Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
http://dx.doi.org/10.5424/fs/2014233-06115

Forest Systems 2014 23(3): 598-610
ISSN: 2171-5068
eISSN: 2171-9845

OPEN ACCESS

Land cover fire proneness in Europe

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Abstract

Aim of study: The characterization of the fuels is an important aspect of the fire regime in each specific ecosystem while fire is an important disturbance for global vegetation dynamics. This study aims to identify and characterize the spatial and temporal evolution of the fire incidence and of the vegetation types that are most affected by forest fires in Europe, with emphasis on the mixed forests.

Area of study: Europe.

Material and methods: Corine Land Cover maps for 2000 and 2006 (CLC2000, CLC2006) and burned area (BA) perimeters, from 2000 to 2013 in Europe are combined to access the spatial and temporal evolution of the types of vegetation that are most affected by fires using geostatistics and Geographical Information System (GIS) techniques.

Main results: The spatial and temporal distribution of BA perimeters, vegetation and burnt vegetation by fires was performed and different statistics were obtained for Mediterranean and northern Europe, confirming the usefulness of the used land cover classification. A fire proneness index (FPI) is proposed to assess the fire selectivity of land cover classes, to quantify and compare the propensity of vegetation classes and countries to fire.

Research highlights: Mixed forests area is 5% of total European area but has increased 2.1% from 2000 to 2006, while other forest types followed an opposite trend. FPI for scrubs is twice (quadruple) of the value for the forests (agricultural areas) except during the occurrence of mega fire events, when the LCC of forest present higher FPI than the LCC of scrub.

Key words: fire proneness; mixed forests; land cover/land use; fire regime; Europe; GIS; corine land cover.

Introduction

Forest and woodland are recognized as important multi-functional resources (Slee, 2005) providing a wide variety of social, economic and environmental benefits, ranging from easily quantified economic values associated with forest products and less tangible services and contributions to society, to environmental amenities related to air purification, carbon sequestration and prevention of land degradation and desertification (Führer, 2000; FAO, 2010).

The natural vegetation in most of Europe is essentially forest and woodland from the Mediterranean through the deciduous forests of Central and Western Europe to the boreal forests in Fennoscandia (Bengtsson *et al.*, 2000). European forests occupy 1.02 billion ha corresponding to 25% of the total forested area worldwide. Over the last 20 years, the forested area has expanded in all European regions and has gained 0.8 million ha each year (Forest Europe, 2011) except in southern European countries, where fires burnt large areas every year (Schmuck *et al.*, 2011). These countries are an integral part of the Mediterranean region with a temperate type of climate characterized by rainy mild winters and warm dry summers associated to geographical and topographical variation related to the presence of variable coastline and of many mountain ranges. The above mentioned climate characteristics of the region sustain the Mediterranean forests, woodlands and shrub vegetation. Forests and woodlands of Mediterranean region cover about 80 million hectares, almost 9% of the region's land area and constitute a unique world natural heritage in terms of biological diversity, a high degree of tree richness and endemism with extraordinary genetic diversity

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Received: 20-04-14. Accepted: 13-10-14.

which must be preserved (Scarascia-Mugnozza & Matteucci, 2012).

Fires affect a larger area over a wider variety of biomes across the globe than any other natural disturbance to land-based eco-systems (Lavorel *et al.*, 2007; Ichoku *et al.*, 2008). On this respect, the Mediterranean region occupies a prominent position, given the occurrence of devastating summertime fires that burn hundreds of thousands hectares of forests, scrublands and grasslands every year, causing extensive economic and ecological losses and often human casualties (Pyne, 2006; Ventura & Vasconcelos, 2006). A recent review on the role of natural disturbances in European forests from 1850 to 2000 reveals that fires are the second most important disturbance (after the storms) been responsible for 16% of total damage over the 1950-2000 period (Schelhaas *et al.*, 2003). A combination of natural factors (vegetation stress, slopping topography, weather and climate), with a long history of human management practices of natural environments by means of fire, that favour anthropogenic ignitions in the Mediterranean countries, makes this region especially prone to the occurrence of a large number of fire events and to the onset of extreme fire episodes that determine *per se* the majority of the total amount of burnt area (hereafter, BA) in a whole fire season (Viegas *et al.*, 1992; Pereira *et al.*, 2005; Pyne, 2006; Benson *et al.*, 2008; Rasilla *et al.*, 2010; Amraoui *et al.*, 2013). Therefore, it is not surprising that the largest numbers of fires and burnt area in Europe are found in southern European countries, namely Portugal, Spain, France, Italy and Greece (Pereira *et al.*, 2006; Schmuck *et al.*, 2011; Amraoui *et al.*, 2013). On the other hand, several authors reported that the Mediterranean region is considered a "hot spot" for climate change studies, not only because of its high sensitivity to changes in recent decades (Qin *et al.*, 2007; Solomon *et al.*, 2007) but also for the most likely evolution of this region towards a hotter and drier climate, with a significant higher risk of intense heat wave episodes that favour the occurrence of large vegetation fires (Fischer and Schär, 2010; Lindner *et al.*, 2010; Pereira *et al.*, 2013).

There is a long-term interaction between vegetation and fire regime in the Mediterranean region (Colombaroli *et al.*, 2007). Fire selectivity has been studied for vegetation classes in terms of fire frequency and fire size in Canton Ticino, Switzerland (Pezzatti *et al.*, 2009) and Portugal (Barros & Pereira, 2014), alone or integrated with other landscape variables such as topography (slope, aspect, elevation) and distance to roads and towns in central Spain (Moreno *et al.*, 2011) and northern Portugal (Carmo *et al.*, 2011), to test the sensitivity of the landscape to forest fires in peri-urban area of Athens, Greece, to land cover changes (Salvati & Ferrara, 2014) and to define landscape management guidelines and policies based on the relationships between landscape and fires in the Mediterranean region (Moreira *et al.*, 2011). These studies inspired the present work which aims to: (i) analyse the spatial and temporal variability of these statistics within the European countries; and, (ii) identify and characterize the land cover classes most affected by fires and consequently their fire proneness, devoting special attention to mixed forests.

