burned Area; the variable included in both equations is the FWI. Explained variance from the analysis is high even in winter (66% for Fire Number and 58% for Burned Area) and summer (73% for Fire Number and 66% for Burned Area).

Cluster 4 presents the best results in summer and winter, with 63% and 58% of explained variance for Fire Number and Burned Area in summer, respectively, and 61% and 53% of explained variance for Fire Number and Burned Area in autumn, respectively. The variables shown by the equations are the FWI and KBDI for both Fire Number and Burned Area in summer, and the FWI for both Fire Number and Burned Area in autumn.

Finally, Clusters 5 and 6 show the best results in summer and winter. As for summer, explained variance is 64%, 68%, 82% and 89% for Fire Number and Burned Area in Cluster 5 and Fire Number and Burned Area in Cluster 6, respectively. The variables shown by the equations in Cluster 5 are the BUI and the FWI for Fire Number and the FFMC and the DC for Burned Area. In Cluster 6, variables are the DC and FWI for Fire Number and the KBDI and FWI for Burned Area.

Considering autumn, explained variance is 82%, 74%, 82% and 68% for Fire Number and Burned Area in Cluster 5 and Fire Number and Burned Area in Cluster 6, respectively. The variable considered from the analysis is the FWI for each equation.

In summary the results show that the FWI index and the sub-modul DC is a good predictor of fire in summer, in particular for Clusters 5 and 6. In Clusters 1 and 2, the submodules of FWI (FFMC, ISI) and KBDI are the best fire predictors.

Tab. 7.39 Multiple regression between Fire Danger Index and FN, and BA, for all Italy and for each cluster (yearly mean).

Cluster	Fire Number			Burned Area		
	R^2	p	Equation	R^2	p	Equation
Cluster 1						
Cluster 2						
Cluster 3	0.58	***	y=6-140+0.126FFMC+0.009DMC	0.50	***	y=4.849+0.122FFMC+0.018DMC
Cluster 4						
Cluster 5	0.83	***	y=8.868+0.265FWI+0.135FFMC+0.002DC	0.791	***	y=1.464+0.679FWI
Cluster 6	0.75	***	y=-4.673+0.103FFMC+0.013BUI	0.73	***	3.023+0.089FFMC+0.014BUI+0.236ISI
Italy	0.71	***	y=3.177+0.111FFMC+0.010BUI	0.62	***	y=2.663+0.126FFMC+0.013BUI

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

Table 7.40 Multiple regression between BA, FN and Fire Danger Index(seasonal mean). 9a winter; 9b summer; 9c autumn.

a)

Cluster	Fire Number			Burned Area		
	R^2	p	Equation	R^2	p	Equation
Cluster 1	0.58	***	y=3.084+0.409ISI+0.013KBDI+0.057FFMC	0.56	***	y=-9.389+0.176FFMC-0.027KBDI
Cluster 2	0.60	***	y=3.348+0.080FFMC+0.303FWI	0.59	***	y -9.062+0.178FFMC+0.022KBDI
Cluster 3	0.66	***	y=3.937+0.086FFMC+0.474FWI	0.58	***	y=5.046+0.120FFMC+0.480FWI
Cluster 4	0.49	***	y=-4.134+0.111FFMC			
Cluster 5	0.55	***	y=-0.795+0.985ISI			
Cluster 6	0.63	***	y=0.433+1.042FWI	0.58	***	y=0.931+1.337FWI
Italy	0.63	***	y -3.484+0.107FFMC+0.383FWI	0.57	***	y=-4.443+0.150FFMC-0.544FWI

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

b)

Cluster	Fire Number			Burned Area		
	R^2	p	Equation	R^2	p	Equation
Cluster 1	0.49	***	y=2.969+0.007DC+0.049FFMC	0.43	***	y=5.816+0.009DC+0.085FFMC
Cluster 2	0.80	***	y=0.155+0.026BUI+0.003DC	0.70	***	y=-0.611-0.062BUI
Cluster 3	0.73	***	y=7.110+0.007KBDI+0.111FFMC+0.004DC	0.66	***	y=1.402+0.048KBDI+0.166FWI
Cluster 4	0.63	***	y=8.558+0.027KBDI+0.111FFMC	0.58	***	y=17.029+0.46KBDI+0.194FFMC
Cluster 5	0.64	***	y=3.657+0.007BUI+0.171FWI	0.68	***	y=23.851+0.364FFMC+0.002DC
Cluster 6	0.82	***	y=1.548+0.004DC+0.201FWI	0.79	***	y=0.470+0.038KBDI+0.296FWI
Italy	0.80	***	y=3.746+0.184FWI+0.004DC	0.73	***	y=5.783+0.017BUI+0.182FWI

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

c)

Cluster	Fire Number			Burned Area		
	R^2	p	Equation	R^2	p	Equation
Cluster 1	0.41	***	y=0.593+0.353FWI			
Cluster 2						
Cluster 3	0.84	***	y=0.538+0.538FWI	0.71	***	y=1.197+0.634FWI
Cluster 4	0.62	***	y=1.116+0.435FWI	0.54	***	y=1.215+0.655FWI
Cluster 5	0.82	***	y=-0.207+0.751FWI	0.74	***	y=0.739+0.823FWI
Cluster 6	0.82	***	y=1.005+0.578FWI	0.68	***	y=1.002+0.474FWI+0.017KBDI
Italy	0.87	***	y=2.406+0.338FWI+0.003DC	0.75	***	y=3.772+0.005DC+0.263FWI

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

7.4.6 Discussion

The multiple regression analysis has showed wich the FWI index is a good predictor for the clusters with summer fires. Similar result has been found in Portugal (Carvalho 2008). Moreover, the multiple regression analysis highlighting which DC was the variable that explained the large part of variance, in agreement with the finding of Viegas et al. (2004). The Northern Italy was the area with the most variable patterns, and the fire danger indexes showed the lowest explained variance. In Clusters 1 and 2, the submodules of FWI (FFMC, ISI) and KBDI are the best fire predictors.

The trends of fire danger indexes have showed an increase, with an exception of the Cluster 1. The increase of fire danger is in according with the results found by Moriondo et al. (2006), but the clear decrease of the danger in the Cluster 1 is in contrast with findings reported by Wastl et al. (2012), that showed a general increase of fire danger despite this trend was highly variable in consideration of the spatial and the time scale.

The increase of the fire danger was not in according with the results of the fire occurrence trend (i.e. 7.3.1). As reported by other Authors (e.g. Wotton et al. 2003), a possible explanation of this is related to human practices, mainly to changes in fire detection and fire management practices.

