The relationship between temporal patterns of wildfires and phytoclimatic regions in Sardinia (Italy)

S. Bajocco *, A. De Angelis *, L. Rosati *, C. Ricotta *

* Department of Plant Biology, University of Rome “La Sapienza”, Rome, Italy

First published on: 07 December 2009

To cite this Article Bajocco, S., De Angelis, A., Rosati, L. and Ricotta, C.(2009) "The relationship between temporal patterns of wildfires and phytoclimatic regions in Sardinia (Italy)". Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology, First published on: 07 December 2009 (iFirst)

To link to this Article: DOI: 10.1080/11263500903233037
URL: http://dx.doi.org/10.1080/11263500903233037

PLEASE SCROLL DOWN FOR ARTICLE
FIRE REGIMES IN SOUTHERN EUROPE

The relationship between temporal patterns of wildfires and phytoclimatic regions in Sardinia (Italy)

S. BAJOCCO, A. DE ANGELIS, L. ROSATI, & C. RICOTTA

Department of Plant Biology, University of Rome “La Sapienza”, Rome, Italy

Abstract

As a precursor to land management and biodiversity conservation, hierarchical landscape classification and mapping has recently received renewed attention. Since climate is the main factor affecting the coarse-scale spatial distribution of vegetation types, the first step to deal with for developing a hierarchical landscape classification is to categorize the landscape based on the climatic variables that influence the biological systems. Climate also plays an important role in characterizing wildfire regimes. Through its influence on biomass production, climate controls fuel availability. At the same time, climate affects fuel moisture, which is the main determinant for fire ignition and propagation. The influence of climate on coarse-scale landscape classification and fire regimes invites a comparison of phytoclimatic maps to wildfire data. The main objectives of this paper are: (1) to evaluate the phenological uniqueness of the main phytoclimatic regions of Sardinia (Italy) based on five-year data (2000–04) of SPOT-Vegetation NDVI profiles, and (2) to evaluate to what extent the wildfire time series associated to the phytoclimatic regions of Sardinia differ in their temporal properties over the same time span.

Keywords: Fourier transform, NDVI profiles, permutational multivariate analysis of variance (PERMANOVA), SPOT Vegetation

Introduction

Hierarchical landscape classification and mapping have recently received renewed attention, either from a theoretical viewpoint or in case-specific applications (Zonneveld 1995; Bailey 1996; Smalley et al. 1996; Blasi et al. 2000). This is because, as a precursor to land management and biodiversity conservation, landscape units need to be described, characterized and spatially located (Sims et al. 1996).

Whereas all biotic and abiotic components are relevant for landscape classification, their relative importance varies with scale; usually, the significant variables for classifying landscapes are climate, lithology, physiography, soils, human activities, vegetation and fauna (Zonneveld 1995; Blasi et al. 2000). This order of attributes reflects their hierarchy both in time and space, because it moves from relatively stable factors controlling larger ecological scales to more dynamic factors operating at local levels. Accordingly, the first step to deal with for developing a hierarchical landscape classification is to characterize the territory based on the climatic variables that influence the biological systems.

The idea that climate is the main factor affecting the coarse-scale spatial distribution of vegetation types was already recognized by the first phytogeographers, like Humboldt or De Candolle, who first used thermic data to study the climatic distribution of plant formations (see De Philippi 1951). More recently, phytoclimatic classifications based on the characterization of climatic clusters by vegetation types fall into three main categories: studies that attempt to define phytoclimatic regions based on climatic indices (e.g. Thorntwaite 1948; Thorntwaite & Mather 1957; for a review, see Tuhkanen 1980), studies that use a combination of climatic variables and climatic indices (Gadgil & Joshi 1983; White & Perry 1989), and studies that consider climatic variables only (Sun & Feoli 1991; Mazzoleni et al. 1992).

