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Unregulated urban sprawl and spatial distribution of fire events: evidence from Greece

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ABSTRACT
Fire events are an annual phenomenon in Greece with damages and even casualties, making their understanding and management important. In this paper, we present fire events provided by NASA Fire Information for Resource Management System and place them along a number of spatial types defined by relief and land cover classes. Results demonstrate that the occurrence of fire events is related more to some land cover classes than others. The most important in terms of overall frequency in all types of terrain is 'Agricultural Areas', as a result of farming practices that involve fire. The second more important type of areas is 'Artificial Surfaces', especially in low lying areas. These events are related to urban growth and sprawl and are very often a direct outcome of speculation practices with land properties, encouraged by the absence or poor implementation of spatial planning.

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1. Introduction

1.1. Fire events

Every summer more than 45,000 fires burn approximately 0.5 million hectares of forests, olive groves, scrub-land, sclerophyllous plants and other rural lands in the Mediterranean (Camia et al., 2008), and figures reveal continuous increase despite of large invested resources in fire prevention and suppression (Moreira et al., 2011; but Turco et al. (2016) report that these higher numbers of events refer to decreasing burnt areas for the last 30 years). Although fires are an integral part of many Mediterranean ecosystems (Naveh & Carmel, 2004), frequent and intense events are considered as a factor that is contributed to soil degradation achieved with the removal of plant cover that eventually results in soil erosion (Pausas, Llovet, Rodrigo, & Vallejo, 2009). These fires, more often than not, are related to human-induced activities. The most important practices that contribute to more frequent and intense fires are (Alcasena et al., 2015; Camia et al., 2008; Loepfe, Martinez-Vilalta, Oliveres, Piñol, & Lloret, 2010; Moreira et al., 2011; Ruiz-Mirazo, Martínez-Fernández, & Vega-García, 2012): (a) urbanization, which is considered a cause of habitat fragmentation and provides combustion; (b) land use changes, including agricultural abandonment and forest growth, that increase not only the flammable material in the

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landscape but also the abandonment of traditional management activities in forests, including pine resin harvesting and grazing among others; (c) outdoor recreation activities that involve fires; (d) agricultural practices, including e.g. stubble burning after cereal harvesting, the burning of cuttings and pruned branches from trees on site; (e) the management of plant communities of grazing lands, by burning unwanted or unpalatable shrubs in phrygana landscapes; and (f) waste that provide flammable material and combustion sources (glass, paper, etc.).

The importance of human practices in fire ignitions in the Mediterranean has led to the exploration of spatial ignition patterns of human and biophysical variables, which according to Alcasena et al. (2015, p. 1200) 'often show significant correlations however do not necessarily reflect burn probability since the propagation of these latter fires are dependent on fuels and topography at landscape scales' (see also Kalabokidis, Palaiologou, & Finney, 2013; Salis, Ager, Finney, Arca, & Spano, 2014). A direct implication of the human-induced character of many ignitions has been of growing importance to study fire risk and behaviors at the wildland/rural and land/urban interface (Levin & Heimowitz, 2012). Such fires often consist greater danger for 'civil protection' and housing, tourism or industry-related land uses and structures, rather than for the 'wild' vegetation or cultivation and livestock (Pausas et al., 2009; Ruiz-Mirazo et al., 2012). Understanding and managing such risks have proven very important for policy-makers, planners and fire management organizations (Alcasena et al., 2015). Recently, the role of fire has been introduced in socio-ecological systems approaches, related to the concept of resilience (Ferrara et al., 2016; Kelly et al., 2015), with a focus on both so-called fast and slow variables, since a major fire can be an agent of rapid change, but in the long term, fires in general are also agents of slower rates of change in a socio-ecological system. This is a view that we share, in the sense that in our case, fires have been used as an agent of slow landscape change in favor of urban sprawl.

1.2. Fire events in Greece

In Greece, fires are an annual phenomenon (Stamou, Xystrakis, & Koutsias, 2016), with almost daily reports in the news on smaller or bigger fires in different areas of the country from roughly the middle of the dry season and onwards (starting in July, August and continuing through September) when the dry summer months have increased the probability of combustion and the flammable vegetation, especially in days with strong winds. Damages reported and even casualties (Diakakis, Xanthopoulos, & Gregos, 2016) have made understanding and management of fire events urgent (Kalabokidis et al., 2016). The Greek Authority responsible for Civil Protection (GSCP) reported in 2013 that during the period between 2000 and 2012, 140,000 fire events in Greece burned 7000 km^2 and costed 125 lives. According to Fire Service data quoted by GSCP, one in four of these events was caused by 'negligence' and one in two caused 'intentionally', reaching 80% for human-induced fire events. Although it is often very difficult to distinguish between 'negligence' and 'intention' and fires are part of the ecology of some Mediterranean ecosystems, the frequency of occurrence, the devastating human losses and economic and environmental costs call for a deeper understanding of the type of spaces where fires occur and the practices behind these events.

Geographical features of the Greek peninsula have been considered as very important factors for fires (Kalabokidis et al., 2013). These features are climate, geomorphology and relief. Although the mountains of Greece are not very high (less than 2900 m), the relief is fragmented with steep slopes and few level areas, while the mountain range of Pindos effectively separates the peninsula into western and eastern Greece and in many smaller ones. Administrative mountainous areas cover 42.3% of the total area of the country, but only a tenth of the total population lives there (MEPPPW, 2003a). Most of the population and productive activities are located in the extended coastal zone (with a 5 km buffer zone 33,000 km^2 or 25% of the total territory being included in it, along with 6000 islands and islets, 112 of which are inhabited). The climate is Mediterranean with a number of variations: wetter in the west and wet and cold along the Pindos range, while it becomes drier and warmer in the south-east and semi-dry on the islands and in the south.

Land cover and use follows this distribution (Kizos & Vlahos, 2012), with deciduous forests in the mountains in North and Central Greece, evergreen Mediterranean forests and shrubland in lower altitudes and in the South (most of which have been grazed by sheep and goats from the past until nowadays), while level areas are cultivated with arable crops and some fruit plantations or olives. Pine forests are found all around the country, but they are more abundant in the coastal strip, semi-mountainous areas, on the islands and in the South (Tsilimigkas & Kizos, 2014). Recent changes in these land use patterns are important, some of which can also be attributed to fires (Stamou et al., 2016), mostly related to shrubs and maquis vegetation.

The rest of human geography follows more or less this particular geographical context. In the last decades, the population moved from uplands to lowlands and along the coastal strip, where most major transport infrastructures and industries are also located. This rural exodus, typical of all Mediterranean counties in the late twentieth century (Benoit & Comeau, 2005), has brought the following developments: (a) Abandonment of land management activities (agriculture, livestock and forestry) in the uplands (Moisides, 1986), where maquis – forest regeneration replaced cultivated and grazing lands and/or managed forests. (b) Intensification of cultivation in the level and lowland areas, assisted by large-scale projects of land reclamation, irrigation and mechanization (Tsilimigkas & Kizos, 2014). (c) Rapid and largely 'unplanned' urbanization increased the size of the cities, with Athens being a characteristic example of explosive growth (Salvati, 2016), both of the city of Athens and in Athens peri-urban zones (Chorianopoulos, Tsilimigkas, Koukoulas, & Balatsos, 2014). This rapid increase has brought a 'blur' of urban-industrial and rural areas with new settlements, typically unplanned and random; that is, expansion around older settlements with new buildings in the countryside in former fields and along the road network, or in scenic locations with views. There has also been an expansion of capital settlements of administrative centers that encroached the surrounding countryside (Tsilimigkas & Kizos, 2014). (d) The emergence of tourism and second home ownership has placed even more pressure on the coastal strip with three developments leading to an increased number of buildings (Kizos, Tsilimigkas, & Karampela, 2017) inside or outside settlements: first homes for permanent residents, second homes for domestic or foreign owners and tourism facilities. In the following section, unregulated urban sprawl (which does not concern only Greece, e.g. Biasi, Colantoni, Ferrara, Ranalli, & Salvati, 2015) is given some space as it provides a key to interpreting fire events.