8 CONCLUSIONS

Climate, vegetation and landscape patchiness, and anthropic activities greatly influence the fire regime in Italy. As a consequence, fire seasonality, fire-weather, and fire danger relationships are characterized by different and complex patterns. In this thesis, an attempt to characterize the fire occurrence, and its driving factors in the Italian peninsula through statistical and descriptive approaches has been done.

The identification of piro-climatic areas combining fire occurrence and weather patterns along the 1985-2008 periods was firstly obtained. It allowed to achieve clear and different results in each area, giving a more comprehensive frame of the fire phenomena in Italy.

With respect to the fire seasonality, the analysis allowed to identify three clear patterns along Italy, as described in the first part of the results. The analysis hasalso showed, despite of the relatively short time frame (23 years), that some changes in fire seasonality are occurring, with different characteristics among the piro-climatic areas. Not only humans, but also climatic changes can be responsible for those changes.

A detailed analysis to characterize the fire-weather relationships for each piro-climatic area and at national level was then carried out. The results showed that fire occurrence is clearly influenced by the main weather variables (temperature, relative humidity, rainfall), but with a different impact in each piro-climatic area. A partially unexpected general result was observed comparing the trend of temperature (that increases during the study period) and the fire occurrence (decreasing). Firefighting techniques improving, and better suppression technology are supposed to have a key role in this process.

Fire danger is generally increasing in Italy, due to changes in weather trends. Both FWI and KBDI showed a rising trends in all areas, but in the Cluster 1. The relationship between fire danger and fire occurrence, already assessed in this analysis, showed complex and not linear connections in function of the piro-climatic area. The regions with summer fires showed a better response of the fire danger models used in the analysis to reproduce the fire regime. It is a limitation of both FWI and KBDI that are typical weather indexes, and then are not able to modeling some effects of the weather on the vegetation (e.g. frost damages and desiccation during the winter season, that make the vegetation prone to fire).

In conclusion, this thesis provides a perspective of the complexity of wildfires in Italy, identifying fire and weather patterns and showing that a multiple approach analysis greatly improves our knowledge of fire science.

APPENDIX A

Appendix A. Comparation between unimodal and bimodal distribution

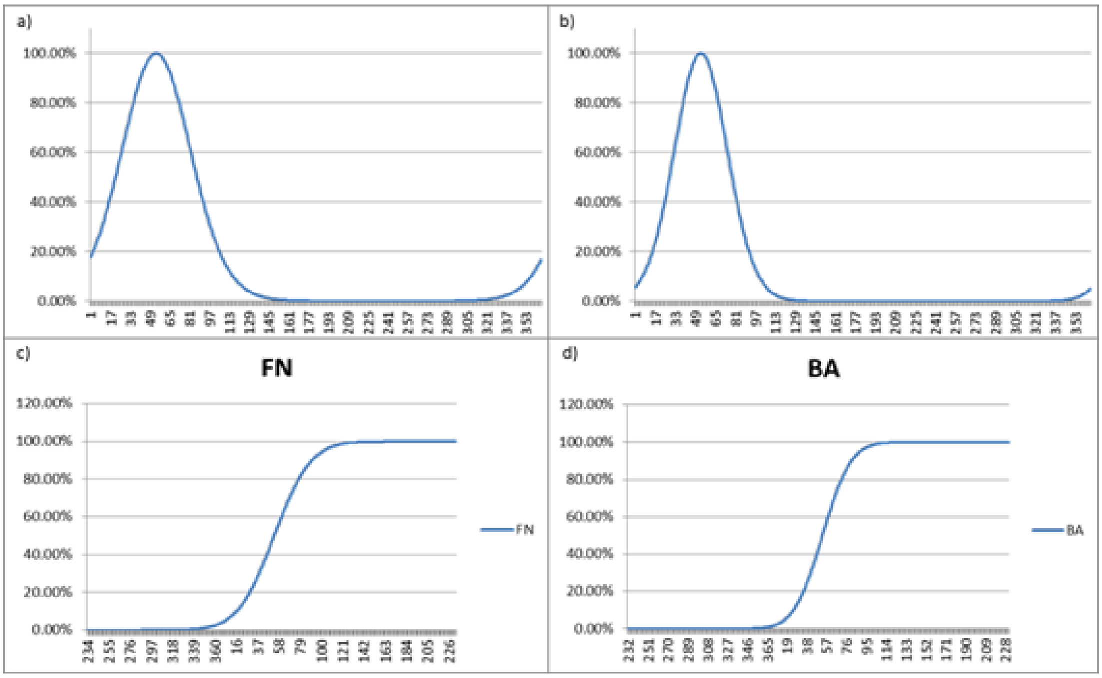
Table A.1 Summary of the unimodal distribution for Fire Number and Burned Area for each Cluster

Cluster	Fire data	R^2	θ	Kj	Day of peak
Cluster 1	FN	0.92	0.93	4.44	54
	BA	0.94	0.92	7.55	54
Cluster 2	FN	0.94	0.92	4.86	54
	BA	0.93	0.87	5.41	51
Cluster 3	FN	0.82	3.56	7.17	207
	BA	0.94	3.42	53.72	198
Cluster 4	FN	0.56	0.86	10.01	50
	BA	0.72	0.55	2.97	32
Cluster 5	FN	0.99	3.54	2.99	206
	BA	1.00	3.44	5.05	200
Cluster 6	FN	0.99	3.59	5.24	209
	BA	1.00	3.48	6.00	202

Table A.2 Summary of the bimodal distribution for Fire Number and Burned Area for each Cluster