This work is also motivated by the need to study: (a) the propensity of fire on a continental scale, taking into account the spatio-temporal variability of land cover and fire incidence in Europe; (b) the propensity of fire in the different sub classes of forest and scrubland, taking advantage of the large number of classes of Corine Land Cover database, which was developed specifically for Europe; and, (c) using the most complete, reliable, larger and updated datasets.

Material and methods

To achieve the purposed objectives, this study must rely on land cover and fire datasets with detailed spatial information as those obtained from satellite measurements and provided in GIS framework. The former is the Corine Land Cover (hereafter, CLC) database which was finalized in the early 1990s as part of the European Commission programme to COoRdinate INformation on the Environment (Corine) and it provides consistent, reliable and comparable information on land cover across Europe (Stathopoulou and Cartalis, 2007). This study is based on the CLC inventories for 2000 (hereafter, CLC2000) and 2006 (hereafter, CLC2006). Detailed information about the CLC may be found in European Environment Agency website and on official publications of the European Community (Annoni and Perdigao, 1997; Büttner *et al.*, 2004).

The CLC has a standardized nomenclature based mainly upon physiognomic attributes of landscape objects and spatial relationships of the landscape objects with three class levels (Feranec *et al.*, 2010). In this study, a specific combination of first, second and third level CLC classes was considered resulting in the following set of 11 Land Cover Classes (LCC): Artificial surfaces, Agricultural areas, Broad-leaved forest, Coniferous forest, Mixed forest, Natural grasslands, Sclerophyllous vegetation (which comprises the Moors and heathland, Sclerophyllous vegetation, Transitional woodland-shrub and Sparsely vegetated areas CLC classes), Non vegetated areas (that encompasses the Beaches, dunes, sands, Bare rocks and Burnt areas), Glaciers and perpetual snow, Inland water (which is the union of Inland marshes, Peat bogs, Salt marshes, Salines, Intertidal flats, Water courses, Water bodies and Coastal lagoons) and Estuaries, coastal water and sea (which represents the Estuaries and Sea and ocean CLC classes). In general, results obtained for the non-flammable LCC are not presented in the Tables and Figures nor discussed in the manuscript. Since the CLC2006 does not contain information for Greece, this country was not considered in some of the analysis performed and, in those cases, Greek data was excluded from the CLC2000.

The fire database is composed by the perimeters of area burnt by fires in Europe provided by the European Forest Fire Information System (EFFIS). This comprehensive dataset (hereafter, EFFIS) comprises fire records for 21 European countries (Bulgaria, Croatia, Cyprus, Czech, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Spain, Sweden, Switzerland and Turkey) recently updated for the 14-year period defined between 2000-2013. The EFFIS database contains a total of 15,518 fire records providing a detailed description of the shape, size and location (geographical coordinates as well as the country, province and place) of each fire. However, the complete fire ignition date information (day, month and year) is only available for 8,784 fires which corresponds to 57% of total number of fires (NF) while for the remaining records only the year of occurrence is provided. For this reason, this study was performed at annual temporal scale. For proper comparison purposes, the BA in each country should be normalized, by dividing the annual total values by each country land area.

The CLC and EFFIS databases were managed, analysed and combined with GIS to assess the amount of each LCC's area burnt by fires in each year, by intercepting the yearly BA perimeters with the LCC for the most recent previous year. For example, perimeters for the periods of 2000-2006 and 2007-2013 were combined with CLC2000 and CLC2006, respectively. Descriptive statistics were used to perform exploratory data analysis to characterize the spatial distribution and temporal evolution of BA in most affected LCC. Two specific spatial/geo statistical methods were used in this study: the Kappa test (Cohen, 1960) to compare LCC changes in time; and the Global Moran's I test (Anselin, 1995) which is a spatial autocorrelation statistic, to describe the overall dependence of fire perimeters over the entire region. The Cohen's k is defined by

$$k = (n_a - n_\varepsilon) / (n - n_\varepsilon),$$

where n is the number of subjects, n_a the number of agreements and n_ε the number of agreements due to chance. Assuming the independency of CLC classifications and taking into account the large size of the Corine database, k is normally distributed, the standard error and the 95% confidence interval may be easily computed.

In this study, a fire proneness index (FPI) is proposed to assess the fire propensity of the different LCC to fire in Europe. The FPI is defined as the ratio between the area burned by fire in each class (BA_i) and the area of each class ($LCCA_i$),

$$FPI = (BA_i) / (LCCA_i)$$

The assessment of the fire proneness of the land cover types took into account the eventual changes in the area of the LCC over time.

Results

Obtained results for the spatial distribution and the temporal evolution of land cover/land use types, fire incidence and fire proneness will be presented in the following subsections.

Land use/land cover types

The most important features of the spatial distribution of the land use/land cover in Europe (Fig. 1) are: (i) the apparent contrast between the highly forested Sweden and Finland and the remaining Europe dominated by Agricultural areas in the low lands and forests in the highlands; (ii) the high abundance of Sclerophyllous vegetation in Norway and Iceland; and, (iii) the low amount of the European area devoted to non-flammable LCC (*e.g.,* Non vegetated areas and artifi-

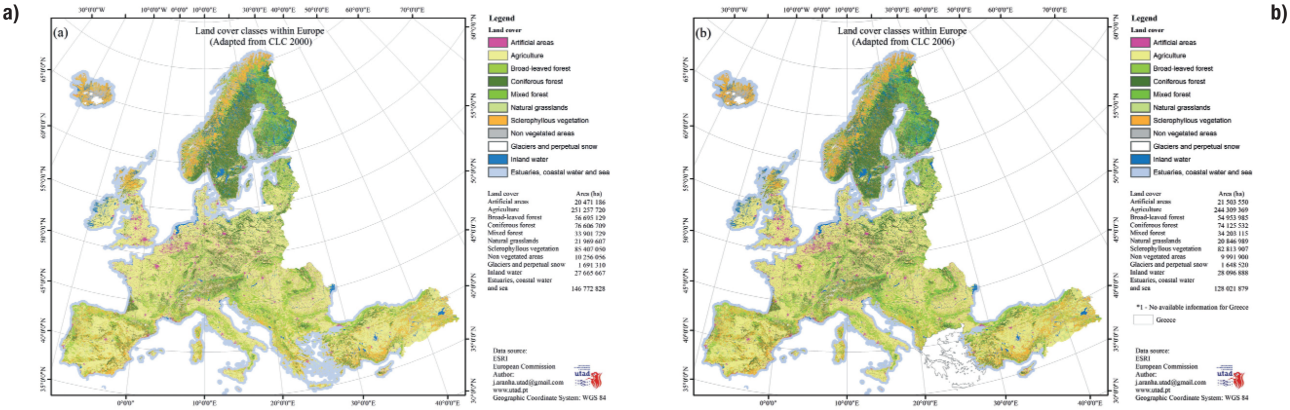


Figure 1. Land Cover Classes (LCC) for Europe based on a specific combination of first, second and third level the Corine land cover classes respecting to (a) 2000 and (b) 2006.