1.3. Spatial planning framework and urban sprawl in Greece

This short note on the spatial planning framework (for more details see Christofilopoulos, 2007; Economou, Economou, Sarigiannis, & Serraos, 2004; Giannakourou, 2004; Karidis, 2006) will help explain some unregulated urban sprawl and urban areas *dispersion*. The first institutional act considered a milestone in the development and growth of cities and settlements dates to 1923 (GOG, 1923) to set the conditions and resolve issues concerning urban areas and settlements in general (Giannakourou, 2004). Although it has been amended, many of its provisions are still valid today (Christofilopoulos, 2007; Giannakourou, 2004), the most important of which is the excessive rights of land owners against the public interest, setting the status of land 'outside the urban planning zone' [*ektos sxediou polis*, in Greek], which is private owned land, located outside delineated urban areas, but with certain building rights. This regulation drove a massive, very often uncontrolled, growth of residential areas through legal or illegal practices in peri-urban areas. Later additions provided even more favorable status for properties proximate to roads, intensifying the so-called ribbon residential development around roads (Christofilopoulos, 2007).

The spatial planning framework changed drastically during the 1970s and 1980s, when the negative consequences of the 1923 legislation were widely acknowledged (Karidis, 2006). The new era for spatial planning began with the revision of the 1975 Constitution (art. 24), introducing state responsibility for the protection of the 'natural and cultural environment' and for guidelines for planning and spatial policy (Giannakourou, 2004). The enactment of the Law No. 360/1976 (GOG, 1976), under which spatial plans at national and regional levels and spatial studies for specific areas, and the foundation of the National Council for Regional Planning and the Environment are important steps of the period. But, for a number of reasons related to the political unwillingness and technical inadequacy of competent bodies to implement it, a number of provisions remained inactive. At the same period, Law No. 947/1979 (GOG, 1979) was enacted, introducing 'Land Use Plans' at the sub-regional and urban planning tools at the settlement level. For similar reasons with the previous one, this law remained also inactive to a degree, due to significant reactions that brought together widely divergent political and economic interests, including house and land owners, engineers and building companies, potential buyers, etc. (Christofilopoulos, 2007; Giannakourou, 2004).

The following attempt in the 1980s was Law No. 1337/83 (GOG, 1983), under which 'Master Plans' were implemented for many Greek cities and the establishment of the 'Urban Development Control Zone' (UDCZ) [Zoni Oikistikou Elegxou, in Greek]. It is a regulatory tool only for ex-urban areas for: (a) land use control; (b) conditions, limits and restrictions in building construction; and (c) limits on the land partition for a plot to be considered eligible for the construction permit. In the 1990s, Law No. 2508/97 (GOG, 1997) again attempted to regulate urban and settlement organization and development issues by establishing three hierarchical levels: (a) Master Plans for all metropolitan areas (apart from Athens for seven more areas); (b) General Urban Plan (GUP) ['Geniko Poleodomiko Schedio', in Greek] and the Open City Spatial and Housing Organization Plan (OCSHOP) ['Schedio Chorikis kai Oikistikis Organosis Anoichtis Polis', in Greek] at the Local Administrative Unit level 2 (LAU2); and (c) Urban studies.

In the same period, Law No. 2742/99 (GOG, 1999) introduced spatial planning processes, again hierarchically: (a) at the national level with the General Spatial Planning and Sustainable Development Framework (GFSP&SD) ['Geniko Plaisio Chorotaxikou Schediasmou kai Aeiforou Anaptyxis', in Greek] (Official Government Gazette [OGG], 2008) and the sectoral spatial plans, namely the Special Frameworks for Spatial Planning and Sustainable Development (SFSP&SD) ['Eidiko Plaisio Chorotaxikou Schediasmou kai Aeiforou Anaptyxis', in Greek] which have been institutionalized for tourism (OGG, 2009b), industry (OGG, 2009a), renewable energy resources (OGG 2008) and aquaculture (OGG, 2011); and (b) at the regional level by the 'Regional Frameworks for Spatial Planning and Sustainable Development (RFSP&SD)' ['Perifereiako Plaisio Chorotaxikou Schediasmou kai Aeiforou Anaptyxis', in Greek] that set land use zones and pose restrictions. In 2014, it was replaced by Law No. 4269/2014 (OGG, 2014) and again by Law No. 4447/2016 (OGG, 2016).

This complex picture results to a number of handicaps and malfunctions caused by the ambiguities of regulations (a characteristic example being the setting up of urban development limits in maps of unsuitable scale, leaving the ground limits open to local interpretation), the often contradictory rules, the lack of coordination between the various spatial planning tools, and the lengthy procedures for approval and review (Economou et al., 2004; Giannakourou, 2004; Karidis, 2006). The final result is the inability to provide a framework that can manage critical spatial problems (Tsilimigkas & Gourgiotis, 2013; Tsilimigkas & Kizos, 2014), fire events being one. The mechanism is quite simple: burned areas can be easily considered as 'non-forest areas' and then fall under some of the many loopholes left in the legislative and planning system and be converted into plots and built. This mode of excessive urban sprawl (Chorianopoulos, 2014) is the result not only of the lack of planning tools but also of the enforcement of existing policies and laws, as typically illegal constructions are made legal with a fine more than once in the last three decades.

1.4. Aims and scope of the study

In this paper, we attempt to shed light on some aspects of the complex multi-dimensional and multi-scale relationships emerging between unregulated urban sprawl and generally the dominant urban areas development mode and spatial distribution of fire events in Greece. To that end, we present fire events provided by NASA Fire Information for Resource Management System and place them along a number of 'spatial types' composed by basic variables : (a) Relief; (b) Land Cover and (c) Protected areas. Most of them are related to proximity to urban areas, which are classified keeping in mind inferred socioeconomic driving forces, such as the mode of urbanization in the past or the character of urban sprawl nowadays, and correlated with these. The question raised is related to the suitability of these spatial types to explain fire occurrence and severity and thus use them as proxy indicators for spatial planning under the conditions that this is institutionalized and implemented.

2. Methodology

2.1. Spatial typology

In order to better understand fire occurrence in Greece, a spatial typology is constructed, which is based on remote sensing data of 100×100 m pixels, instead of using fire

Table 1. Criteria used for spatial typologies synthesis.

Components	Variables	Major categories Criteria description
RELIEF	Level areas (Low)	Elevation 0–400 with slope 0–10%
	Transition zones (Trans)	Elevation 0–400 with slope >10% and Elevation 400–600 with any slope and Elevation 600–800 with slope < 3%
	Mountain (Mount)	Elevation 600–800 with slope > 3% and Elevation 800+ with any slope
CLC 2012	Artificial surfaces (Arti)	Continuous urban fabric (111), Discontinuous urban fabric (112), Industrial or commercial units (121), Road and rail networks and associated land (122), Port areas (123), Airports (124), Mineral extraction sites (131), Dump sites (132), Construction sites (133), Green urban areas (141), Sport and leisure facilities (142)
	Agricultural areas (Agri)	Non-irrigated arable land (211), Permanently irrigated land (212), Rice fields (213), Vineyards (221), Fruit trees and berry plantations (222), Olive groves (223), Pastures (231), Annual crops associated with permanent crops (241), Complex cultivation patterns (242), Land principally occupied by agriculture with significant areas of natural vegetation (243), Agro-forestry areas (244)
	Semi-natural areas (Semi)	*Natural grasslands(321), Moors and heathland (322), Sclerophyllous vegetation (323), Transitional woodland-shrub (324), Beaches dunes sands (331), Bare rocks (332), Sparsely vegetated areas (333), Burnt areas (334), Glaciers and perpetual snow (335)*
	Forests (For)	*Broad-leaved forest (311), Coniferous forest (312), Mixed forest (313),*
	Wetlands & Water bodies (Wet)	Inland marshes (411), Peat bogs (412), Salt marshes (421), Salines (422), Intertidal flats (423), Water courses (511), Water bodies (512), Coastal lagoons (521), Estuaries (522), Sea and ocean (523)
PROTECTED AREAS	NATURA 2001	SPAs Directive 79/409/EEC SCIs Directive 92/43/EEC

Source: Authors' analysis.

inventories that follow administrative boundaries, which rarely coincide with burnt areas. The spatial typologies result from the synthesis of three components (Table 1):

(a) Relief which is composed by the synthesis of elevation and slope. We adopt four elevation classes (0–400 m, 400–600 m, 600–800 m, >800 m) and 3 slope classes (0–3%, 3–10%, >10%), following the official ones that have already been used in Greece in regional planning studies (MEECC, 2010). The superposition of elevation and slope has resulted in 12 categories that have been reclassified in three, following the official classification of EL.STAT (2001) (Figure 1(a)): (i) Level areas, characterized by elevation form 0 to 400 m and slope from 0% to10%, which represent 30,775.93 km^2 (23.4% of the total area); (ii) Transition zones, characterized by elevation from 0 to 400 and slope greater than 10%, and elevation form 400 to 600 m and any slope and zones with elevation form 600 to 800 m and slope lower than 3%, which represent 43,606.54 km^2 (33.2% of the total); and (iii) Mountain areas, characterized by elevation form 600 to 800 m with slope greater than 3%, and zones with elevation higher to 800 and any slope, which represent 56,888.38 km^2 (43.3% of the total).