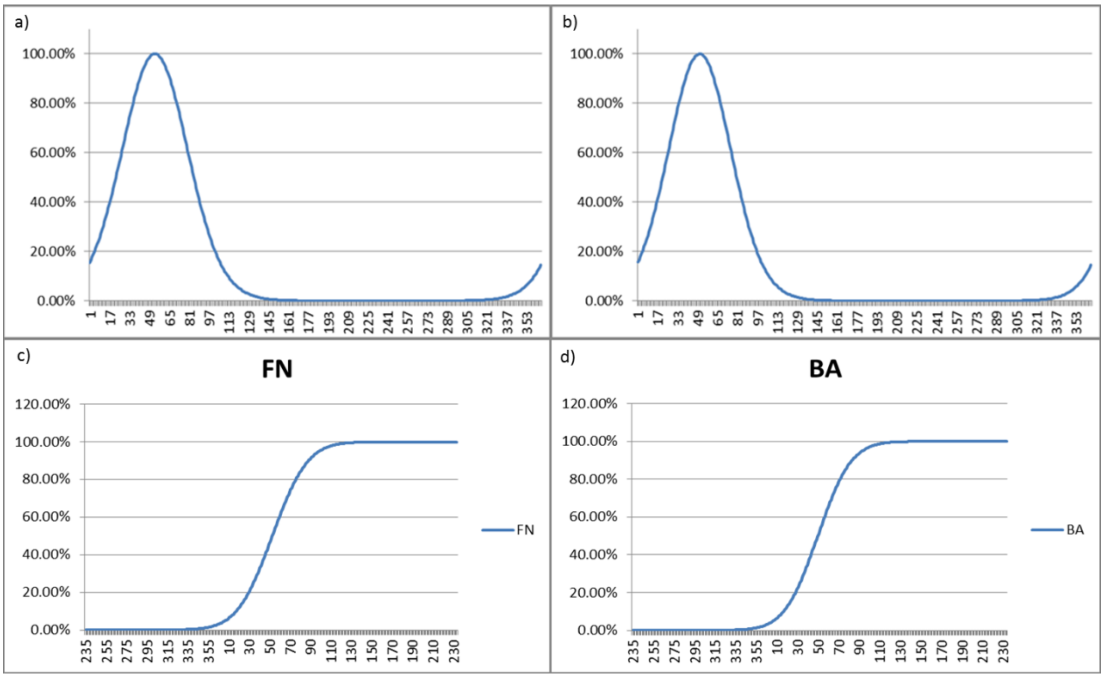
Cluster	Fire data	R^2	W_1	θ_1	Kj_1	W_2	Kj_2	θ_2	Day of first peak	Day of second peak
Cluster 1	FN	0.93	0.95	0.92	3.95	0.05	3.77	52.07	54	219
	BA	0.94	0.95	0.92	7.55	0.05	3.92	520.88	30	204
Cluster 2	FN	0.95	0.95	0.92	4.46	0.14	3.59	22.51	53	209
	BA	0.93	0.95	0.87	5.29	0.05	3.82	209.40	27	198
Cluster 3	FN	0.92	0.43	0.92	5.02	0.57	3.57	6.61	53	207
	BA	0.99	0.18	0.93	7.04	0.82	3.50	7.37	54	203
Cluster 4	FN	0.91	0.63	0.75	2.85	0.37	3.73	4.80	44	217
	BA	0.91	0.78	0.52	1.76	0.22	3.82	6.13	30	222
Cluster 5	FN	1.00	0.56	3.22	5.60	0.44	3.94	6.69	187	229
	BA	1.00	0.95	3.44	5.03	0.05	3.49	5.44	197	200
Cluster 6	FN	1.00	0.90	3.55	6.61	0.10	4.38	34.85	206	254
	BA	1.00	0.14	3.43	7.88	0.86	4.06	6.64	196	233

Appendix A. Von Mises distribution and Cumulative Distribution



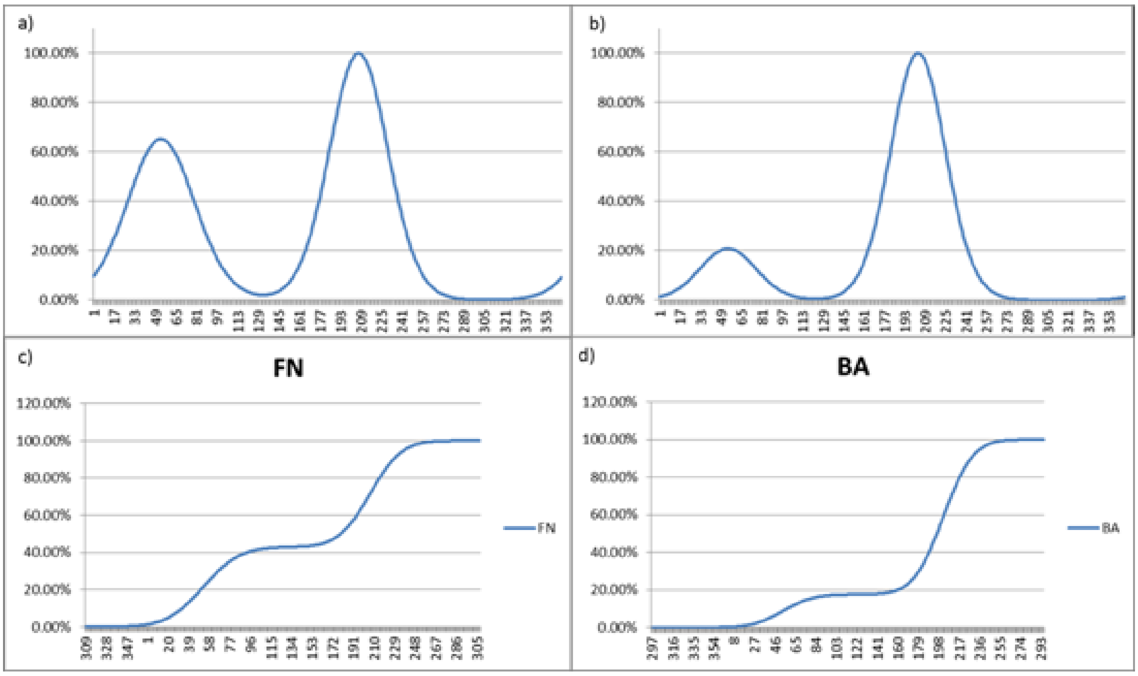
Notes: x axis is the time scale which is in Days; y axis is the scale (%) of FN and BA.

Figure A.1 a) Von Mises distribution for Cluster 1 for Fire Number (a) and for Burned Area (b); Cumulative Distribution (CD) for Cluster 1 for Fire Number (c) and for Burned Area (d).



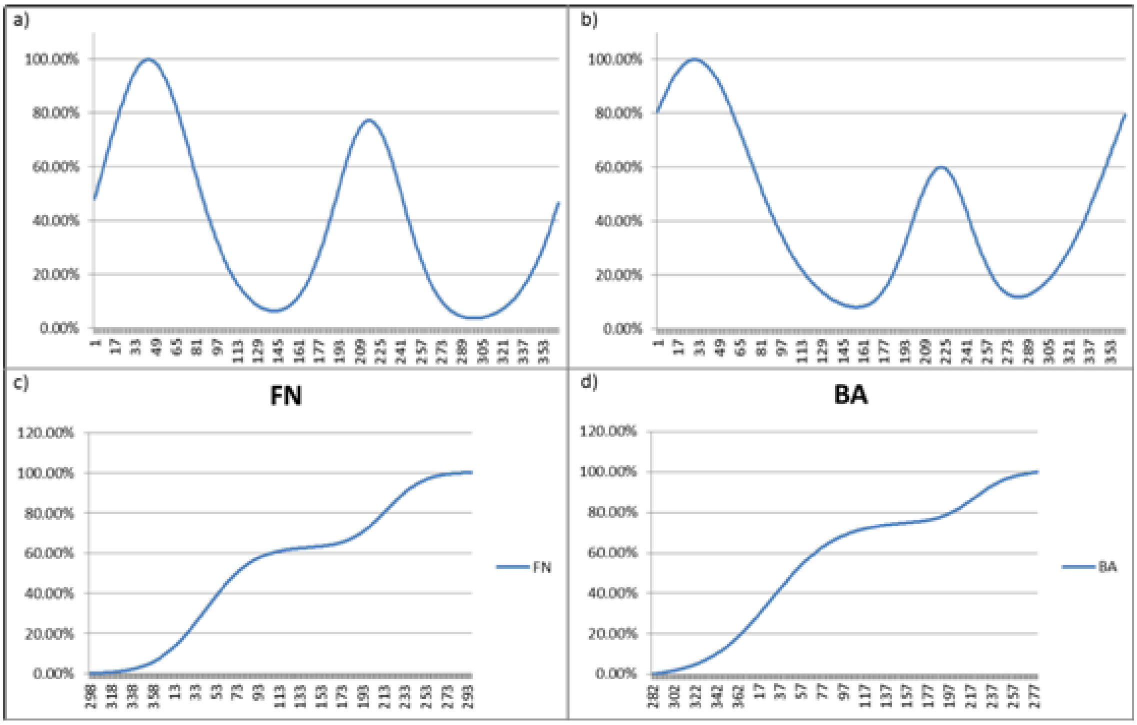
Notes: x axis is the time scale which is in Days; y axis is the scale (%) of FN and BA