Climate also plays an essential role in characterizing wildfire regimes at the landscape scale. On the one hand, climate affects vegetation phenology...
(Lieth & Whittaker 1975), which is the main determinant for fuel availability; on the other hand, it affects the conditions for fire ignition and propagation through its influence on fuel moisture content (Rothermel 1983) such that good correlations between fire occurrence and climate variables have been found (Vázquez & Moreno 1993; Viegas & Viegas 1994; Vázquez et al. 2002). The observation that phytoclimatic regions and fire regimes are both controlled by climate invites a comparison of phytoclimatic maps to wildfire data. The objective of this paper is twofold: first, to evaluate the phenological uniqueness of the main phytoclimatic regions of Sardinia (Italy) based on SPOT-Vegetation (VGT) NDVI profiles over a five-year period (2000–04), and, second, to evaluate to what extent these phytoclimatic regions differ in the temporal properties of their wildfire time series over the same time span.

**Study area**

The island of Sardinia is located between 38° 51’ N and 41° 15’ N latitude and between 8° 8’ E and 9° 50’ E longitude, and covers roughly 24,000 km² (Figure 1). Sardinia is characterized by a complex physical geography, with a prevalently hilly topography and extreme heterogeneity in geological and morphological features, with a wide variety of biotopes and a long history of human presence. The highest elevation is 1834 m; average elevation is 338 m. The climate of Sardinia is predominantly Mediterranean with hot and dry summers and mild and rainy winters. Average annual rainfall range from less than 500 mm in the coastal areas to more than 900 mm in the inner mountainous regions. Mean annual temperature ranges from 11° C to 17° C. According to the Italian checklist of vascular flora (Conti et al. 2005) the island’s flora comprises 2407 species, 10% of which are endemic. Land use along the coast and the main river valleys is dominated by agriculture that covers about 45% of the study area. In the interior areas, forest stands combined with pastures and shrublands prevail. The principal formations include *Quercus ilex* and *Quercus suber* forests. At higher elevations the sclerophyllous oak forests merge with broadleaved forests of *Quercus pubescens* s.l.

**Data**

**Phytoclimatic map**

Based on summer values of the ombro-thermic index of Rivas-Martinez (2004), Sardinia was classified in three main phytoclimatic regions (AAVV 2005; Blasi & Michetti 2007) – Mediterranean, Transitional Mediterranean and Transitional Temperate – that are characterized by a clear gradient of decreasing summer drought.

From a vegetational viewpoint, besides aholphilous and psammophilous costal vegetation, the potential
natural vegetation (PVN) of the Mediterranean phytoclimatic region is dominated by *Juniperus turbinata*, *Olea europea var. sylvestris*, *Pinus halepensis*, *Quercus virgiliana* and *Q. ilex* communities (i.e. *Oleo-Juniperetum*, *turbinatae*, *Cyclaminio repandi-Oleetum sylvestris*, *Erico arboreae-Pinetum halepensis*, *Lonicero implexae-Quercetum virgilianae*, *Prasio majoris-Quercetum ilicis*).

The actual land cover is composed of sclerophyllous shrubs differentiated by the dominance of *Dendroides majoris-Quercetum ilicis*, *Lonicero implexae-Quercetum virgilianae*, *Praasio tum sylvestris*, *Erico arboreae-Pinetum halepensis*, and *Oleo-Juniperetum turbinatae*, *Cyclamo repandi-Oleae Quercus virgiliana* (i.e. *spinosae turbinata*, *Olea europea*)

natural vegetation (PNV) of the Mediterranean and Temperate phytoclimatic region the dominated by secondary sclerophyllous shrubs (i.e. *etea mediae*).

The PNV of the Transitional Mediterranean region is mainly characterized by *Q. suber* and *Q. ilex* forests (*Galio scabri-Quercetum suberis*, *Violo-Querce-tum suberis*, *Prasio-Quercetum ilicis*). Land cover is dominated by secondary sclerophyllous shrubs (i.e. *Erico-Arbutetum*, *Calycomo-Myrtetum*), garrigues dominated by *Genista corsica*, *Thymus capitatus*, *Sarcopoterium spinosum*, *Rosmarinus officinalis*, *Cistus sp.pl.* (Teucrium mari*, *Cisto-Ericion*), *Q. ilex* forests and arable land. Most urban areas of Sardinia fall into this phytoclimatic region.