cial areas, surrounding the most important cities). In 2000, the vegetation classes that occupy higher percentage of total area (Table 1) are Agricultural areas (34%), forests (23%) and scrubs (15%), here defined as the LCC of Sclerophyllous vegetation and Natural grasslands. The forested area is dominated by Coniferous forests (11%) and Broad-leaved forests (8%). The Mixed forests occupy only 5% of total area, are relatively wide spread within continental Europe (Fig. 2) but are particularly concentrated around the Baltic Sea (Finland, Baltic States and Poland), Alpine states, Turkey and NW Iberia.

Changes between the CLC2000 and CLC2006 classifications for entire Europe were evaluated using the Cohen's kappa coefficient and obtained result ($k = 0.963$) points for an excellent agreement. In fact, from 2000 to 2006, the percentage of total area of each LCC did not change much (< 0.3%) in time except in the area devoted to agriculture (0.7%) and occupied by Sclerophyllous vegetation (0.5%). Maximum relative differences from 2000 to 2006 were detected on the non-flammable land cover types. The area covered by Sclerophyllous vegetation and Natural grasslands increased (1.4% and 0.2% respectively) whereas the Coniferous and Broad-leaved forests present a cumulative relative decrease of 3.3%. On the contrary, Mixed forests have increased 2.1%.

Fire incidence

According to the EFFIS database, the Mediterranean countries are the most prone for fires (Table 3). In fact, by decreasing order of total BA, Portugal,

Table 1. Total and relative area of each Land Cover Type (LCC) in Europe for the two assessment years of 2000 and 2006

Land cover class (LCC)	Area			
	2000		2006	
	(ha)	(%)	(ha)	(%)
Artificial surfaces	20,171,326	2.9	21,503,550	3.1
Agricultural areas	245,850,008	35.1	244,309,369	34.9
Broad-leaved forest	55,436,997	7.9	54,953,985	7.8
Coniferous forest	75,834,087	10.8	74,125,532	10.6
Mixed forest	33,464,345	4.8	34,203,115	4.9
Natural grasslands	20,764,441	3.0	20,846,989	3.0
Sclerophyllous vegetation	81,587,010	11.6	82,813,907	11.8
Non vegetated areas	10,200,693	1.5	9,991,900	1.4
Glaciers and perpetual snow	1,764,581	0.3	1,648,520	0.2
Inland water	27,375,728	3.9	28,096,888	4.0
Estuaries, coastal water and sea	128,066,418	18.3	128,021,879	18.3
Sum	700,515,634	100.0	700,515,634	100.0

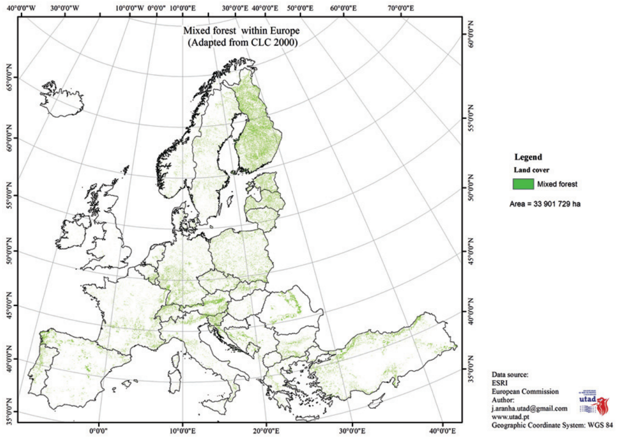


Figure 2. Spatial distribution of the Mixed forests in Europe for the year 2000.

Spain, Greece, Italy and France accounts for an impressive 78% of the grand total burnt area by fires within Europe during the 2000-2013 period. These southern European countries account for an even higher fraction (83%) of the total number of fire records but with a higher NF in Italy than in Greece. Only two other European countries (Albania and Bosnia) present values of fire incidence comparable to those of the lesser affected southern European countries (France and Greece, respectively). For this reason, most of this study will be focused on Mediterranean Europe.

Total, relative (to take into account the country size) and average fire incidence statistics (Table 4) also help to put in evidence the distinct magnitude of this hazard within the Mediterranean region. All fire statistics, except average fire size, are much higher for Portugal than for the other countries. For example, the ratio between the NF in Portugal and in each of the other countries ranges between 2.4 (with Spain) to 13.2 (with Greece) while the correspondent fraction for BA ranges between 1.3 (also with Spain) and 11.2 (with France). Opposite results are obtained for the average size of fires where the lowest values are obtained for Portugal and Italy and are about half of those obtained for Spain and France and nearly a sixth of the annual average fire size in Greece.

The spatial distribution of the fire incidence are only shown for these five most affected countries (Fig. 3) because the BA perimeters are almost imperceptible in the other European Countries. The obtained spatial pattern is also non-uniform, revealing regions with high density of fire polygons, namely the Northern half of Portugal, Spanish region of Galicia, southern Italy, Greek regions of Peloponnese and southern Euboea and the islands of Corsica, Sardinia and Sicily. Large fire perimeters are also found in the southern coast of Portugal and eastern Spain. France is much less affected by fires and the BA are concentrated near the Mediterranean coast.