(b) Land cover that is composed by grouping from CORINNE CLC 2012 geospatial data-set Label 3 categories in five major categories (Figure 1(b) and Table 1 for details): (i) Artificial surfaces, which is composed by 11 classes (making up 3905.55 km^2, or 2.93% of the total area; (ii) Agricultural areas, composed by the 11 classes, in total 52,000.87 km^2, or 39.03% of the total area; (iii) *Semi-natural areas, composed by nine classes of 49,534.01 km^2, or 37.18% of the total area*; (iv) *Forests, composed by three classes with 25,691.89 km^2, or 19.29% of the total area*; (e) Wetlands & Water bodies,

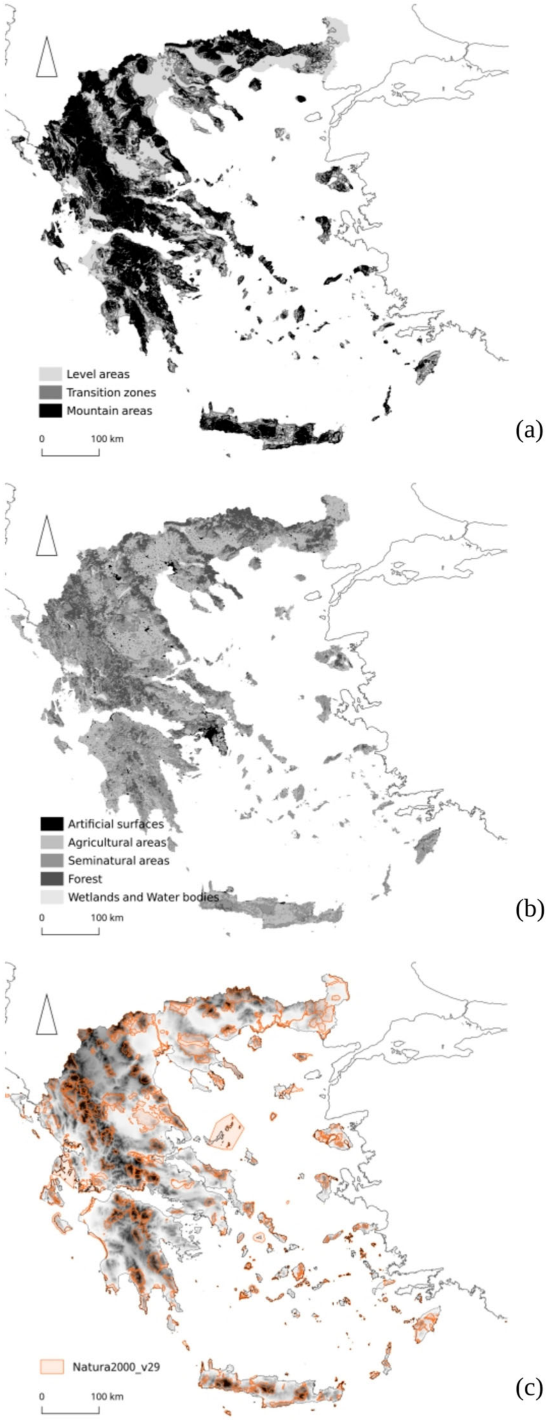

Figure 1. Spatial components for spatial typologies synthesis. (a) Relief component, (b) land cover component and (c) protected areas component. Source: Authors' analysis: (a) DEM of Greece derived by Shuttle Radar Topography Mission SRTM; (b) CLC 2012; (c) NATURA 2000.

composed by 10 classes of 2086.65 km^2, or 1.57% of the total area. The official statistical land use data (EL.STAT., 2001) and use similar categories, but refer to administrative boundaries and have different definition criteria for forests and semi-natural areas.

(c) Protected areas, which are also typically used as a separate land cover class in spatial planning in Greece and are composed by the NATURA areas network (Figure 1(c)), which includes 163 Special Protection Areas (SPAs), according to the Directive 79/409/EEC, and 239 Sites of Community Importance (SCIs), according to the Directive 92/43/EEC (MEECC, 2013). We chose here to ignore a number of national protected areas schemes due to extended superposition between them and the NATURA network and the need for comparable results at the European level.

2.2. Data

The scale of analysis was determined at 1:100,000, a typical physical planning scale that is also available from and geospatial data-sets. Therefore, the dimension of the cell size representing the area covered on the ground is set on 100×100 m (Waldo, 1988). Two different sets of spatial data were used, one for the spatial typology and another for fire events. For the spatial typologies the data used come from (Figure 1):

(a) Elevation is derived from a public domain Digital Elevation Model (DEM). Here, Shuttle Radar Topography Mission (SRTM) data are used. The original spatial resolution of this data-set is 90×90 m. It was re-sampled however to 100×100 m pixel resolution in order to match the working scale. The data-sets were transformed into Greek Geodetic Reference System of 1987 (GGRS87) projection from that of the World Geodetic System 1984 (WGS84).

(b) Land Cover data come from the European Commission program to COoRdinate INformation on the Environment (CORINE) Land Cover 2012 (CLC 2012) derived from the National Cadastre and Mapping Agency (NCMA, 2014). Land cover assigns different types according to the broad land cover types with the use of CLC 2012 data of 1:100,000 scale. The data-set was rasterized on 100×100 m pixel resolution. Two are the main issues arising from the use of CLC 2012 data in the study: the first concerns their updating, the proposed typologies are less representative of today's reality, particularly concerning the issue of urban expansion (artificial surfaces, variable). The second relates to the geographical complexity and the physical fragmentation of the Greek territory, which has as a result some categories of land cover not properly attributed. The data-sets CLC 2012 here are chosen despite data accuracy questions, first, because the provided data-sets are in pertinent spatial resolution, according to the study questions, and, second, because there are no more pertinent geospatial data-sets for Land Cover at the national level.

(c) The data-sets for the Natura network come from the European Environment Information and Observation Network (EIONET) Central Data Repository and were used in vector structure, into the Greek Grid, GGRS87 projection system.

(d) The geospatial data-sets for fire events are provided from NASA, Fire Information for Resource Management System (FIRMS) which delivers global MODerate

Resolution Imaging Spectroradiometer (MODIS) hotspots/fire locations observations. The MODIS hotspots/fire locations provide information at the global scale on the spatial and temporal distribution of fire events, thus allowing time series and comparative analysis (NASA FIRMS, 2016). This data-set was provided by the University of Maryland and NASA FIRMS operated by NASA/GSFC/ESDIS with funding provided by NASA/HQ (NASA/University of Maryland., 2002). The data-sets have been used world – widely as fire management tools with many different applications in character and scales (Davies, Ilavajhala, Wong, & Justice, 2009; Molinario, Davies, Schroeder, & Justice, 2014; Palumbo, Grégoire, Simonetti, & Punga, 2011) and great potentialities, especially for countries like Greece, where fires are an annual phenomenon and in cases, particularly devastating (Psarros, Theleritis, Martinaki, & Bergiannaki, 2008). Although we need to take into consideration a detailed analysis of the caveats when working with FIRMS (Davies et al., 2009), we have used this with the following considerations: (i) a fire event may have been too small or too cool to be detected, as MODIS routinely detects both flaming and smoldering fires of at least 1 km^2 in size; (ii) a fire event may be completely obscure due to cloud cover, heavy smoke, forest canopy etc.; (iii) fires that have started and ended between satellite overpasses are not observed; (iv) not all hotspot surfaces are vegetation fires of 1 km^2 in size, but at least one fire is located within this area; (v) Occasionally, the MODIS instruments are inoperable for extended periods of time and no data are observed during these time periods (NASA FIRMS, 2016). Data for the time period from 2001 to 2015 (Figure 2) are used. The 1 km (approx.) MODIS active fire pixel is considered sufficiently detailed to provide information on the spatial and temporal distribution of fire events in Greece. National time-series data-sets for fire events are available from the Ministry of Civil Protection (MCP) and the Hellenic Fire Service (HFS) from May 1999 until May 2015, but these events are localized only by the site place name and the closest municipality, while coordinates are available only for events between May 2008 and December 2009 (HFS, 2016; MCP, 2016). This is the reason this data-set was used only for the discussion of the results. Given all these, we consider that despite the known issues discussed briefly above of MODIS data, the fact that these data are the only available time-series geospatial set for fires events and that their scalar features correspond with these of the spatial typologies that this paper develops and therefore with spatial planning scales, we have decided to use them in a preliminary and exploratory approach. Further evaluation of their quality would be extremely important.