Figure A.2 a) Von Mises distribution for Cluster 2 for Fire Number (a) and for Burned Area (b); Cumulative Distribution (CD) for Cluster 2 for Fire Number (c) and for Burned Area (d).



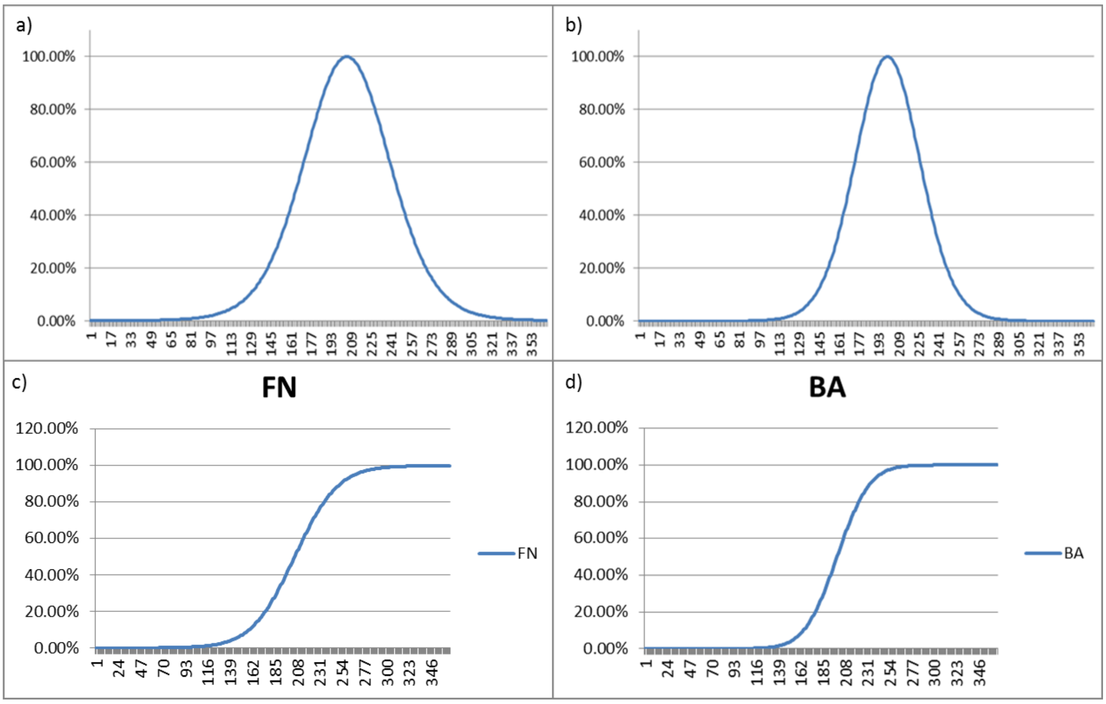
Notes: x axis is the time scale which is in Days; y axis is the scale (%) of FN and BA

Figure A.3 a) Mixture von Mises distributions for Cluster 3 for Fire Number (a) and for Burned Area (b); Cumulative Distribution (CD) for Cluster 3 for Fire Number (c) and for Burned Area (d).



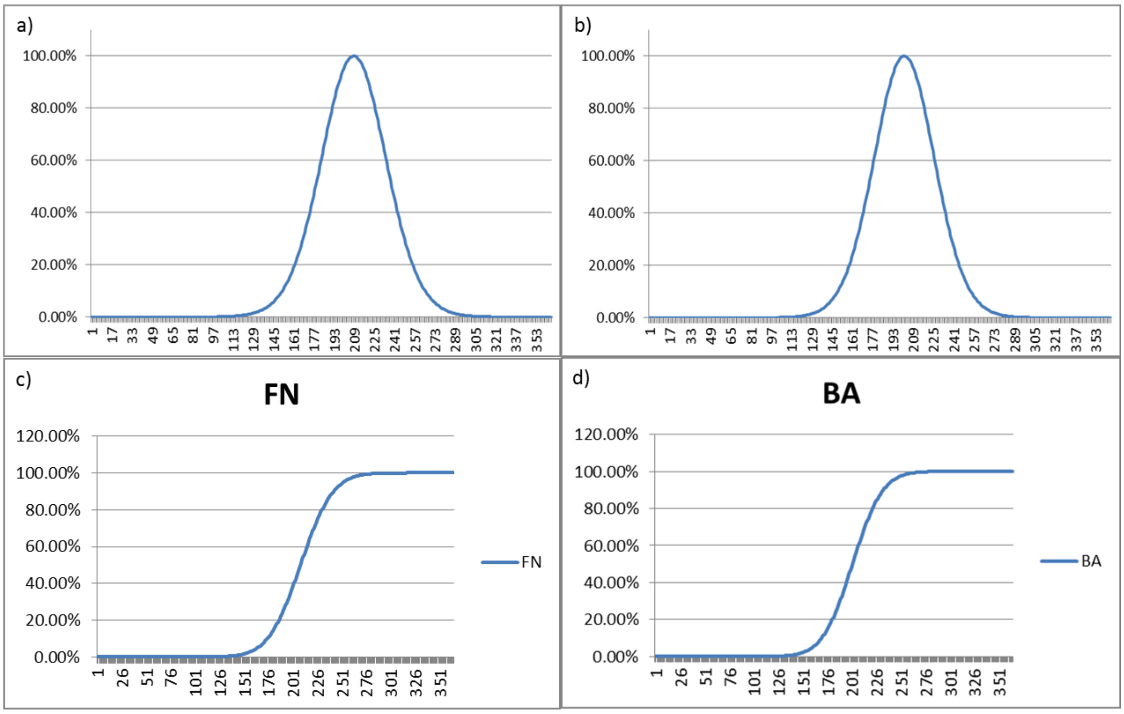
Notes: x axis is the time scale which is in Days; y axis is the scale (%) of FN and BA

Figure A.4 a) Mixture von Mises distributions for Cluster 4 for Fire Number (a) and for Burned Area (b); Cumulative Distribution (CD) for Cluster 4 for Fire Number (c) and for Burned Area (d).