The evolution of total annual BA (Fig. 4) reveals a pronounced inter-annual variability with maximum values registered in 2003 and 2005 in Portugal, 2007 in Greece and Italy, and 2012 in Spain. In the fourteen years of the study period, values of annual BA are higher in Portugal and/or Spain in ten years and in Italy and/or Greece in just two years. Maximum fire recu-

Table 2. Total and relative area of Mixed Forests in each European country for the year 2000

Country	Area	
	(ha)	(%)
Austria	1,296,133	3.8
Belgium	277,611	0.8
Bulgaria	643,358	1.9
Switzerland	470,874	1.4
Cyprus	614	0.0
Czech Republic	613,160	1.8
Germany	2,420,192	7.1
Denmark	131,947	0.4
Estonia	854,535	2.5
Greece	409,661	1.2
Spain	1,542,830	4.6
Finland	9,030,859	26.6
France	1,930,892	5.7
Croatia	268,501	0.8
Hungary	162,452	0.5
Ireland	22,418	0.1
Iceland	7,984	0.0
Italy	1,066,019	3.1
Liechtenstein	4,299	0.0
Lithuania	747,564	2.2
Luxembourg	16,174	0.0
Latvia	1,219,769	3.6
Montenegro	104,514	0.3
Macedonia	53,946	0.2
Malta	102	0.0
Netherlands	94,789	0.3
Norway	485,820	1.4
Poland	2,266,032	6.7
Portugal	545,907	1.6
Romania	1,035,207	3.1
Sweden	1,653,998	4.9
Slovenia	462,583	1.4
Slovakia	363,802	1.1
Turkey	3,646,001	10.8
United Kingdom	51,182	0.2
Sum	33,901,729	100.0

Table 3. Fire incidence in European countries. Total and relative number of fires (NF) and burned area (BA) for the countries contemplated in EFFIS fire database for the 2000-2013 period

Country	BA		NF	
	(ha)	(%)	(#)	(%)
Albania	273,128	6	687	5
Belgium	2,180	0	3	0
Bosnia	181,772	4	286	2
Bulgaria	107,800	2	159	1
Croatia	75,299	2	142	1
Cyprus	12,388	0	42	0
France	118,208	2	377	3
FYROM	113,713	2	238	2
Germany	133	0	1	0
Greece	593,396	12	653	5
Hungary	1,897	0	5	0
Ireland	24,883	1	25	0
Italy	530,969	11	2,382	17
Kosovo under UN	25,010	1	74	1
Latvia	65	0	1	0
Montenegro	83,219	2	216	2
Norway	3,610	0	3	0
Portugal	1,564,400	32	5,211	37
Romania	6,531	0	31	0
Serbia	32,670	1	75	1
Slovenia	1,170	0	3	0
Spain	1,052,295	21	3,334	24
Sweden	2,602	0	13	0
Switzerland	74	0	1	0
The Netherlands	148	0	1	0
Turkey	89,163	2	137	1
United Kingdom	22,642	0	60	0
Total	4,919,365	100	14,160	100

rrence is very similar in Portugal and Italy (where the same parcel may burn 6-7 times in the last 14 years) and much higher than for Spain, Greece and France (3-4 times).

The results of this subsection lead to focus the following analysis on the countries of southern Europe with the exception of Greece because the CLC2006 do not comprise information for this country.

Table 4. Absolute and relative fire incidence statistics for the most affect Mediterranean countries of Europe in the period 2000-2013. Descriptive statistics includes absolute total number of fires (NF) and burned area (BA), and relative to country land area (CLA), maximum fire recurrence, annual averaged NF, BA and size of the fire (BA/NF)

Country	France	Greece	Italy	Portugal	Spain
Total number of fires (NF) (#)	410	771	3,482	10,143	4,190
Maximum fire recurrence (#)	3	4	6	7	4
Total burned are (BA) ($\times 10^3$ ha)	116	565	467	1,304	1,003
Land area (LA) ($\times 10^6$ ha)	55	13	30	9	50
BA/LA (%)	0.211	4.279	1.553	14.656	2.011
NF/LA (%)	0.001	0.006	0.012	0.114	0.008
Annual average BA (ha)	8,304	40,328	33,386	93,117	71,639
Annual average NF (#)	29	55	249	725	299
Annual average BA/NF (ha)	284	732	134	129	239

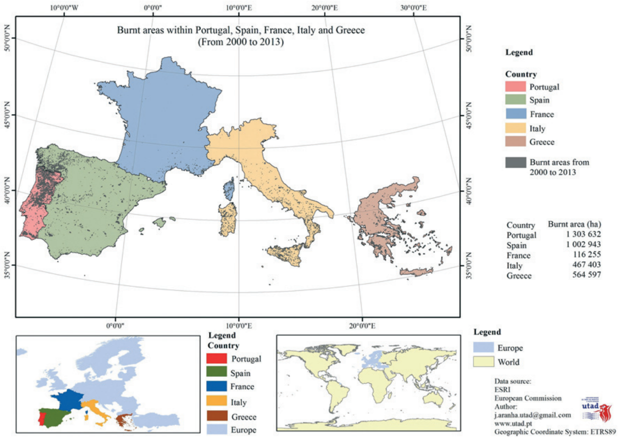


Figure 3. Perimeters of area burnt by fires in the five most affect Mediterranean countries of Europe in the 2000-2013 period.