Here, a generalization of typologies (sieve) is chosen in order to achieve much 'smoother' typologies by waving small and dispersed patches. This process produces comprehensible and operational results as well as amplifying typology coherency. Sieve filter removes isolated patches (patches smaller than the 500 m threshold size) and replaces them with the pixel value of the largest neighbor polygon, using morphological operators (here diagonal pixels are considered directly connected) (Figure 3). Generalization drives in under-representing typologies characterized by high degree of distribution (clumping typologies) and typologies with high edge density in

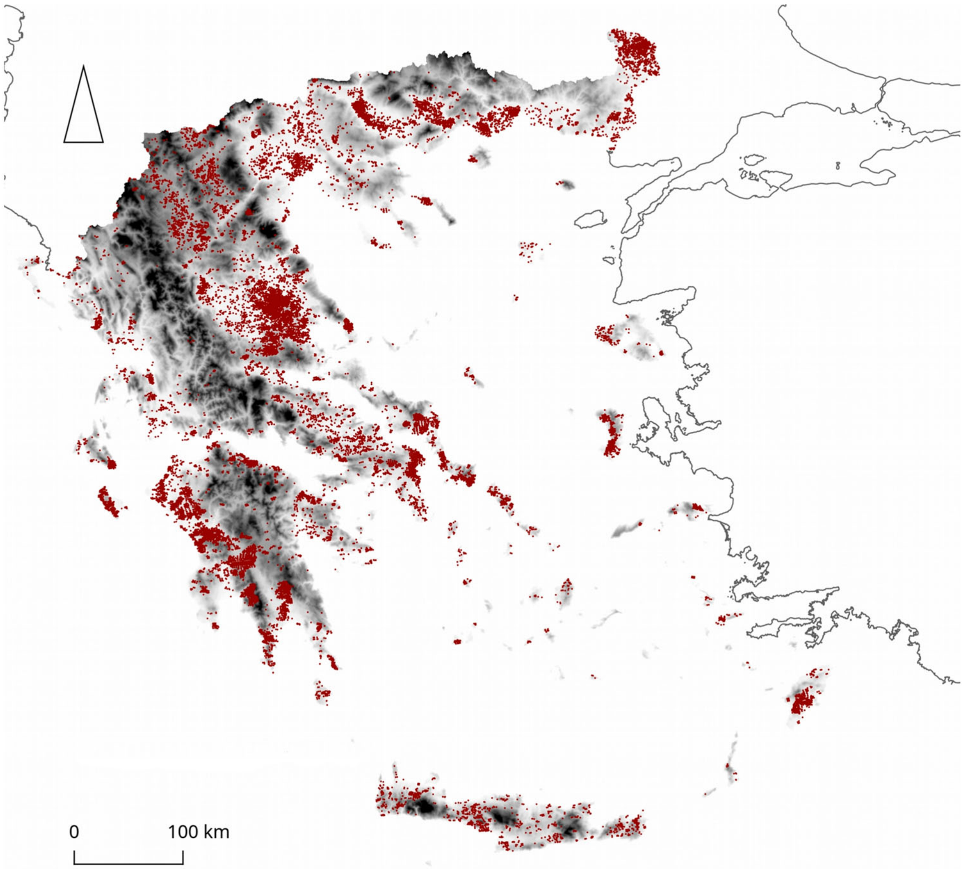

Figure 2. Fire events (2001–2015). Source: Authors' analysis; DEM of Greece derived by Shuttle Radar Topography Mission SRTM; Fire Information for Resource Management System (FIRMS) which delivers global MODerate Resolution Imaging Spectroradiometer (MODIS).

patches spatial configuration (e.g. artificial surfaces) and over-represented more aggregated categories (e.g. agricultural areas, forests).

3. Results

3.1. Fire events frequency

The total number of fire events as provided by FIRMS/MODIS 2016 data-sets is 22,094. The annual distribution of these events (Figure 4) reveals a peak in 2007, which represents an extreme case and considered as a major natural disaster. A series of major fires in many parts of the country, especially in August, burned about 2700 km^2 and caused major damages and casualties (Diakakis et al., 2016). It goes beyond the present study to discuss the reasons of the destruction or to make a detailed reference to it, since several studies have already approached the issue (Koutsias et al., 2012), or to move to an analysis of issues over who is 'responsible' for fire management (the Forest Service or the Fire Brigade) as these issues have already been analyzed in detail (Kalabokidis, Iosifides, Henderson, & Morehouse, 2008 Morehouse, Henderson, Kalabokidis, & Iosifides, 2011)

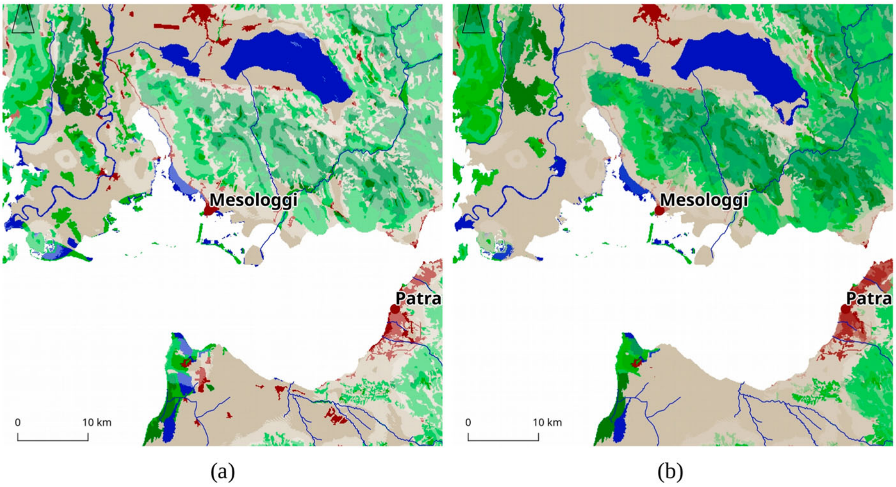

Figure 3. Example of typologies generalization. (a) Typologies representation; and (b) sieve of 500 m size threshold. Source: Authors' analysis.

3.2. Fire density

The density of the fire events per square kilometer is used as the principal indicator to correlate events with the spatial typology used. The values were standardized to ensure comparability (Table 2). The standardization was performed according to the following formula:

$$\text{Standardized value} = \frac{\text{Value} - \text{Mean}}{\text{Standard deviation}}. \tag{1}$$

'Level Areas' types represent the higher average fire events frequency (0.23 per km^2). More specifically, the 'Artificial Surfaces' and 'Agricultural Areas' represent 0.45 events/km^2 and 0.35 events/km^2, respectively, which is the highest value of all types (Table 2).