The PNV of the Transitional Mediterranean region is mainly characterized by *Q. suber* and *Q. ilex* forests (*Galio scabri-Quercetum suberis*, *Violo-Quercetum suberis*, *Prasio-Quercetum ilicis*). Land cover is dominated by secondary sclerophyllous shrubs (i.e. *Erico-Arbutetum*, *Calycomo-Myrtetum*), garrigues (*Cisto-Lavanduletea*, *Rosmarinetea*), arable land and pastures (*Poetea annuae*, *Stellarietea*, *Tuberarietea*).

In the inner mountain ranges of the Transitional Temperate phytoclimatic region the *Quercus congesta* and *Q. ilex* forests are the most widespread vegetation types (*Ornithogalo pyrenaci-Quercetum ichnusae*, *Glechomo sardoae-Quercetum congestae*, *Galio scabri-Quercetum ilicis*, *Saniculio europaeae-Quercetum ilicis*). Deciduous and sclerophyllous shrublands (i.e. *Erichon arboreae*, *Cytiseta striato-scoparitii, Prunetalia spinosae*) are found in dynamic series with pastures (i.e. *Molinio-Arhenateretea*, *Poetea annuae*, *Stellarietea mediae*), while the orophilous vegetation is mainly composed of *Genista saltzmannii*, *Santolina insularis* and *Astragalus gennargetei* communities (*Carici-Genistetalia lobelii*). For a thorough review of the vegetation series of Sardinia, see Bacchetta et al. (2005).

**SPOT-VGT NDVI data**

A sequence of five years (2000 through 2004) of decadal NDVI maximum value composite (MVC) data of the SPOT-VGT instrument is used in this study. The SPOT Vegetation (VGT) is a new generation of space borne optical sensors with a resolution compatible to NOAA-AVHRR that were designed for space observation of vegetation and land surface (Zhang et al. 2004). VGT provides daily coverage of the globe at 1-km spatial resolution. The NDVI product is atmospherically corrected for ozone, aerosols and water vapor (see Rahman & Dedieu 1994). According to the maximum value compositing procedure (Holben 1986), the NDVI decadal data are generated by selecting for each pixel location the maximum NDVI value within a 10-day period, so there are three 10-day composites for each month: days 1–10, 11–20 and 21 to the last day of a month. This approach helps to reduce problems common to single-date remote sensing studies such as cloud contamination and variability in atmospheric optical depth (Holben 1986). All 180 NDVI MVC images used in this study (36 decadal composites for each year × 5 years) were freely downloaded from the web site of the VITO Center (http://www.vgt.vito.be) and reprojected in UTM coordinates.

**Wildfire data**

We compiled a five-year wildfire time series of Sardinia containing 13377 records on individual fires from 2000 to 2004. For each fire, the records include the date of ignition, the geographic (UTM) coordinates of its ignition point and a field estimate of the burnt area. The database contains all fires that were recorded by the Forest Service, and is assumed to be complete and reliable down to the smallest fires. The recorded size of burnt area ranges between 0.01 and 1815 ha. The total surface burnt during 2000–04 is approximately 88,800 ha.

As concerns fire size distribution, 8782 fires in the 2000–04 period examined are less than 1 ha in size and only 172 fires are larger than 100 ha. While these large fires represent less than 2% of the fires recorded, they account for 53% of the total area burnt in Sardinia from 2000 to 2004.

Though most of the recorded fires are human-caused rather than “natural” in origin, fire is a process largely governed by climate with a peak of the fire season occurring during the hottest and driest portion of the year. As shown in Figures 2 and 3, fire is strongly seasonal: 68% of fires and 74% of area burnt occur between July and September with a peak of fires and hectares burnt during July.

**Methods**

**Fourier analysis of the NDVI profiles**

Phenology has been defined as “the study of the timing of recurring biological events, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species” (Lieth 1974, p. 4). Phenological studies investigate the influence of seasonally varying environmental conditions such as day length, air temperature and water availability on the timing of plant development stages or phenophases, including germination, flowering and senescence (Lloyd 1990). Phenological studies have been traditionally led by ground-based observations of single individuals. In
recent years, however, remotely sensed vegetation indices, such as the NDVI, have been largely adopted to monitor vegetation phenology from satellite-borne imaging systems.