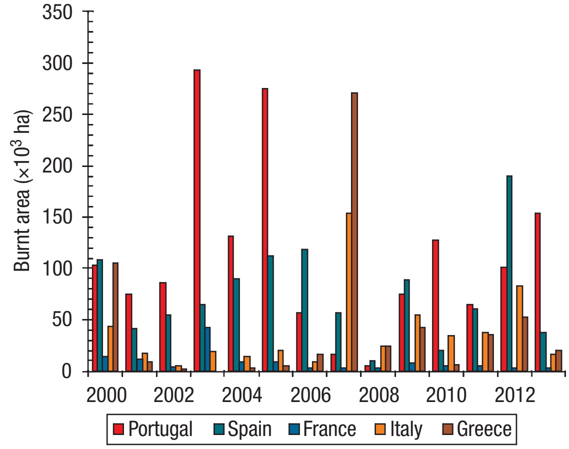
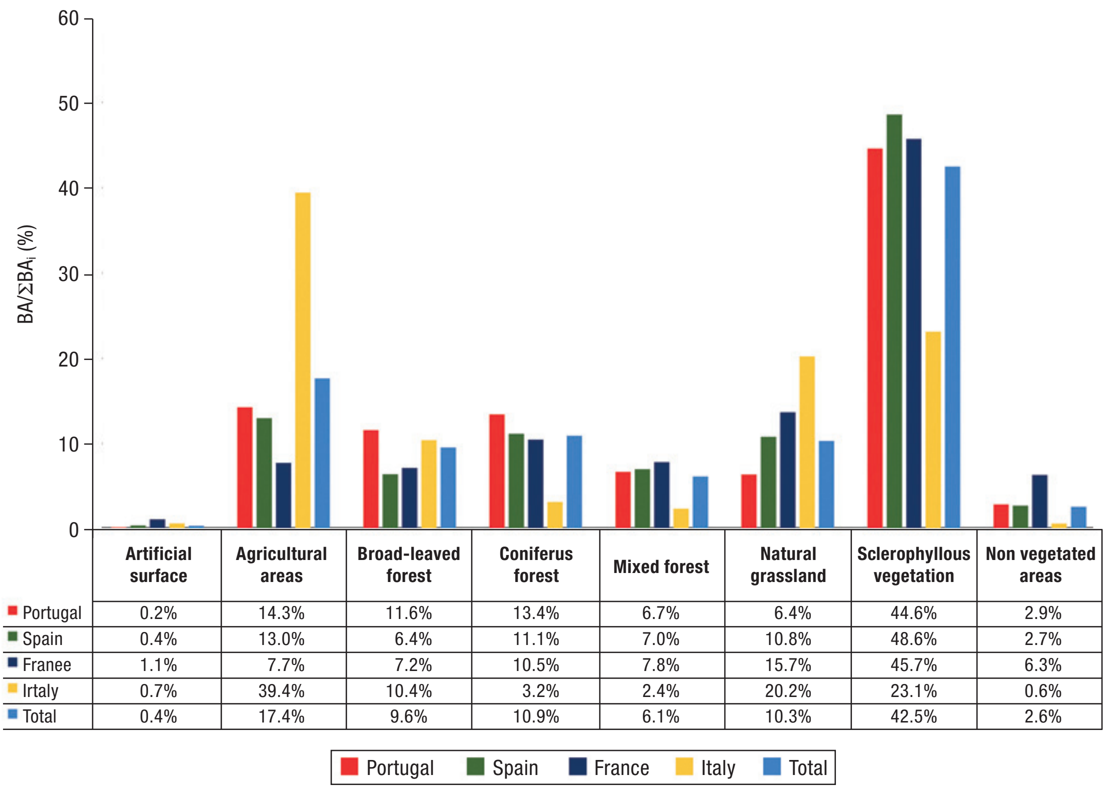


Figure 4. Total annual burnt area in the five most affect Mediterranean countries of Europe. Same colour palette for countries as Fig. 3.

Fire proneness

The relative burnt area in each LCC for each and for all of the four Mediterranean countries together are presented in Fig. 5. At regional scale, about 60% of the total burnt area occur in the Sclerophyllous vegetation (42.5%) and Agricultural areas (17.6%). These results are a consequence of the higher relative burnt area in the Sclerophyllous vegetation for Portugal, Spain and France (between 45% and 49%) and in the Agricultural areas for Italy (40%). Percentage of total burnt area is similar (10%) for Natural grasslands, Coniferous and Broad-leaved forests but much smaller for Mixed forests (6.1%).



	Artificial surface	Agricultural areas	Broad-leaved forest	Coniferus forest	Mixed forest	Natural grassland	Sclerophyllous vegetation	Non vegetated areas
Portugal	0.2%	14.3%	11.6%	13.4%	6.7%	6.4%	44.6%	2.9%
Spain	0.4%	13.0%	6.4%	11.1%	7.0%	10.8%	48.6%	2.7%
Franee	1.1%	7.7%	7.2%	10.5%	7.8%	15.7%	45.7%	6.3%
Irtaly	0.7%	39.4%	10.4%	3.2%	2.4%	20.2%	23.1%	0.6%
Total	0.4%	17.4%	9.6%	10.9%	6.1%	10.3%	42.5%	2.6%

Figure 5. Total burnt area in each land cover class (BA_i) in percentage of total burnt areas in all land cover classes (ΣBA_i) for each and for and all (Total) of the four southern European countries most affected by fires. Same colour palette for countries as Fig. 3.

As expected, LCC of forest, scrub (Sclerophyllous vegetation and Natural grassland) and Agricultural areas account for 93% (in France) to 99% (in Italy) of total area burnt by fires. However, the distribution of the BA in different LCC is not uniform between the four countries. The percentage of BA in agriculture, forest and scrub classes is about 39%, 16% and 43% for Italy, about 10%, 25% and 60% for Spain and France and 14%, 32% and 51% for Portugal. In general, the values for the Mixed forests are the lowest obtained for the three forest types and about half of the remainder in Portugal.

These results already integrate the changes in time of each LCC's area. In spite of the Cohen's *k* confirm the excellent agreement (*k*= 0.947) between the CLC2000 and CLC2006 for the four southern European countries (regional scale) there are significant relative changes at local scale, namely in Portugal (Fig. 6). However, the percentage of total burnt area in each LCC do not take into account the total area of the LCC nor eventual differences in the structure of land cover/land use between the Mediterranean countries.

The FPI allows the comparison of the fire proneness for different LCC in the Mediterranean Europe and among the countries of this region (Fig. 7). The FPI is very small for the Agricultural areas, in both regional and country scales, a consequence of the high total area of this LCC. FPI is moderate for forest and high for the scrub LCC. At regional scale, the Mixed forests presents higher FPI than the other forest classes. This is also the case for Spain and France while the Coniferous forests presents the higher FPI in Portugal and Italy. The temporal evolution of the FPI of each LCC in each country (Fig. 8) highlights the anomalous value of FPI for the Non vegetated areas in 2000 and the high FPI of the scrubs classes throughout the years except in the years of high BA in Portugal and Spain. Actually, the LCC with higher FPI for Portugal in the years of 2003 and 2005 are the Coniferous and Broad-leaved forests whereas for Spain in 2006 is the Mixed forests.