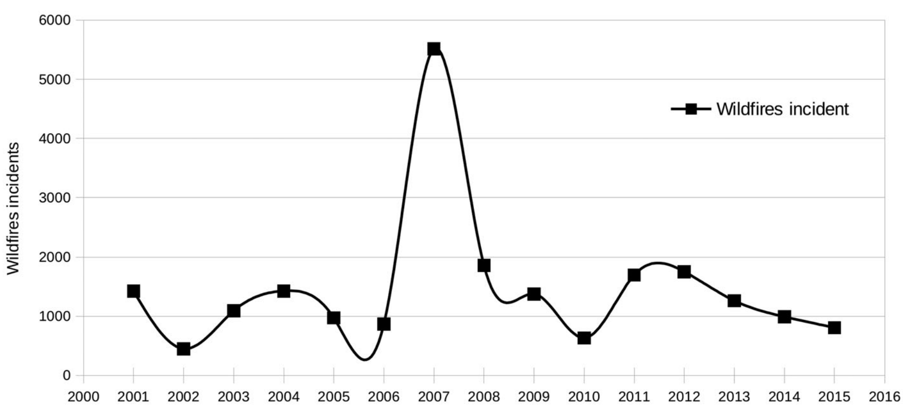

Figure 4. Fire events per year. Source: Authors' own analysis; Fire Information for Resource Management System (FIRMS) which delivers global MODerate Resolution Imaging Spectroradiometer (MODIS).

Table 2. Spatial typologies.

	Component A: Relief	Component B: CLC 2012	Code name	Typologies (km^2)	Typologies (%)	MODIS fires[a] (Nbr)	MODIS fires[a] (fires/ km^2)	MODIS fires[a] (St. values) (fires/km^2)
1	Level areas	Artificial surfaces	Lev-Art	858.86	0.66	389.00	0.45	2.49
2	Level areas	Agricultural areas	Lev-Agr	24,622.68	18.82	8651.00	0.35	1.68
3	Level areas	Semi-natural areas	Lev-Sem	1,147.09	0.88	190.00	0.17	0.21
4	Level areas	Forest	Lev-For	595.99	0.46	34.00	0.06	−0.65
5	Level areas	Wetlands and W. bodies	Lev-Wet	1233.16	0.94	137.00	0.11	−0.22
			Total	28,457.78	21.75	9401.00	0.23 (Ave)	
6	Transition zones	Artificial surfaces	Tra-Art	842.16	0.64	130.00	0.15	0.12
7	Transition zones	Agricultural areas	Tra-Agr	22,594.66	17.27	4947.00	0.22	0.63
8	Transition zones	Semi-natural areas	Tra-Sem	13,187.10	10.08	2257.00	0.17	0.25
9	Transition zones	Forest	Tra-For	5178.23	3.96	332.00	0.06	−0.60
10	Transition zones	Wetlands and W. bodies	Tra-Wet	222.67	0.17	4.00	0.02	−0.96
			Total	42,024.82	32.11	7670.00	0.13 (Ave)	
11	Mountain areas	Artificial surfaces	Mou-Art	45.88	0.04	2.00	0.04	−0.76
12	Mountain areas	Agricultural areas	Mou-Agr	4536.52	3.47	663.00	0.15	0.06
13	Mountain areas	Semi-natural areas	Mou-Sem	35,837.41	27.39	3856.00	0.11	−0.25
14	Mountain areas	Forest	Mou-For	19,930.13	15.23	502.00	0.03	−0.90
15	Mountain areas	Wetlands and W. bodies	Mou-Wet	29.81	0.02	0.00	0.00	−1.10
			Total	60,379.75	46.14	5023.00	0.06 (Ave)	

Source: Authors' analysis; Fire Information for Resource Management System (FIRMS) which delivers global MODerate Resolution Imaging Spectroradiometer (MODIS).
[a]MODIS fires/hotspot observations.

'Level Agricultural Areas' types cover almost 19% (24,623 km^2) of the total Greek territory (Figure 5) and the high percentage of fire events per km^2 indicates a correlation between agricultural activity and fire events. 'Artificial Surfaces' – apart from the compact urban areas that are excluded from the study – are largely located in peri-urbans zones, very often along streets, and they are commonly composed of dispersed built-up areas of residential or second houses clusters. They are considered 'hybrid' areas that are characterized by land use intensity that often by land use conflicts (Karidis, 2006; Tsilimigkas, Stathakis, & Pafi, 2015). Fire events frequencies per square kilometer in 'Transition Zones' represent an average almost half (0.13 events/km^2) than 'Level Areas'. The highest values in this type of areas are found in 'Agricultural Areas' (0.22 events/km^2) and 'Semi-natural Areas' (0.17 events/km^2) (Table 2). Again here, a correlation between agricultural and livestock activities and fire events may be assumed.

'Mountain Areas' are the most extensive of the types, covering 60,379.75 km^2 or 46.14% of the Greek territory. Fire event are less frequent here (Figure 3), with an average (0.06 events/km^2) almost four times smaller than that of 'Level areas'. The highest value, and

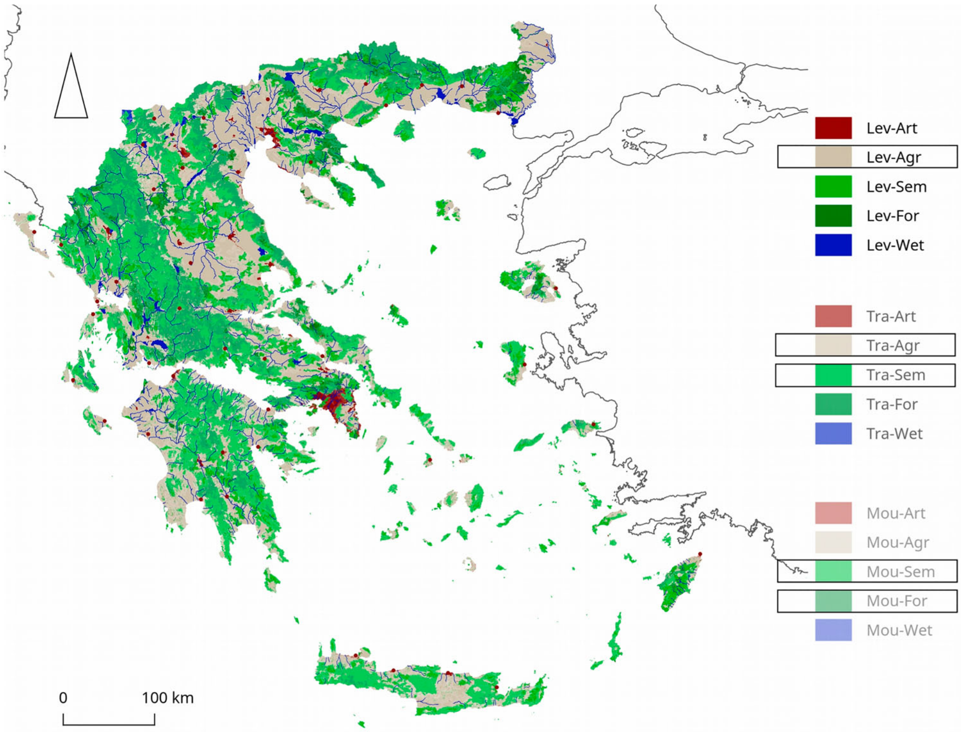

Figure 5. Spatial typologies. Source: Authors' analysis; (a) DEM of Greece derived by Shuttle Radar Topography Mission SRTM; (b) CLC 2012; (c) NATURA 2000.

the only one above the overall average, is found again in 'Agricultural Areas' with a value of 0.15 events/km^2 (Table 2), confirming again the importance of agriculture-related events. In all relief types, the lowest frequencies on average are found for 'Wetlands' and 'Water Bodies' (Table 2). Concerning the findings for Natura network areas, the count for the study period 2001–2015 is 6256 fire events, or 28.32% of the total number of events.

4. Discussion

In this paper, we use spatial typologies in order to understand the dynamics of fire events in Greece. This is an approach that has not been used so far in the literature to this extent (Kalabokidis, Koutsias, Konstantinidis, & Vasilakos, 2007), so far typically applied to smaller (regional or local) scales. Some shortcomings are related to the availability and comparability of land cover and fire occurrence data. CORINE land cover data offer comparability at the EU scale, but they cannot always capture finer grain details in land cover and land use that are nevertheless very important for understanding fire occurrence, especially in relation to heterogeneous landscapes such as peri-urban mosaics of small plots and fields and shrublands, maquis and phrygana Mediterranean forest areas. Moreover, the issue of time is not sufficiently covered, in the sense that when fires do occur in a Mediterranean landscape, the probability of future occurrence decreases for a number of years that is related to land cover and availability of fuel (Kalabokidis et al., 2008). Finally, issues of fire intensity and duration are not covered. Despite these shortcomings though, we believe that this exploratory approach has provided insights into spatial configurations of fire events and their frequency within particular land cover types. Therefore, these results should be treated as indicative of trends and input for planning towards fewer and less destructive events.