Notes: x axis is the time scale which is in Days; y axis is the scale (%) of FN and BA

Figure A.5 a) Mixture von Mises distributions for Cluster 5 for Fire Number (a) and for Burned Area (b); Cumulative Distribution (CD) for Cluster 5 for Fire Number (c) and for Burned Area (d).



Notes: x axis is the time scale which is in Days; y axis is the scale (%) of FN and BA

Figure A.6 a) Mixture von Mises distributions for Cluster 6 for Fire Number (a) and for Burned Area (b); Cumulative Distribution (CD) for Cluster 6 for Fire Number (c) and for Burned Area (d).

Appendix A. Seasonality parameters for each cluster for both Fire Number and Burned Area

Table A.3 Summary of the seasonality analysis of cluster 1 for Fire Number and Burned Area

Fire Data	Distribution	Day of peak	R^2	θ	K	Interval of cumulative function	Begin of season	End of Season	Length of season
						5-95%	5	102	97
FN	Unimodal	54	0.92	0.93	4.44	10-90%	16	90	74
						20-80%	29	77	48
						5-95%	17	89	72
BA	Unimodal	54	0.94	0.92	7.55	10-90%	25	80	55
						20-80%	34	71	37

Notes: k is adimensional; θ and the Peak are the same mean one is expressed radiant and the other in day of the year; the start and end of season are expressed in day of the year; the length of the season is in number of days.

Table A.4 Summary of the seasonality analysis of cluster 1 for Fire Number and Burned Area

Fire Data	Distribution	Day of peak	R^2	θ	K	Interval of cumulative function	Begin of season	End of Season	Length of season
						5-95%	7	99	92
FN	Unimodal	54	0.94	0.92	4.86	10-90%	17	88	71
						20-80%	30	76	46
						5-95%	6	93	87
BA	Unimodal	51	0.93	0.87	5.41	10-90%	16	83	67
						20-80%	28	71	43

Notes: k is adimensional; θ and the Peak are the same mean one is expressed radiant and the other in day of the year; the start and end of season are expressed in day of the year; the length of the season is in number of days.

Table A.5 Summary of the seasonality analysis of cluster 3 for Fire Number

Distribution	R^2	Season	Day of peak	W	θ	K	Interval of cumulative function	Begin of season	End of Season	Length of season
Bimodal	0.92	First season	53	0.43	0.92	5.02	5-95%	7	97	90
							10-90%	18	87	69
							20-80%	30	75	45
		Second season	207	0.57	3.57	6.61	5-95%	167	245	78
							10-90%	176	236	60
							20-80%	187	226	39

Notes: w and k are adimensional; θ and the Peak are the same mean one is expressed radiant and the other in day of the year; the length of the season is in number of days.

Table A.6 Summary of the seasonality analysis of cluster 3 for Burned Area

Distribution	R^2	Season	Day of peak	W	θ	K	Interval of cumulative function	Begin of season	End of Season	Length of season
Bimodal	0.99	First season	42	0.18	0.93	7.04	5-95%	16	91	75
							10-90%	24	82	58
							20-80%	34	72	38
		Second season	203	0.82	3.50	7.37	5-95%	166	239	73
							10-90%	174	230	56
							20-80%	184	221	37

Notes: w and k are adimensional; θ and the Peak are the same mean one is expressed radiant and the other in day of the year; the length of the season is in number of days.

Table A.7 Summary of the seasonality analysis of cluster 4 for Burned Area

Distribution	R^2	Season	Day of peak	W	θ	K	Interval of cumulative function	Begin of season	End of Season	Length of season
Bimodal	0.91	First season	44	0.63	0.75	2.85	5-95%	346	109	128
							10-90%	361	93	97
							20-80%	12	75	63
		Second season	217	0.37	3.73	4.80	5-95%	170	262	92
							10-90%	180	251	71
							20-80%	193	239	46

Notes: w and k are adimensional; θ and the Peak are the same mean one is expressed radiant and the other in day of the year; the length of the season is in number of days.

Table A.9 Summary of the seasonality analysis of cluster 4 for Burned Area

Distribution	R^2	Season	Day of peak	W	θ	K	Interval of cumulative function	Begin of season	End of Season	Length of season
Bimodal	0.91	First season	14	0.78	0.52	1.76	5-95%	318	146	193
							10-90%	335	107	137
							20-80%	357	77	85
		Second season	222	0.22	3.82	6.13	5-95%	178	259	81
							10-90%	188	251	63
							20-80%	200	240	40

Notes: w and k are adimensional; θ and the Peak are the same mean one is expressed radiant and the other in day of the year; the length of the season is in number of days.

Appendix A. Seasonality changes

Table A.3 Summary of the seasonality analysis of Fire Number for each interval and for Cluster.

Cluster	Time interval	r^2	Number of seasons
1	1985-1990	0.82	1
	1991-1996	0.97	2
	1997-2002	0.97	1
	2003-2008	0.78	-
2	1985-1990	0.85	1
	1991-1996	0.97	2
	1997-2002	0.98	1
	2003-2008	0.95	2
3	1985-1990	0.96	2
	1991-1996	1.00	2
	1997-2002	1.00	2
	2003-2008	0.97	2
4	1985-1990	0.71	-
	1991-1996	0.99	2
	1997-2002	0.98	2
	2003-2008	0.98	2
5	1985-1990	0.97	1
	1991-1996	0.98	1
	1997-2002	0.98	1
	2003-2008	1.00	1
6	1985-1990	0.99	1
	1991-1996	0.99	1
	1997-2002	0.98	1
	2003-2008	1.00	1

Table A.4 Summary of the seasonality analysis of Burned Area for each interval and for Cluster.