Discussion

The higher fire incidence in the southern European countries have been evidenced by several studies using other databases (Pereira *et al.*, 2011; Schmuck *et al.*, 2011). This result is most likely due to the temperate type of climate of this region (Peel *et al.*, 2007) that

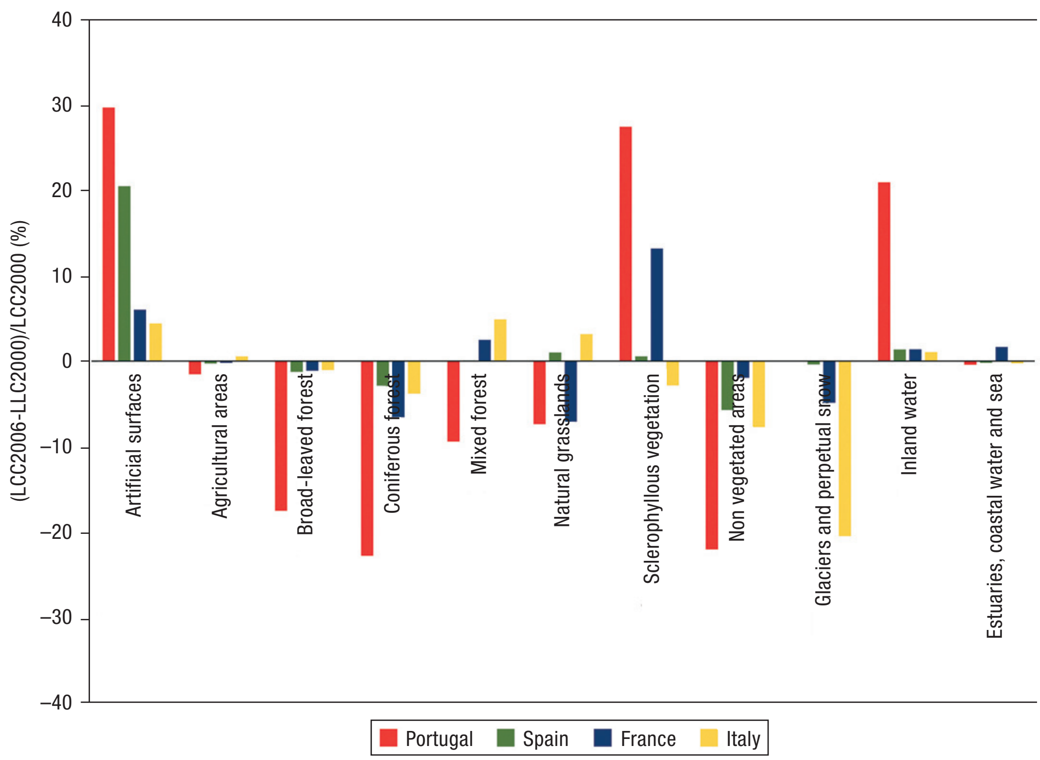


Figure 6. Relative changes, from 2000 to 2006, in the area of each land cover class (LCC) in the four Mediterranean countries of Europe most affect by fire. Same colour palette for countries as Figure 3.

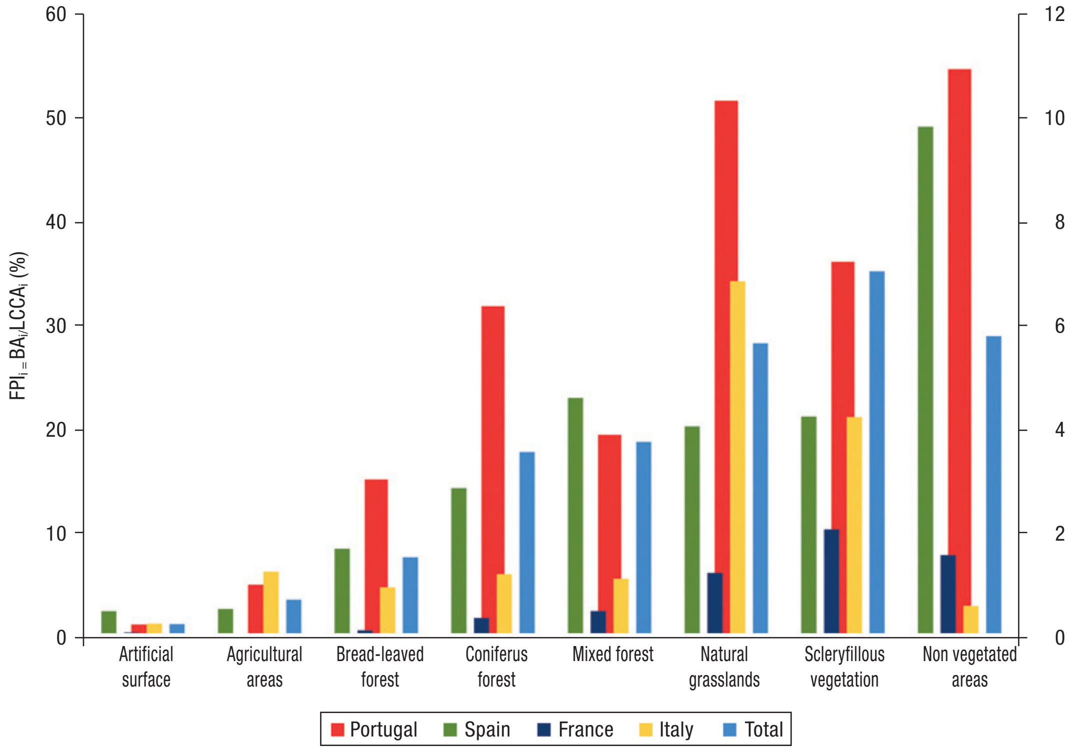


Figure 7. Values of the fire proneness index (FPI) for each land cover class and in the four Mediterranean countries. Series for Portugal is plotted in wider column and in primary axis and for the other countries in secondary axis.

favors the existence and growth of the vegetation during the mild and rainy winters and its hydric and thermal stress during the hot and dry summers (Pereira *et al.*, 2013). Portugal is the most affected country, with about one third of the total NF and BA, a position that is even enhanced by relative fire statistics. However, in contrast, Portugal presents the smallest average fire size which is consistent with the highly asymmetric fire-size distribution in this country, where 10% of the largest fires are responsible for 90% of total burnt area (Pereira *et al.*, 2011). The spatial distribution of the fire perimeters in Southern Europe, shows clustering patterns (Figure 3) similar to those identified and characterized in previous studies (Krawchuk *et al.*, 2009; Bowman *et al.*, 2013).