Our results demonstrate that the occurrence of fires is related to some land cover classes more than others. These are 'Agricultural Areas' in terms of overall frequency in all types of terrain, i.e. areas that are cultivated or where animal husbandry (and grazing) is practiced. High frequency in these areas is a result of farming practices that involve fire, including (a) burning of hay in cereals after harvesting (June–July), which is not allowed but still practiced; (b) burning of prunings or other excess biomass that needs to be removed from permanent plantations (Spring); (c) burning of field boundaries to clear 'wild' vegetation is another fire-related practice of farming systems in Greece; (d) while in grazing lands (the difference from pastures refers to the high percentage of cover by maquis and phrygana) occasional fires in autumn are used to remove unwanted and unpalatable shrubs and increase annual plants biomass available to grazing sheep and goats; and (e) fire use to clear fields abandoned for years or decades for cultivation and/or grazing (Calvo, Marcos, Baeza, Papanastasis, & Santana, 2012; Jouffroy-Bapicot, Vannière, Iglesias, Debret, & Delarras, 2016; Kizos, Plieninger, & Schaich, 2013). Some of these practices are related to fire events in 'Semi-natural Areas', which in Central and Southern Greece and in low altitudes and are frequently grazing lands. Finally, it should be noted that a number of events in these spatial types may be related to urban sprawl, with land 'cleared' with fire in order to change use.

The second more important type of areas in terms of frequency, but the first in terms of intensity is 'Artificial Surfaces', especially in low lying areas. These events are related to urban growth and sprawl. As discussed earlier, spatial and urban planning laws and regulations may be very strict on paper for forest protection and scattered urban growth, but in practice its many loopholes have proven far more effective in 'promoting' the use of fire for clearing land that can be used later for illegal or semi-legal building, which is legalized at the end with the payment of fines. Therefore, speculation practices with land properties are encouraged. Two different processes are at work here:

(a) The expectation of building on land plots 'cleared' through burning is encouraged by the absence of *cadaster*s and in many cases of poor or absent documentation of public lands, forests maps (which clearly mark what is considered as 'forest' and 'forest areas' and what is not) and of detailed land use plans for many areas of the Greek territory, especially around settlements and towns. These *expectations have been fulfilled, especially in* peri-urban residential development clusters and even, in some extreme cases, by encroaching public land (in peri-urban forests areas, coastal zones, etc.).
(b) The *ex-post* legalization of individual or clusters of unauthorized constructions. Many different Greek administrations over the past three decades have given the opportunity to owners of unauthorized buildings to legalize them by paying fines to the Greek state. These owners consist of very different social and economic groups, from low-end houses in the edge of towns, to large villas in coastal areas or in and around forests. These opportunities have served as an incentive to further build unauthorized houses in the hope of future legalization.

The third type of areas associated with fires is forests. Although this would be the first type of spatial type where the frequency and the density of the events would be expected to be high, this is not the case for two reasons: (a) many of these forests, especially the ones at medium and higher altitudes are not as friendly to fire as Mediterranean pine forests and maquis areas are (Calvo et al., 2012), although, of course, they burn especially at the end of the dry season if there is a fire; (b) population density is much lower along their edges and indeed in many upland forest areas the recorded depopulation has been among the greatest in Greece in the past century (Kizos & Vlahos, 2012) and, therefore, agriculture-related fire events are few (few cultivations and even for grazing lands fire has not been part of the management systems in the past) and building related to fires even fewer.

5. Conclusions

As discussed above, 'Artificial Areas' and their surrounding zones (often urban sprawl clusters) are important spatial types for fire events. These are events that could be reduced in frequency and intensity, by reducing loopholes and implementing spatial planning legislation and policing. The integration of fire events as a distinct variable at all levels of spatial planning, mostly by developing proactive policies, could help in that direction. Therefore, the integration of enforcement systems as well as monitoring, assessment and control mechanisms with the implementation of spatial policies, urban and regional plans should be pursued. To that end, an observatory on fire events could be helpful.

A necessary prerequisite to take into consideration in the development procedures is the strategic spatial planning framework, meaning : (a) on the national level, the GFSP&SD (OGG, 2008) and the SFSP&SD which have been institutionalized for tourism (OGG, 2009b, OGG 2013), industry (OGG, 2009a), renewable energy resources (OGG, 2008b) and aquaculture (OGG, 2011); and (b) on the regional level, the RFSP&SD could have a positive effect on the diminution of fire events. Additionally, we consider that the following steps, on physical planning scale, could be very helpful in reducing the number of events and the intensity of fires in these types of areas in Greece: (a) Land use plans implementation for all ex-urban areas where building construction is not a priori excluded (the areas that are excluded include forests, coasts, archaeological sites, etc.) which will establish a reliable database of geospatial data that will support mechanisms of adaptive management for fire-stricken areas; (b) Cadastral survey and cadastral map implementation, which will contribute to addressing issues related to the clarification of property rights as the existing confusion encourages practices of land use speculation; (c) Forest maps of the whole country that will reduce expectations for building on forest land; (d) Archaeological cadaster which can contribute to protection of sites; and (e) the consensus (political and social) for the implementation of these policies. Currently, such consensus is lacking and repeating waves of regularization of illegal buildings, even in forest areas, by imposing fines make its building difficult.

Farming related to fire events can also be minimized, although it is difficult to imagine that they would stop completely. The most important practices in terms of producing uncontrolled fires are clearing of grazing lands and field boundaries and hay burning. Clearing is a spring–autumn practice that may produce uncontrolled fires, but the probability is lower than hay burning which takes place in the summer. Therefore, providing alternatives to these practices to farmers might be more effective than bans, which as the results indicate, are not very effective.

To conclude, fires in the Mediterranean are complex phenomena that depend both on physical-geographical and socioeconomic factors. We have attempted to shed some light on their dynamics by applying a macroscopic spatial approach. As demonstrated by our findings, fires in Greece have acted as both 'fast' and 'slow' variables, as besides rapid destruction and damage, in the long term, they may be treated as slower rate agents of change in the Greek landscape. It is clear that this is not enough and more data is required for the events and the local context. We nevertheless believe that such an approach can form the basis for a more effective spatial planning framework by the incorporation of fire events as a variable at all levels of spatial planning procedures in order to develop a proactive policy against such events.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Alcasena, F. J., Salis, M., Ager, A. A., et al. (2015). Assessing landscape scale wildfire exposure for highly valued resources in a Mediterranean area. *Environmental Management*, *55*, 1200–1216.

Benoit, G., & Comeau, A. (2005). *A sustainable future for the Mediterranean: The Blue Plan's environment and development outlook*. London: Earthscan.

Biasi, R., Colantoni, A., Ferrara, C., Ranalli, F., & Salvati, L. (2015). In-between sprawl and fires: Long-term forest expansion and settlement dynamics at the wildland–urban interface in Rome, Italy. *International Journal of Sustainable Development & World Ecology*, *22*(6), 467–475.

Calvo, L., Marcos, E., Baeza, M. J., Papanastasis, V. P., & Santana, V. M. (2012). Post-fire management of shrublands. In F. Moreira, M. Arianoutsou, P. Corona, & J. De las Heras (Eds.), *Post-fire management and restoration of Southern European forest* (pp. 293–319). Springer. doi:10.1007/978-94-007-2208-8_12.

Camia, A., San-Miguel-Ayanz, J., Kucera, J., Amatulli, G., Boca, R., Libertà, G., … Bucki, M. (2008). *Forest fires in Europe 2007*. Luxembourg: Joint Research Centre – Institute for Environment and Sustainability, Office for Official Publications of the European Communities.

Chorianopoulos, I. (2012). State spatial restructuring in Greece: Forced rescaling, unresponsive localities. *European Urban and Regional Studies*, *19*, 331.

Chorianopoulos, I., Tsilimigkas, G., Koukoulas, S., & Balatsos, T. (2014). The shift to competitiveness and a new phase of sprawl in the Mediterranean city: Enterprises guiding growth in Messoghia – Athens. *Cities*, *39*, 133–143.

Christofilopoulos, D. (2007). To nomothetiko kai organotiko plesio tou poleodomikou sxediasmou stin ellada[The institutional framework of urban planning in Greece]. In A. Aravantinos (Ed.), *Poleodomikos sxediasmos: Gia mia viosimi anaptixi tou astikou xorou* [Urban planning: For a sustainable development of urban space] (pp. 97–118). Athens: Symmetria. (In Greek).