Cluster	Time interval	r^2	Number of season
1	1985-1990	0.89	1
	1991-1996	0.94	1
	1997-2002	0.90	1
	2003-2008	0.85	2
2	1985-1990	0.89	1
	1991-1996	0.93	1
	1997-2002	0.96	1
	2003-2008	0.87	2
3	1985-1990	0.96	2
	1991-1996	1.00	2
	1997-2002	1.00	2
	2003-2008	0.99	1
4	1985-1990	0.55	-
	1991-1996	0.92	2
	1997-2002	0.96	2
	2003-2008	0.92	2
5	1985-1990	1.00	1
	1991-1996	1.00	1
	1997-2002	1.00	1
	2003-2008	1.00	1
6	1985-1990	0.98	1
	1991-1996	0.98	1
	1997-2002	0.99	1
	2003-2008	1.00	1

Tab. A.5 Seasonality of fire of Fire Number for four interval of time of Cluster 1

Interval	Distribution	Day of peak		Confident Interval	Begin of season	End of Season	Length of season
1985-1990	Bimodal	45		5-95%	343	111	133
				10-90%	359	95	101
				20-80%	12	76	64
1991-1996	Bimodal	First season	56	5-95%	358	117	124
				10-90%	8	102	94
				20-80%	25	85	60
		Second season	250	5-95%	235	263	28
				10-90%	238	260	22
				20-80%	242	256	14
1997-2002	Unimodal	55		5-95%	10	98	88
				10-90%	20	88	68
				20-80%	32	76	44
2003-2008				-			

Notes: the day of Peak are is expressed on day of the year; the start, the end and the length of the season is in number of days

Tab. A.6 Seasonality of fire of Burned Area for four interval of time of Cluster 1

Interval	Distribution	Day of peak		Confident Interval	Begin of season	End of Season	Length of season
1985-1990	Unimodal	51		5-95%	21	80	59
				10-90%	27	73	46
				20-80%	35	65	30
1991-1996	Unimodal	50		5-95%	1	97	96
				10-90%	12	86	74
				20-80%	25	73	48
1997-2002	Unimodal	58		5-95%	23	91	68
				10-90%	31	83	52
				20-80%	40	74	34
2003-2008	Bimodal	First season	39	5-95%	8	67	59
				10-90%	15	61	46
				20-80%	23	53	30
		Second season	186	5-95%	178	191	13
				10-90%	180	189	9
				20-80%	181	188	7

Notes: the day of Peak are is expressed on day of the year; the start, the end and the length of the season is in number of days

Tab. 5.7 Seasonality of fire of Fire Number for four interval of time of Cluster 2

Interval	Distribution	Day of peak		Confident Interval	Begin of season	End of Season	Length of season
1985-1990	Unimodal		49	5-95%	359	103	109
				10-90%	7	90	83
				20-80%	21	75	54
1991-1996	Bimodal	First season	53	5-95%	358	151	158
				10-90%	7	109	102
				20-80%	24	87	63
		Second season	203	5-95%	190	243	53
				10-90%	193	243	50
				20-80%	198	243	45
1997-2002	Unimodal		54	5-95%	8	97	89
				10-90%	18	87	69
				20-80%	30	75	45
2003-2008	Bimodal	First season	58	5-95%	13	72	59
				10-90%	22	70	48
				20-80%	32	64	32
		Second season	198	5-95%	178	192	14
				10-90%	180	192	12
				20-80%	183	191	8

Notes: the day of Peak are is expressed on day of the year; the start, the end and the length of the season is in number of days

Tab. A.8 Seasonality of fire of Burned Area for four interval of time of Cluster 2

Interval	Distribution	Day of peak		Confident Interval	Begin of season	End of Season	Length of season
1985-1990	Unimodal	47		5-95%	2	91	89
				10-90%	12	80	68
				20-80%	24	68	44
1991-1996	Unimodal	50		5-95%	359	103	109
				10-90%	7	90	83
				20-80%	22	76	54
1997-2002	Unimodal	55		5-95%	13	96	83
				10-90%	22	86	64
				20-80%	34	75	41
2003-2008	Bimodal	First season	60	5-95%	28	90	62
				10-90%	35	83	48
				20-80%	43	75	32
		Second season	210	5-95%	205	213	8
				10-90%	205	212	7
				20-80%	207	211	4

Notes: the day of Peak are is expressed on day of the year; the start, the end and the length of the season is in number of days

Tab. A.9 Seasonality of fire of Fire Number for four interval of time of Cluster 3

Interval	Distribution	Day of peak		Confident Interval	Begin of season	End of Season	Length of season
1985-1990	Bimodal	First season	53	5-95%	7	97	90
				10-90%	17	87	70
				20-80%	29	75	46
		Second season	214	5-95%	165	260	95
				10-90%	176	249	73
				20-80%	189	237	48
1991-1996	Bimodal	First season	55	5-95%	9	99	90
				10-90%	19	88	69
				20-80%	32	76	44
		Second season	208	5-95%	169	246	77
				10-90%	177	237	60
				20-80%	188	227	39
1997-2002	Bimodal	First season	59	5-95%	21	94	73
				10-90%	29	86	57
				20-80%	39	76	37
		Second season	207	5-95%	167	244	77
				10-90%	176	235	59
				20-80%	186	225	39
2003-2008	Bimodal	First season	60	5-95%	6	114	108
				10-90%	18	101	83
				20-80%	33	86	53
		Second season	200	5-95%	149	248	99
				10-90%	160	237	77
				20-80%	174	223	49

Notes: the day of Peak are is expressed on day of the year; the start, the end and the length of the season is in number of days

Tab. A.10 Seasonality of fire of Fire Number for four interval of time of Cluster 4

Interval	Distribution	Day of peak		Confident Interval	Begin of season	End of Season	Length of season
1985-1990				-			
1991-1996	Bimodal	First season	35	5-95%	317	185	233
				10-90%	335	128	158
				20-80%	359	90	96
		Second season	213	5-95%	95	189	94
				10-90%	107	179	72
				20-80%	120	167	47
1997-2002	Bimodal	First season	52	5-95%	8	94	86
				10-90%	18	84	66
				20-80%	29	72	43
		Second season	212	5-95%	173	248	75
				10-90%	181	240	59
				20-80%	192	229	37
2003-2008	Bimodal	First season	49	5-95%	352	116	129
				10-90%	1	99	98
				20-80%	18	80	62
		Second season	210	5-95%	148	266	118
				10-90%	163	253	90
				20-80%	180	238	58

Notes: the day of Peak are is expressed on day of the year; the start, the end and the length of the season is in number of days

Tab. A.11 Seasonality of fire of Burned Area for four interval of time of Cluster 4

Interval	Distribution		Day of peak	Confident Interval	Begin of season	End of Season	Length of season
1985-1990				-			
1991-1996	Bimodal		15	5-95%	321	80	124
				10-90%	334	63	94
				20-80%	350	46	61
			204	5-95%	129	257	128
				10-90%	150	245	95
				20-80%	169	230	61
1997-2002	Bimodal	First season	44	5-95%	2	85	83
				10-90%	11	75	64
				20-80%	22	64	42
		Second season	224	5-95%	197	249	52
				10-90%	203	243	40
				20-80%	210	236	26
2003-2008	Bimodal	First season	35	5-95%	5	63	58
				10-90%	11	56	45
				20-80%	19	49	30
		Second season	228	5-95%	202	252	50
				10-90%	208	247	39
				20-80%	214	240	26