In spite of their coarse spatial resolution, remotely sensed NDVI profiles are still capable of capturing changes in vegetation conditions at the landscape scale. From a biophysical viewpoint, since the pioneer work of Rouse et al. (1974), high correlations between NDVI and parameters such as absorbed photosynthetically active radiation and leaf area index (LAI) have been found. Also, since the amount of photosynthetically active radiation absorbed by the vegetation canopy during the growing season is the major driving factor in net primary productivity (Monteith 1977), a direct relationship between the seasonal net primary productivity and integrated seasonal values of NDVI has been first documented by Tucker et al. (1981).

In a sense, NDVI profiles can thus be defined symphenological indicators according to Ricotta and Avena (2000), as they quantify variations in (remotely sensed) vegetation photosynthetic activity, due to seasonal changes in bioclimatic conditions (Paruelo & Lauenroth 1995; Nemani & Running 1997; Alcaraz et al. 2006).

To analyze the remotely sensed symphenological variability of the bioclimatic regions of Sardinia, Fourier analysis was applied to the multitemporal NDVI profiles on a per-pixel basis for the entire study area. Each annual NDVI profile was analyzed separately.
Basically, harmonic (Fourier) analysis permits a complex signal to be expressed as the sum of a series of sine and cosine waves and an additive term. Each sinusoidal wave is defined by an amplitude and a phase angle, where the amplitude value is half the height of a wave, and the phase angle defines the offset between the origin and the peak of the wave over the range $0–2\pi$ (Jakubauskas et al. 2002).

The advantage of the Fourier analysis is that it decomposes a complex NDVI temporal profile into simpler periodic terms such that the frequency of each term designates the number of complete cycles completed by a wave over the defined time interval (i.e. the first term completes one cycle, the second term completes two cycles, etc.). Successive harmonic terms are added to produce a complex curve (Figure 4).

Figure 4. Principle of Fourier Transform decomposition. (a) Annual NDVI temporal profile of an arbitrary pixel. (b) 1st, 2nd and 3rd harmonic terms of the annual NDVI profile in (a).
Since vegetation phenological cycles generally occur on a one-year time scale, we assume annual NDVI profiles as our basic unit. Furthermore, assuming decadal composited NDVI MVC data, 36 successive NDVI images will be available for each annual profile.

Significant amplitude values associated to low periodic terms indicate significant inter-annual variability of NDVI in response to the annual patterns of temperature and rainfall. The amplitude at one-year period measures the maximum variability of the NDVI values over one year, from the minimum to the maximum NDVI value, while for the period of six months the amplitude is a measure of the variability of NDVI within half-year (Azzali & Menenti 2000). Finally, the additive term is the arithmetic mean over the annual NDVI time series (36 periods) and can therefore be considered a good indicator of the coarse-scale net primary productivity on an annual basis (Ricotta et al. 1999).

Another advantage of the Fourier analysis is that it is rather insensitive to residual noise in the NDVI profiles after maximum value compositing, since atmospheric and cloud-contamination effects generally occur at much higher frequencies (Azzali & Menenti 2000). In this study, the per-pixel additive terms and the amplitude values for the first two periodic terms of each annual NDVI profile were extracted using the classical Discrete Fourier Transform (for mathematical details see Ricotta et al. 1999) and used for further analysis.

Analysis of variance

Because of the landscape-scale approach of this study, together with the coarse resolution of the SPOT-VGT images, small polygons of the original phytoclimatic map of Sardinia were eliminated by combining them with larger adjacent polygons, such that the minimum mapping unit of the combined polygons was 50 km2 (i.e. roughly 50 SPOT pixels). To evaluate the remotely sensed phenological uniqueness of the phytoclimatic regions of Sardinia, first, we randomly sampled 500 pixels for each phytoclimatic region; this was done to reduce pseudoreplication effects due to intense autocorrelation between neighboring pixels. Next we performed a permutational multivariate analysis of variance (PERMANOVA) considering for each pixel sampled the additive term and the amplitude values of the first two periodic terms of the Fourier analysis as independent variables.