Consequently, the Global Moran's I test was applied to BA perimeters map in order to analyse the existence of spatial autocorrelation using several options (*e.g.* inverse distance, inverse squared distance, Euclidean distance and Manhattan distance). Obtained results always indicated that BA are randomly scattered by landscape. These results are due to BA spatial distribution characteristics within the four countries in analysis: Portugal, Spain, France and Italy. While for North Portugal average distance between burnt areas is around 2,500 m, in South Portugal the average distance between burnt areas is around 7,500 m. Very different results were attained for France where average distance between burnt areas is around 7,500 m in the South and over 150,000 m in the North.

There is an high inter-annual variability of the fire incidence, with a few extremely high annual BA values which are a consequence of the occurrence of mega fires associated to extreme meteorological conditions (Pereira *et al.*, 2005; Trigo *et al.*, 2006; Pereira *et al.*, 2011; Amraoui *et al.*, 2013; Trigo *et al.*, 2013). It is also worth noting the apparent oscillation between the periods of higher fire incidence among the countries of western and eastern Mediterranean as well as the higher average fire size in Greece which motivates further research that, however is out of the scope of this study.

In this study we considered a specific combination of first, second and third level CLC classes, that we believe best help to achieve the proposed objectives of identifying and characterizing the LCC most affected by forest fires and with highest fire proneness. Three groups of LCC were considered to embrace the three types of forest and all types of scrubs and Agricultural areas. These three types of vegetation classes we-

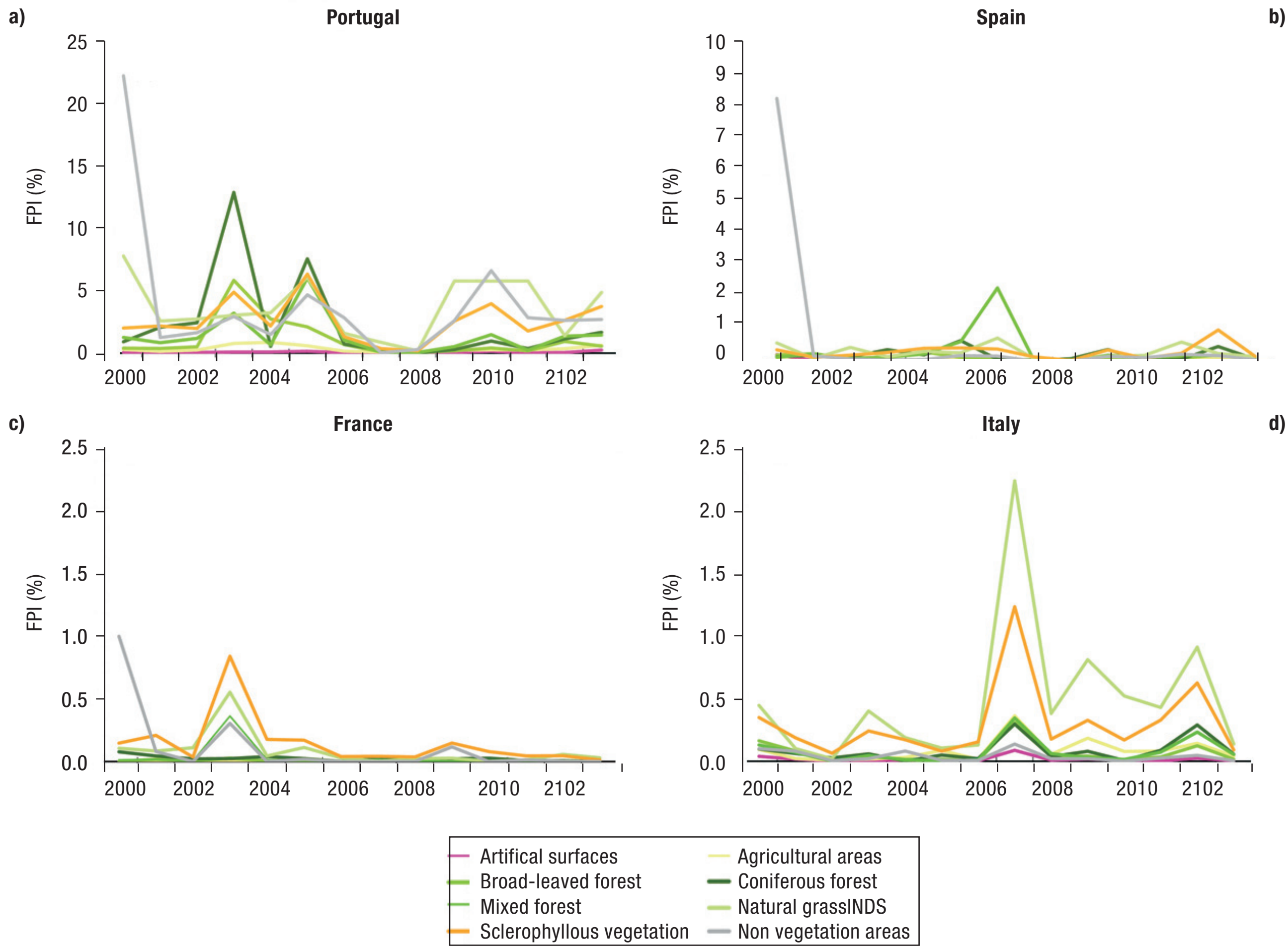


Figure 8. Temporal evolution of FPI of each LCC for (a) Portugal, (b) Spain, (c) France, and (d) Italy. Upper limit of the vertical axis are not equal in the four plots. Same colour palette for LCC as Fig. 1.

re defined for being susceptible for fire occurrence and are also used in fire datasets at national level (Pereira *et al.*, 2011).

Differences in land use/land cover structure between southern and northern Europe may also help to understand why Mediterranean countries are most affected by fires (Fig. 4). In the Southern Europe countries, agriculture, scrubs and forests occupy, respectively, 25%, 3% and 1% more area than the remaining Europe. In addition, the four Southern European countries, have more 7% of Broad-leaved forests but less 5% and 2% of Coniferous and Mixed forests, respectively.