Notes: the day of Peak are is expressed on day of the year; the start, the end and the length of the season is in number of days

Tab. A.12 Seasonality of fire of Fire Number for four interval of time of Cluster 5

Interval	Distribution	Day of peak	Confident Interval	Begin of season	End of Season	Length of season
			5-95%	161	269	108
1985-1990	Unimodal	216	10-90%	173	256	83
			20-80%	188	242	54
			5-95%	152	264	112
1991-1996	Unimodal	209	10-90%	165	251	86
			20-80%	180	236	56
			5-95%	126	260	134
1997-2002	Unimodal	194	10-90%	142	244	102
			20-80%	161	226	65
			5-95%	132	256	124
2003-2008	Unimodal	196	10-90%	147	242	95
			20-80%	164	225	61

Notes: the day of Peak are is expressed on day of the year; the start, the end and the length of the season is in number of days

Tab. A.13 Seasonality of fire of Burned Area for four interval of time of Cluster 5

Interval	Distribution	Day of peak	Confident Interval	Begin of season	End of Season	Length of season
			5-95%	166	248	82
1985-1990	Unimodal	208	10-90%	175	238	63
			20-80%	186	227	41
			5-95%	164	244	80
1991-1996	Unimodal	205	10-90%	173	235	62
			20-80%	184	224	40
			5-95%	141	232	91
1997-2002	Unimodal	188	10-90%	152	221	69
			20-80%	164	209	45
			5-95%	148	234	86
2003-2008	Unimodal	192	10-90%	158	225	67
			20-80%	169	213	44

Notes: the day of Peak are is expressed on day of the year; the start, the end and the length of the season is in number of days

Tab. A.14 Seasonality of fire of Fire Number for four interval of time of Cluster 6

Interval	Distribution	Day of peak	Confident Interval	Start of season	End of Season	Length of season
			5-95%	165	258	93
1985-1990	Unimodal	213	10-90%	176	247	71
			20-80%	188	235	47
		213	5-95%	165	258	93
1991-1996	Unimodal		10-90%	176	247	71
			20-80%	188	235	47
		202	5-95%	161	241	80
1997-2002	Unimodal		10-90%	170	232	62
			20-80%	181	221	40
		206	5-95%	158	251	93
2003-2008	Unimodal		10-90%	169	240	71
			20-80%	181	228	47

Notes: the day of Peak are is expressed on day of the year; the start, the end and the length of the season is in number of days

Tab. A.15 Seasonality of fire of Burned Area for four interval of time of Cluster 6

Interval	Distribution	Day of peak	Confident Interval	Start of season	End of Season	Length of season
			5-95%	158	258	100
1985-1990	Unimodal	209	10-90%	170	246	76
			20-80%	183	233	50
		209	5-95%	158	258	100
1991-1996	Unimodal		10-90%	170	246	76
			20-80%	183	233	50
		194	5-95%	160	226	66
1997-2002	Unimodal		10-90%	167	218	51
			20-80%	176	210	34
		201	5-95%	161	240	79
2003-2008	Unimodal		10-90%	170	231	61
			20-80%	180	220	40

Notes: the day of Peak are is expressed on day of the year; the start, the end and the length of the season is in number of days

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APPENDIX B

Appendix B. Spearman Correlation with yearly and seasonal mean

Table B.1 Spearman's correlation coefficient (Rho) between yearly mean of burned area and number of fires, and yearly mean of selected meteorological variables.

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

Area	Burned area				Fire Number			
	R	RH	Tx	Tn	R	RH	Tx	Tn
Cluster 1	n.s.	n.s.	n.s.	-0.41*	n.s.	n.s.	n.s.	-0.61**
Cluster 2	n.s.	n.s.	n.s.	n.s.	-0.42*	n.s.	n.s.	-0.51*
Cluster 3	-0.51**	n.s.	n.s.	-0.42*	-0.42*	n.s.	n.s.	-0.53**
Cluster 4	n.s.	n.s.	n.s.	-0.49*	n.s.	n.s.	n.s.	-0.56**
Cluster 5	n.s.	n.s.	n.s.	n.s.	-0.43*	n.s.	n.s.	n.s.
Cluster 6	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Italy	-0.63***	n.s.	n.s.	n.s.	-0.58**	n.s.	n.s.	n.s.

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

Table B.2 Spearman's correlation coefficient (Rho) between burned area, number of fires and selected meteorological variables (seasonal mean). 9a winter; 9b spring; 9c summer; 9d autumn.

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

a)

Area	Burned area				Fire Number			
	R	RH	Tx	Tn	R	RH	Tx	Tn
Cluster 1	n.s	n.s	0.54**	n.s	-0.43*	n.s	0.56**	n.s
Cluster 2	-0.56**	n.s	n.s	n.s	-0.62***	n.s	n.s	n.s
Cluster 3	-0.57**	n.s	n.s	-0.46*	-0.56**	n.s	n.s	n.s
Cluster 4	-0.54**	n.s	n.s	-0.52**	-0.42*	n.s	n.s	-0.54**
Cluster 5	-0.53**	n.s	n.s	n.s	-0.41*	n.s	0.42*	n.s
Cluster 6	-0.70***	n.s	n.s	n.s	-0.64***	n.s	n.s	n.s
Italy	-0.73***	n.s	n.s	-0.53**	-0.69***	n.s	n.s	n.s

b)

Area	Burned area				Fire Number			
	R	RH	Tx	Tn	R	RH	Tx	Tn
Cluster 1	n.s	n.s	n.s	n.s	-0.41*	n.s	n.s	n.s
Cluster 2	n.s	n.s	n.s	-0.43*	n.s	n.s	n.s	n.s
Cluster 3	n.s	n.s	n.s	-0.65***	n.s	n.s	n.s	-0.64***
Cluster 4	n.s	n.s	n.s	-0.41*	n.s	n.s	n.s	-0.46*
Cluster 5	n.s	-0.57**	0.47*	n.s	n.s	-0.66***	0.52**	n.s
Cluster 6	n.s	n.s	n.s	n.s	n.s	-0.48*	n.s	n.s
Italy	n.s	n.s	n.s	-0.41*	n.s	n.s	n.s	-0.44*

c)