PERMANOVA, which represents a multivariate extension of traditional analysis of variance (ANOVA), is a test of significant difference between two or more groups, based on any distance measure (see Anderson 2001; McArdle & Anderson 2001). In analogy with ANOVA, the test calculates an F-value by dividing the variance of all the distances between observations that do not occur in the same group by the variance of all the distances between observations that occur in the same group. A p-value is then computed by permutation of group membership (i.e. by appropriately shuffling the rows and columns of the corresponding dissimilarity matrix).

Based on the Bray-Curtis dissimilarity (Bray & Curtis 1957), differences in the phenological timing of the phytoclimatic regions were tested separately for each year from 2000 to 2004 using 999 permutations. All calculations were done with the program PAST, freely available at: http://folk.uio.no/ohammer/past.

To evaluate to what extent the phytoclimatic regions differ in the temporal properties of their wildfire time series, we computed the starting Julian day (JD) of each fire (i.e. the integer number of days that have elapsed since January 1st of each year). Leap years were not taken into consideration in the computation of the JD such that for all years the starting JD of fires are measured in the range [1–365]. Next, the Kruskal-Wallis statistics (i.e. a non-parametric alternative to ANOVA; Zar 1999) was used to test for differences in the seasonal occurrence of fires in the different phytoclimatic regions on a yearly base.

Results

Multivariate analysis of variance showed a significant phenological difference between the phytoclimatic regions of Sardinia for all years analyzed (Table I). When all observed F-values are compared with the distribution found from these values and 999 alternative F-values obtained by randomly reallocating the pixels to the different phytoclimatic regions, we obtained the most extreme significance level possible $p = 0.001$ (i.e. 1 in 1000). In addition, a pairwise comparison between phytoclimatic regions (essentially a multivariate permutational $t$-test) revealed that all phytoclimatic regions were statistically unique at the $p = 0.05$ level during the 2000–04 period (data not shown here).

At the same time, the Kruskal-Wallis test of no difference in the temporal distribution of wildfires across the phytoclimatic regions obtained using the starting JD of fires as independent variable provided strong support for significant uniqueness in the seasonality of wildfire time series (Table II). A notable exception is the year 2002, for which the test provided only marginal evidence for differences in wildfire seasonality ($H = 4.738, p = 0.093$).

Results of pairwise a posteriori Mann-Whitney tests confirm this observation; for all years but 2002 all phytoclimatic regions were statistically unique in
terms of wildfire seasonality at the $p = 0.05$ level of significance. By contrast, in 2002, the analyzed phytoclimatic regions did not show any significant difference in the wildfire temporal distribution (data not shown here).

**Discussion**

Evaluating the impact of fire on the landscape requires that information on fire regimes are obtained from ecologically meaningful landscape units. Phytoclimatic units can provide one such type of landscape classification. Many significant parameters that characterize coarse-scale fire regimes, like climate, vegetation types and their associated fuel characteristics are directly or indirectly involved in the definition and mapping of phytoclimatic units.

Also, since seasonal and interannual vegetation conditions, whether natural or agricultural, are closely linked to temperature and water supply, even land use is related to phytoclimatic units to some extent (Vázquez et al. 2002). Therefore, our working hypothesis is that there is a significant difference between the phenological characteristics and the temporal patterns of fire regimes associated with the main phytoclimatic regions in Sardinia.

This hypothesis is based on the assumption that the process of classifying and mapping phytoclimatic units could adequately integrate several determinant factors of phenological dynamics and fire occurrence at the landscape scale. Such phytoclimatic classification could then be used as a framework for monitoring seasonal dynamics in ground cover and fire occurrence over large areas. However, as in Sardinia most fires are of human origin, the relationships between phytoclimatic units, phenology and fire temporal patterns may be considerably altered.

Human impact may conduce to a vegetation cover whose fire-related properties (i.e. fuel load and spatial continuity) do not necessarily correspond to those of the natural vegetation. Similarly, humans can also modify fire regimes in terms of ignition frequencies and locations (Vázquez et al. 2002). All these changes may lead to fire regimes that differ to some extent from those expected from the basic characteristics of climate, natural vegetation and its associated fuel load.

A relevant question is then to what extent regional fire occurrence can be related to the coarse-scale ecological classification of a landscape. The analysis of variance on the Fourier components of the annual NDVI profiles and on the starting JD of fires shows a clear and coherent segregation of the major phytoclimatic units in terms of phenological dynamics and temporal characteristics of wildfire regimes.