For sake of simplicity but without compromising the significance of the results, the analysis of the amount of BA in each LCC was performed for the European countries with higher fire incidence. Main results points to a large variability between the western and eastern Mediterranean countries, especially in the forests and scrubs which is dominated by the BA in Sclerophyllous vegetation in Portugal (42%), Spain (48%) and France (45%), almost equally distributed between Sclerophyllous vegetation (20%) and natural grasslands (23%) in Italy. This west-east Mediterranean spatial trend is also characterized by the increase of BA in Agricultural areas.

In Portugal, significant differences between the area of the LCC in 2006 and 2000 were detected in the Artificial surfaces due to high rural abandonment and urbanization in the last years, Inland waters owing to the construction of the Alqueva hydro basin, which is the largest artificial lake in Europe, and a significant decrease in the area of forest and Natural grasslands mainly due to fires. The other southern European countries only registered significant changes in the Glaciers and perpetual snow for Italy and France, most likely due to climate change.

A fire proneness index was defined as the ratio between the area burned by fires in each LCC and the area of the LCC. Obtained results suggest the scrublands and grasslands as the most preferred by fire, followed by forests with intermediate preference while the Agricultural areas and Artificial surfaces tend to be avoided. These results are in good agreement with the findings of previous studies (most of them for the same study area), that combine several characteristics of the landscape and fire regime including its frequency, intensity, size, season, type and extent (Nunes *et al.*, 2005; Bajocco & Ricotta, 2008; Moreira *et al.*, 2011; Archibald *et al.*, 2013; Oliveira *et al.*, 2013; Barros & Pereira, 2014).

Higher fire proneness in scrublands and regional variations in fire proneness for land cover have been suggested for Portugal by other authors (Carmo *et al.*, 2011) which also suggest the introduction of fuel breaks in agricultural areas in flat slopes. The greater propensity of scrublands to burn and/or an increase in the fire frequency are positive feedbacks for fire occurrence able to promote landscapes covered by fire-prone scrublands (Mermoz *et al.*, 2005; Moreira *et al.*, 2011).

The interpretation of the anomalous features of the temporal evolution of the FPI (Figç 8) is as follows. The anomalous value of FPI for the Non vegetated areas in 2000 due to: (i) the CLC2000 comprises the Burnt areas LCC which already accounted for BA perimeters in this year; and (ii) the amplification of this effect, through the normalization of the BA by very small area of this class (< 0.9% of total area in Portugal, Spain and France). The greatest value of the FPI in forest LCC in years of higher BA, when the mega fires occurred, suggests that small fires have propensity for scrubs LCC while large fires have greater propensity for LCC forest. This result had already been suggested in other studies, in particular for Portugal, based on the 1991 fires (Nunes *et al.*, 2005).

Conclusions

Major differences between northern and southern European countries were found in the land cover and fire incidence as well as among the southern countries (Portugal, Spain, France and Italy) in fire proneness. The land cover conditions, in association with other structural (*e.g.* climate and socioeconomic activities) and circumstantial (*e.g.* extreme warm and dry weather events) characteristics may help to understand why fire incidence is much higher in the Mediterranean (83% of total NF and 78% of total BA) than in the northern European countries.

In summary, the major findings of this study respecting the land cover and fire incidence distributions are: (a) the LCC spatial pattern is not uniform but presents differences between the northern (Scandinavian Peninsula, Finland and Iceland) and the remaining Europe; (b) the CLC2000 and CLC2006 do not present significant differences at continental and regional scales, however significant changes were founded for Portugal in almost all LCC; (c) the southern European countries are, by far, the most affected by fires and Portugal presents the worst fire statistics except the averaged fire size which is consistent with the high predominance of small fires in this country.

To achieve the proposed objectives, this study used the most comprehensive and updated versions of the European official database of CLC and EFFIS to assess the fire proneness in Europe, for their high spatial information content. However, the temporal size of the EFFIS database is only a fraction of some of the national databases. Nevertheless, the results obtained using this database for the fire incidence in entire Europe are consistent with those obtained for specific European countries and regions.

Most important conclusions from the fire proneness analysis, which accounts for changes in the LCC's area, comprises: (d) the higher percentage of total BA in scrubs (53%), forests (27%) and agriculture areas (18%); (e) the ability of the proposed fire proneness index (FPI) to effectively assess the propensity to fire of each LCC in each and in all the four southern European countries, by taking into account the LCC's size and the different LCC structure within the Mediterranean countries; (f) the identification of the scrubs (principally Sclerophyllous vegetation) as the LCC with the highest fire proneness, followed by forests with moderate propensity to fire while Agricultural areas have much smaller FPI; (g) the constancy of this pattern in all the four southern countries; (h) its persistence in time except during the occurrence of mega fire events, when the LCC of forest present higher FPI than the LCC of scrub; and, (i) the increased propensity of forest LCC for large forest fires.

The most important conclusions pertaining to Mixed forests includes: (j) its wide distribution throughout continental Europe that do not disguise the existence of zones of higher density; (k) be the type of forest that occupies less area but experiencing the major increase from 2000 to 2006, (l) following an opposite trend to that found for the other two forest types; and, (m) being the type of forest with the lowest percentage of BA but with the highest proneness to fire. For these reasons, special attention should be devoted to forest management and fire prevention in this type of forest.

Mediterranean region is the most affected by fires in Europe. Natural conditions like the morphology of the landscape, land cover and weather strongly affect fire activity. The fire regimes, among other factors, depend on the land cover/land use type. In this context, knowing the evolution of the LCC most affected by fire and its spatiotemporal distribution are essential to characterize the referred fire regime and, consequently, may improve the planning and management of agroforestry system as well as can support prevention measures of fire occurrence and firefighting.

Acknowledgements

Fire data were provided by the European Forest Fire Information System-EFFIS (http://effis.jrc.ec.europa.eu) of the European Commission Joint Research Centre while the Corine Land Cover was download from the European Environment Agency website (http://forest.jrc.ec.europa.eu/effis/). The authors are especially thankful to João Pereira for the spelling and grammar review of the Manuscript. The networking in this study has been supported by COST Action FP1206 EuMIXFOR. The authors are also grateful to two anonymous reviewers for their suggestions and comments that helped make the manuscript much clearer and consistent.

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