Davies, D. K., Ilavajhala, S., Wong, M. M., & Justice, C. O. (2009). Fire information for resource management system: Archiving and distributing MODIS active fire data. *IEEE Transactions on Geoscience and Remote Sensing*, *47*(1), 72–79.

Diakakis, M., Xanthopoulos, G., & Gregos, L. (2016). Analysis of forest fire fatalities in Greece: 1977–2013. *International Journal of Wildland Fire*, *25*(7), 797–809.

Economou, D., Economou, D., Sarigiannis, J., & Serraos, K. (2004). Poleodomiki politiki stin ellada: Domika charaktiristika kai simerines taseis[The urban policy in Greece. Structural characteristics and current tendencies]. In *Poli kai horos apo ton 20o ston 21o aiona* [City and space from the 20th to the 21st century] (pp. 371–382). Athens: Memphis. (in Greek).

EL.STAT (Hellenic Statistical Authority). (2001). *Katanomi tis ektasis tis Elladas stis basikes katigories xrisis / kalipsis kata YPA, nomo, dimo i kinotita (1999–2000)* [Distribution of Greece state on general categories of land use/cover at: Regions, Departments and municipality (1999–2000)] (in Greek).

Ferrara, A., Kelly, C., Wilson, G. A., Nolè, A., Mancino, G., Bajocco, S., & Salvati, L. (2016). Shaping the role of fast and slow drivers of change in forest-shrubland socio-ecological systems. *Journal of Environmental Management*, *169*, 155–166.

Giannakourou, G. (2004). To thesmiko plesio tou sxediasmou ton poleon stin ellada: istorikes metamorfosis kai sigxrona etimata [The institutional framework for urban planning in Greece: Historical transformations and contemporary requests]. In D. Economou & G. Petrakos (Eds.), *I anaptixi ton Ellinikon poleon: diepistimonikes proseggisis astikis analisis kai politikis* [The Greek cities development: Interdisciplinaries approaches to urban analysis and policy] (pp. 457–480). Volos: University of Thessaly Gutenberg. (in Greek)

Hellenic Fire Service. (2016). *Arxeio Symvanton. Dedomena pou aforoyn ta Dasika kai Astika symvanta sta opoia epemvainei to P.S* [Events archive data concerning forest and urban events which intervenes in PS] (in Greek). Retrieved from http://www.fireservice.gr

Jouffroy-Bapicot, I., Vannière, B., Iglesias, V., Debret, M., & Delarras, J. F. (2016). 2000 years of grazing history and the making of the Cretan Mountain Landscape, Greece. *PLoS ONE*, *11*(6), e0156875.

Kalabokidis, K., Ager, A., Finney, M., Athanasis, N., Palaiologou, P., & Vasilakos, C. (2016). AEGIS: A wildfire prevention and management information system. *Natural Hazards and Earth System Sciences*, *16*(3), 643–661.

Kalabokidis, K., Iosifides, T., Henderson, M., & Morehouse, B. (2008). Wildfire policy and use of science in the context of a socio-ecological system on the Aegean Archipelago. *Environmental Science & Policy*, *11*(5), 408–421.

Kalabokidis, K., Koutsias, N., Konstantinidis, P., & Vasilakos, C. (2007). Multivariate analysis of landscape wildfire dynamics in a Mediterranean ecosystem of Greece. *Area*, *39*(3), 392–402.

Kalabokidis, K., Palaiologou, P., & Finney, M. (2013). Fire behavior simulation in Mediterranean forests using the minimum travel time algorithm. In International Association of Wildland Fire (ed.), *Proceedings of 4th fire behavior and fuels conference* (pp. 468–492). St. Petersburg: International Association of Wildland Fire.

Karidis, D. (2006). *Ta efta vivlia tis poleodomias* [The seven books of urban planning]. Athens: Papasotiriou. (in Greek).

Kelly, C., Ferrara, A., Wilson, G., Ripullone, F., Nole`, A., Harmer, N., & Salvati, L. (2015). Community resilience and land degradation in forest and shrubland socio-ecological systems: Evidence in Gorgoglione, Basilicata, Italy. *Land Use Policy*, *46*, 11–20.

Kizos, T., Plieninger, T., & Schaich, H. (2013). 'Instead of 40 sheep there are 400': Traditional grazing practices and landscape change in Western Lesvos, Greece. *Landscape Research*, *38*(4), Special Issue: Animals and the landscape, 476–498.

Kizos, T., Tsilimigkas, G., & Karampela, S. (2017). What drives built-up area expansion on islands? Using soil sealing indicators to estimate built-up area patterns on Aegean Islands, Greece. *Tijdschrift voor Economische en Sociale Geografie*, *108*(6), 836–853.

Kizos, T., & Vlahos, G. (2012). The evolution of the agricultural landscape. In T. Papayiannis & P. Howard (Eds.), *Reclaiming the Greek landscape* (pp. 133–143). Athens: MED-INA.

Koutsias, N., Arianoutsou, M., Kallimanis, A., Mallinis, G., Halley, J., & Dimopoulos, P. (2012). Where did the fires burn in Peloponnisos, Greece the summer of 2007? Evidence for a synergy of fuel and weather. *Agricultural and Forest Meteorology*, *156*, 41–53.

Levin, N., & Heimowitz, A. (2012). Mapping spatial and temporal patterns of Mediterranean wildfires from MODIS. *Remote Sensing of Environment*, *126*, 12–26.

Loepfe, L., Martinez-Vilalta, J., Oliveres, J., Piñol, J., & Lloret, F. (2010). Feedbacks between fuel reduction and landscape homogenisation determine fire regimes in three Mediterranean areas. *Forest Ecology and Management*, *259*(12), 2366–2374.

Ministry of Civil Protection. (2016). *Istoriko Agrotodasikon Pyrkagion* [WildFires archive]. Retrieved from http://geodata.gov.gr/geodata/

Ministry of Environment, Energy and Climate Change. (2010). *Prodiagrafes meleton aksiologisis, anatheorisis and eksidikefsis thesmothetimenon periferiakon plaision xorikou sxediasmou kai aiforou anaptiskis* [Specification studies – Assessment, review and specialization of the institutionalized regional frameworks for spatial planning and sustainable development] (in Greek).

Ministry of Environment, Energy and Climate Change. (2013). *Prostateuomenes perioxes stin Ellada* [Protected areas in Greece] (in Greek). Retrieved from http://www.ypeka.gr/Default.aspx?tab

Ministry of Environment Physical Planning and Public Works. (2003a). *Proposition for a Spatial framework for the spatial planning and sustainable development for mountains areas* [Idiko plaisio xorotaxikou sxediasmoy kai aiforou anaptiksis gia ton orino horo]. (in Greek).

Moisides, A. (1986). *I Agrotiki koinonia sti sygxroni Ellada 1950–1980* [Rural society in modern Greece 1950–1980]. Athens: Mediterranean Studies Foundation(in Greek).

Molinario, G., Davies, D. K., Schroeder, W., & Justice, C. O. (2014). Characterizing the spatio-temporal fire regime in Ethiopia using the MODIS-active fire product: A replicable methodology for country-level fire reporting. *Journal African Geographical Review*, *33*(2), 99–123.

Morehouse, B., Henderson, M., Kalabokidis, K., & Iosifides, T. (2011). Wildland fire governance: Perspectives from Greece. *Journal of Environmental Policy & Planning*, *13*(4), 349–371.

Moreira, F., Viedma, O., Arianoutsou, M., Curt, T., Koutsias, N., Rigolot, E., … Bilgili, E. (2011). Landscape–wildfire interactions in Southern Europe: Implications for landscape management. *Journal of Environmental Management*, *92*(10), 2389–2402.