These results also emphasize a gradient in the mean starting JD of fires; for instance, the earliest mean time of burning is usually related to the Mediterranean phytoclimatic region, which is also the region that experiences the highest number of fires, while the latest mean time of burning is associated to the Transitional Temperate region (see Table II).

Overall, this means that there is a strong climatic control in the temporal characteristics of wildfires, even in regions of high human pressure. Nonetheless, unlike for remotely sensed phenological

### Table I. Results of the permutational multivariate analysis of variance on the NDVI profiles of 500 pixels sampled at random from each phytoclimatic region of Sardinia.

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>225.753</td>
<td>265.345</td>
<td>247.514</td>
<td>167.485</td>
<td>165.883</td>
</tr>
<tr>
<td>p</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Each yearly NDVI profile was analyzed separately; for each pixel sampled the additive term and the amplitude values of the first two periodic terms of the Fourier analysis were used as independent variables. The analysis is based on the Bray-Curtis dissimilarity and 999 permutations.

### Table II. Results of the non-parametric Kruskal-Wallis test of no difference in the temporal distribution of wildfires across the phytoclimatic regions of Sardinia.

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fires</td>
<td>M</td>
<td>1022</td>
<td>1569</td>
<td>1064</td>
<td>1689</td>
</tr>
<tr>
<td></td>
<td>TM</td>
<td>873</td>
<td>1479</td>
<td>667</td>
<td>1112</td>
</tr>
<tr>
<td></td>
<td>TT</td>
<td>200</td>
<td>360</td>
<td>114</td>
<td>184</td>
</tr>
<tr>
<td></td>
<td>Tot</td>
<td>2095</td>
<td>3408</td>
<td>1845</td>
<td>2985</td>
</tr>
<tr>
<td>Mean JD</td>
<td>M</td>
<td>205.960</td>
<td>213.475</td>
<td>192.285</td>
<td>199.856</td>
</tr>
<tr>
<td></td>
<td>TM</td>
<td>213.744</td>
<td>233.180</td>
<td>191.215</td>
<td>205.696</td>
</tr>
<tr>
<td></td>
<td>TT</td>
<td>219.975</td>
<td>238.136</td>
<td>175.043</td>
<td>208.875</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>38.669</td>
<td>186.970</td>
<td>4.738</td>
<td>52.092</td>
</tr>
<tr>
<td>p</td>
<td>0.001</td>
<td>0.001</td>
<td>0.093NS</td>
<td>0.001</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Each yearly wildfire time series was analyzed separately; the starting Julian day (JD) of each fire was used as independent variable. For each phytoclimatic region the number of wildfires and the mean starting JD are also shown. M = Mediterranean region, MT = Transitional Mediterranean region, TT = Transitional Temperate region. NS = not significant at the $p = 0.005$ level.
characteristics, this climatic control is influenced by intense short-term climatic variations. For instance, the months from October 2001 to April 2002 were the driest in the last century; on the other hand, the period July–August 2002 was the rainiest period of the last 60 years (Servizio Agrometeorologico Regionale per la Sardegna 2007). This peculiar precipitation trend leads to a generalized decrease in the number of fires in all phytoclimatic regions, especially in the number of summer fires, and to a consequent increase in the relative number of spring fires. This latter effect was particularly intense in the Transitional Temperate phytoclimatic region. As a consequence, in 2002 there were no significant differences at the $p = 0.05$ level in mean time of burning among the different phytoclimatic regions of Sardinia (see Table II).

To conclude, the results obtained in this study contribute to fire risk assessment at the landscape scale, indicating that risk of wildfire is directly or indirectly related to climate and vegetation phenology. From a practical viewpoint, fire agencies need to have effective decision support tools for quantifying fire risk. Specifically, to improve fire prevention, fire managers need information concerning the spatial and temporal distribution of fires across the landscape (Lasaponara & Lanorte 2007). In this framework, ecologically meaningful landscape classifications may provide geographical units with great potential for the development of strategies for fire risk assessment and fire prevention.

References


Smalley GW, Sharber LB, Gregory JC. 1996. Ecological land classification as a basic theme for the management of