Area	Burned area				Fire Number			
	R	RH	Tx	Tn	R	RH	Tx	Tn
Cluster 1	-0.62***	-0.43*	n.s	n.s	-0.62***	-0.61***	n.s	n.s
Cluster 2	-0.75***	n.s	n.s	n.s	-0.70***	-0.49*	0.43*	n.s
Cluster 3	-0.55**	n.s	n.s	n.s	-0.67***	n.s	n.s	n.s
Cluster 4	-0.67***	n.s	n.s	n.s	-0.61***	n.s	n.s	n.s
Cluster 5	-0.73***	n.s	n.s	n.s	-0.69***	n.s	n.s	n.s
Cluster 6	-0.67***	-0.61**	0.59**	n.s	-0.57**	-0.53**	n.s	n.s
Italy	-0.77***	n.s	n.s	n.s	-0.78***	n.s	n.s	n.s

d)

Area	Burned area				Fire Number			
	R	RH	Tx	Tn	R	RH	Tx	Tn
Cluster 1	-0.70***	-0.66***	0.41*	-0.47*	-0.64***	-0.65***	n.s.	n.s.
Cluster 2	-0.64***	n.s.	n.s.	-0.42*	-0.70***	n.s.	n.s.	-0.47*
Cluster 3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Cluster 4	-0.57**	n.s.	0.46*	n.s.	-0.57**	n.s.	n.s.	n.s.
Cluster 5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Cluster 6	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.42*	n.s.
Italy	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Appendix B. Multiple linear regression with yearly and seasonal mean

Table B.3 Multiple regression between weather variables and Fire number and Burned area, for all Italy and for each cluster (Yearly mean).

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

Cluster	Fire Number				Burned Area			
	Significant variables	R^2	p	Equation	Significant variables	R^2	p	Equation
Cluster 1	R	0.351	**	Y = -0.0013R + 10.718	Tn, Tx;	0.400	**	y = -0.351Tn+0.692Tx+0.942
Cluster 2	Tn	0.293	**	y =-0.232Tn + 7.954	Tn	0.380	***	y = -0.482Tn + 11.866
Cluster 3	Tn, R	0.408	**	y=-0.162Tn-0.002R+9.885	R, RH	0.455	**	y =-0.0053R+0.1320Rh+3.132
Cluster 4	R	0.171	*	y=-0.002R+7.897	Tn	0.225	*	y = -0.380+12.221
Cluster 5	n.s.				n.s.			
Cluster 6	n.s.				n.s.			
Italy	R	0.343	**	y =-0.0022R+10.718	R, RH	0.414	***	y = -0.004R+14.109

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

Table B.4 Multiple regression between burned area, number of fires and selected meteorological variables(seasonal mean). 9a winter; 9b spring; 9c summer; 9d autumn.

a)

Cluster	Fire Number				Burned Area			
	Significant variables	R^2	p	Equation	Significant variables	R^2	p	Equation
Cluster 1	Tx, Tn	0.437	**	y=0.460Tx-0.460Tn+2.201	Tx, Tn	0.366	**	y=0.684Tx-0.412+2.682
Cluster 2	R;	0.531	***	y=-0.011R+6.425	R;	0.613	***	y=-0.019+9.603
Cluster 3	R;	0.453	***	y=-0.011R+6.496	R, Tn;	0.564	***	y = -0.011R -0.205Tn + 8.409
Cluster 4	R;	0.463	***	y=-0.009R+6.825	R, Tn;	0.518	***	y = -0.010R - 0.341Tn + 10.094
Cluster 5	R;	0.192	*	y=-0.007R+4.560	R, Tn;	0.525	***	y = -0.012R - 0.269Tn + 8.512
Cluster 6	R, Rh;	0.508	***	y=-007R-0.115Rh+14.691	R;	0.449	***	y = -0.009R + 7.947
Italy	R, Tn;	0.669	***	y=-0.011R-0.176Tn+8.83	R, Tn;	0.723	***	y = -0.015R - 0.313Tn + 11.94

b)

Cluster	Fire Number				Burned Area			
	Significant variables	R^2	p	Equation	Significant variables	R^2	p	Equation
Cluster 1	R;	0.176	*	y=-0.004R+5.485	NV			
Cluster 2	Tn;	0.210	*	y=-0.242Tn+6.981	Tn, Tx;	0.421	**	y = -0.477Tn - 0.588Tx+3.100
Cluster 3	Tn, R;	0.506	***	y=-0.309Tn-0.009R+9.309	Tn;	0.318	**	y = -0.400Tn+9.715
Cluster 4	Tn, Rh;	0.376	**	y=-0.312Tn-0.59Rh+11.969	Tn, Tx;	0.415	**	y=-0.604Tn +0.488Tx+3.895
Cluster 5	Rh;	0.485	***	y=-0.172Rh+17.730	Rh;	0.346	**	y=-0.155Rh+17.934
Cluster 6	Rh;	0.282	**	y=-0.110Rh+13.269	n.s.			
Italy	Tn, Rl;	0.432	**	y=-0.195Tn-0.007R+9.707	Tn;	0.293	**	y=-0.353Tn+11.523

c)

Cluster	Fire Number: Significant variables	R^2	p	Equation	Burned Area: Significant variables	R^2	p	Equation
Cluster 1	Rh, R;	0.636	***	y=-0.162Rh-0.005R+16.283	Rainfall, Rh;	0.476	***	y=-0.009R-0.197Rh +20.662
Cluster 2	R, Rh;	0.683	***	y=-0.007R-0.082Rh+11.189	Rainfall;	0.570	***	y =-0.016R+ 8.731
Cluster 3	R	0.506	***	y =-0.008R+7.571	Rainfall;	0.383	***	y=-0.011R+10.025
Cluster 4	R	0.489	***	y=-0.011R+6.603	Rainfall;	0.463	***	y=-0.018R+8.996
Cluster 5	R	0.546	***	y=-0.013R+8.618	Rainfall;	0.534	***	y=-0.023+11.490
Cluster 6	R, Rh;	0.521	***	y=-0.059R-0.007Rh + 11.941	Rainfall, Rh;	0.665	***	y =-0.12R-0.117Rh+18.668
Italy	NV				NV			

d)

Cluster	Fire Number: Significant variables	R^2	p	Equation	Burned Area: Significant variables	R^2	p	Equation
Cluster 1	R;	0.389	***	y=-0.004R+3.884	R;	0.484	***	y=-0.009R+6.520
Cluster 2	R;	0.489	***	y=-0.005R+4.784	R;	0.443	***	y=-0.008R+7.257
Cluster 3	NV				NV			
Cluster 4	R;	0.263	*	y=-0.004R+5.894	Tx;	0.218	*	y=1.123Tx-13.627
Cluster 5	n.s.				n.s.			
Cluster 6	n.s.				n.s.			
Italy	n.s.				n.s.			

Notes: R=rainfall, RH=relative humidity, Tx= maximum temperature, Tn= minimum temperature

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