NASA FIRMS (Fire Information for Resource Management System). (2016). *NASA near real-time and MCD14DL and MCD14ML, MODIS (MODerate Resolution Imaging Spectroradiometer) active fire detections*. Data set. Retrieved from https://earthdata.nasa.gov/active-fire-data#tab-content-6

NASA/University of Maryland. (2002). *MODIS hotspot/active fire detections*. Data set. MODIS (MODerate Resolution Imaging Spectroradiometer) Rapid Response Project, NASA/GSFC [producer], University of Maryland, FIRMS (Fire Information for Resource Management System) [distributors]. Retrieved from http://maps.geog.umd.edu

National Cadastre and Mapping Agency SA. (2014). *Forest maps and natural environment. Land use monitoring*. Retrieved from http://www.ktimatologio.gr

Naveh, Z., & Carmel, Y. (2004). The evolution of the cultural Mediterranean landscape in Israel as affected by fire, grazing and human activities. In S. Wasser (Ed.), *Evolutionary theory and processes: Modern horizons. Papers in honour of Eviatar Nevo* (pp. 337–409). Dordrecht: Springer.

Official Government Gazette. (1923). *Peri Sxedion Poleon, Komon kai Synikismon tou Kratous kai Oikodomis afton*. Efimeris tis Kyverniseos 228/A/16.08.1923 [On urban, villages and settlements plans of the state and these construction, Greek Official Gazette 228/A/16.08.1923]. Legislative Decree No. NΔ/17.07.1923.

Official Government Gazette. (1976). *Peri xwrotaksias kai perivallontos*. Efimeris tis Kyverniseos 151 A/22.06.1976 [On planning and environment, Greek Official Gazette 151 A/22.06.1976]. Law No. 360/1976.

Official Government Gazette. (1979). *Peri oikistikon perioxon*. Efimeris tis Kyverniseos 169/A/26.07.1979 [On residential areas, Greek Official Gazette 169/A/26.07.1979]. Law No. 947/1979.

Official Government Gazette. (1983). *Epektası ton poleodomikon sxedion, oikistikı anaptyksı kai sxetikes rythmiseis*. Efimeris tis Kyverniseos 33/A/14.03.1983. Law No. 1337/1983 [Expansion of urban plans, urban development and relevant regulations, Greek Official Gazette 33/A/14.03.1983].

Official Government Gazette. (1997). *Biosimi oikistiki anaptyxi ton poleon kai alles diataxeis*, Efimeris tis Kyverniseos A΄-124/13-6-1997 [On sustainable residential development of towns and settlements in the Country and Other Provisions, Greek Official Gazette A΄-124/13-6-1997]. Law No. 2508/1997.

Official Government Gazette. (1999). *Chorotaxikos sxediasmos kai aeiforos anaptyxi kai alles diataxeis*. Efimeris tis Kyverniseos 207-A/07.10.1999 [Spatial planning and sustainable development and other provisions. Greek Official Gazette 207-A/07.10.1999]. Law no. 2742/1999 (in Greek).

Official Government Gazette. (2008). *Eidiko Plaisio Chorotaxikou Schediasmou kai Aeiforou Anaptyxis gia tis Ananeosimes Piges Energeias kai tis Stratigikis Meletis Perivallontikon Epiptoseon aftou*. Efimeris tis Kyverniseos 2464 B/03.12.2008 [Special framework for spatial planning and sustainable development for renewable energy resources and the strategic environmental impact assessment. Greek Official Journal 2464 B/ 03.12.2008].

Official Government Gazette. (2009a). *Eidiko Plaisio Chorotaxikou Schediasmou kai Aeiforou Anaptyxis gia ti Viomichania kai tis Stratigikis Meletis Perivallontikon Epiptoseon aftou*. Efimeris tis Kyverniseos 151 ΑΑΠ/13.04.2009 [Special framework for spatial planning and sustainable development for industry and the strategic environmental impact assessment. Greek Official Journal 151 ΑΑΠ/ 13.04.2009].

Official Government Gazette. (2009b). *Eidiko Plaisio Chorotaxikou Schediasmou kai Aeiforou Anaptyxis gia ton Tourismo kai tis Stratigikis Meletis Perivallontikon Epiptoseon aftou*. Efimeris tis Kyverniseos 1138 B/ 11.06.2009 [Special framework for spatial planning and sustainable development for tourism and the strategic environmental impact assessment. Greek Official Journal 1138 B/ 11.06.2009].

Official Government Gazette. (2011). *Eidiko Plaisio Chorotaxikou Schediasmou kai Aeiforou Anaptyxis gia tis Ydatokalliergeies kai tis Stratigikis Meletis Perivallontikon Epiptoseon aftou*. Efimeris tis Kyverniseos 2505/B/04.11.2011 [Special Framework for Spatial Planning and Sustainable Development for Aquaculture and the Strategic Environmental Impact Assessment. Greek Official Journal 2505/B/04.11.2011].

Official Government Gazette. (2013). *Tropopoiisi Eidikou Plaisiou Chorotaxikou Schediasmou kai Aeiforou Anaptyxis gia ton Tourismo kai tis Stratigikis Meletis Perivallontikon Epiptoseon aftou*. Efimeris tis Kyverniseos 3155 B/12.12.2013 [Amendment Special Framework for Spatial Planning and Sustainable Development for Tourism and strategic environmental impact assessment. Greek Official Journal 3155 B/12.12.2013].

Official Government Gazette. (2014). *Chorotaxiki kai poleodomiki metarithmisi – Viosimi anaptyksi*. Efimeris tis Kyverniseos 142-A/ 28.06.2014 [Regional planning and urban planning reformation – Sustainable development. Greek Official Gazette 142-A/ 28.06.2014]. Law 4269/2014 (in Greek).

Official Government Gazette. (2016). *Chorikos schediasmos – Viósimi anaptyxi kai alles diataxeis*. Efimeris tis Kyverniseos 241-A/23.12.2016 [Spatial planning – Sustainable development and other provisions. Greek Official Gazette 241-A/23.12.2016]. Law no. 4447/2016.

Palumbo, I., Grégoire, J.-M., Simonetti, D., & Punga, M. (2011). Spatio-temporal distribution of fire activity in protected areas of sub-Saharan Africa derived from MODIS data. *Procedia Environmental Sciences*, *7*, 26–31.

Pausas, J. G., Llovet, J., Rodrigo, A., & Vallejo, R. (2009). Are wildfires a disaster in the Mediterranean basin? – A review. *International Journal of Wildland Fire*, *17*(6), 713–723.

Psarros, C., Theleritis, C. G., Martinaki, S., & Bergiannaki, I.-D. (2008). Traumatic reactions of firefighters after wildfires in Greece. *Lancet*, 371, 9609, 301.

Ruiz-Mirazo, J., Martínez-Fernández, J., Vega-García, C. (2012). Pastoral wildfires in the Mediterranean: Understanding their linkages to land cover patterns in managed landscapes. *Journal of Environmental Management*, *98*, 43–50.

Salis, M., Ager, A. A., Finney, M. A., Arca, B., & Spano, D. (2014). Analyzing spatiotemporal changes in wildfire regime and exposure across a Mediterranean fire-prone area. *Natural Hazards*, *71*(3), 1389–1418.

Salvati, L. (2016). From sprawl to compactness and back: Population dynamics (1848–2011) and the economic structure of a Mediterranean city. *GeoJournal*, *81*, 319.

Stamou, Z., Xystrakis, F., & Koutsias, N. (2016). The role of fire as a long-term landscape modifier: Evidence from long-term fire observations (1922–2000) in Greece. *Applied Geography*, *74*, 47–55.

Tsilimigkas, G., & Gourgiotis, A. (2013). Usages du sol et incendies dans la Zone Urbaine Élargie (ZUE) d'Athènes. Méditerranée: Les grands incendies en Méditerranée, Quelle réponse aux désastres environnementaux? *Méditerranée*, *121*, 95–102.

Tsilimigkas, G., & Kizos, T. (2014). Space, pressures and the management of the Greek landscape. *Geografiska Annaler: Series B, Human Geography*, *96*, 159–175.

Tsilimigkas, G., Stathakis, D., & Pafi, M. (2015). Evaluating the land use patterns of medium-sized Hellenic cities. *Urban Research and Practice*, *9*(2), 181–203.

Turco, M., Bedia, J., Di Liberto, F., Fiorucci, P., von Hardenberg, J., Koutsias, N., … Provenzale, A. (2016). Decreasing fires in Mediterranean Europe. *PLoS ONE*, *11*(3), e0150663.

Waldo, T. (1988). Resolution, resampling, and all that. In H. Mounsey & R. Tomlinson (Eds.), *Building data bases for global science* (pp. 129–137). London: Taylor and Francis.