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Brief Report

Road Network and the Spatial Distribution of Wildfires in the Valencian Community (1993–2015)

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Received: 26 March 2019; Accepted: 2 May 2019; Published: 5 May 2019

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Abstract: Understanding the role of wildfire drivers is essential to implement more effective prevention strategies at the regional scale and to promote specific mitigation actions at the local scale. By considering municipalities as the elementary analysis domain, the present study investigates the spatial distribution of wildfires (1993–2015) in the Valencian Community, a Mediterranean fire-prone area with variable climate regimes, heterogeneous landscapes and increasing human pressure. Assuming that a denser road network increases the probability of wildfire occurrence, results of a quantitative analysis exploring the relationship between spatial location of ignition points and roads were presented. The empirical findings of this study contribute to ascertain the role of roads as a direct (or indirect) cause of wildfires in the Mediterranean region.

Keywords: indicators; human activity; land-use; spatial analysis; Mediterranean basin

1. Introduction

Wildfires impact natural environments causing loss of biodiversity [1–4] and soil productivity, soil erosion [5–8] and landscape transformations [9–11], altering agricultural fields and forests [12,13]. Wildland fires are a frequent occurrence in numerous ecosystems, such as in those of Mediterranean Europe, where they are common during the summertime, particularly in dry years [14,15]. Mediterranean Europe is particularly susceptible to large wildfires [9,16–18]. However, several studies have showed that the severity and frequency of wildland fires, specifically those ones during the summer season, will be inclined to increase as a consequence of human activities, e.g., land-use changes [19–23]. For instance, increasing abandonment of rural areas has occurred in the last decades of the 20th century, resulting from several causes (e.g. exodus to more attractive urban contexts), which has resulted in uncultivated land in Mediterranean Europe that has been covered over time, principally by shrubs, grass and other light flora that are very prone to fire [8,19,24–29]. In fact, together with forests, abandoned cropland, pastures and scrub are especially prone to wildfires because the vegetation rapidly develops, accumulating fuel [17,30,31].

With the current issues of desertification and climate change [1,32], Mediterranean contexts in Europe are becoming increasingly sensitive to wildfires, even in relation to unsustainable human activities. In fact, most fires derive from (i) human negligence, i.e., the so-called "accidental" category, or intentional human actions, e.g., those ignited with illegal intent, characteristically considered as "arson"; or (ii) natural phenomena (e.g., lightning) [33–35]. Especially in recent years, human-ignited wildfires have had a negative impact in Southern Europe [33,36]. For instance, along the Iberic peninsula, more than 45% of fire events were caused by human-negligence or accidents [33,37,38]. However, wildfires often depend on anthropogenic drivers, including human carelessness, unconsciousness and planning deregulation [12,24,25]. In addition, the most serious wildfires often occur in forest areas with isolated urban centers, causing significant social impacts [39].

The Mediterranean areas with the greatest risk of fire are those along the coast, which have been extensively built up in recent years [9,14,16,40,41]. Although, in some cases, the availability of fuels has been reduced, the probability of ignition due to human causes has increased significantly [42]. At the same time, in other Mediterranean inland areas, rural abandonment has led to low forest utilization, usually forest of limited productivity, and the consequent growth of fuel loads [19,41,43]. The mixture of these influences makes Mediterranean Europe a high fire risk area [24].

In addition to recent land-use changes (e.g., rural abandonment and low-density urbanization), road infrastructure plays a significant role during extreme natural events, including wildfires [10,44]. The spatial distribution of wildfires over a sufficiently long-time interval have been relatively infrequently measured and analyzed in specific contexts of Southern Europe [33–35]. Distributive patterns were investigated based on fire properties, e.g., mean burned area, mean time of suppression, and cause (e.g., intentional, negligence or unknown) [45]. Earlier studies were developed in the Iberian Peninsula and focused on spatial regimes of natural and human-caused wildfires [34,46–48]. Point distribution techniques were used to analyze fire ignitions in natural environments [33–35]. Defining and understanding wildfire spatial regimes, and the relationship between type of road, ignition point, and fire distribution, has largely been unexplored in Mediterranean environments. Nevertheless, wildfires along local roads have led to increased risk of soil degradation, erosion and landslides [12,49–51]. Based on these premises, the present work explores the intimate characteristics of wildfires that have occurred in the Valencian community from 1993 to 2015, focusing on the spatial linkage with the road network. Assuming that roads contribute to increased risk of wildfires, spatial location of individual fire events was investigated in the Valencian Community, focusing on road density and its (direct or indirect) influence on fire occurrence.

2. Methodology

2.1. Study Area

The Valencian Community is a region located in the east side of the Iberian Peninsula, including 23,255 km^2 of land administered by three provinces (Valencia, Castellón and Alicante) and 534 municipalities. The resident population (4.5 million inhabitants) is distributed along the inland–coastal gradient, from uninhabited internal land to overpopulated coastal districts. With about 500 km of coastline on the Mediterranean Sea, the climate is mainly arid to dry sub-humid, with hot summers and rainy autumns [52–54]. Annual precipitation and elevation respectively range between 300 and 900 mm, and between 0 m and 2000 m at sea level. About 44% of the Valencian Community is devoted to agricultural activities, and 52% of land is covered by forests [53]. Rural abandonment since the late 1970s has increased the incidence of large fires [55]. Replacement of local species with flammable plants was rather common because of recovery of natural vegetation and recurrent fires [56]. Farmland abandonment led to a generalized accumulation of fuel in forests, shrubland and pastures. At the same time, population increase in wildland/urban interfaces (WUI) increased fire risk [56–59]. Wildfires in the Valencian Community occurred primarily during dry and hot summers [1,2], being representative of Mediterranean-type ecosystem complexity.

2.2. Analysis of Wildfire Distribution in the Valencian Community

Based on fire statistics provided by the Spanish Ministry of Agriculture, Environment, Climate Change and Rural Development, Forest Fire Prevention and Awareness, perimeters of each wildfire recorded in the Valencian Community between 1993 and 2015 were mapped in a vector file, including the geographical coordinates of the ignition point. The geographical coordinates were estimated during the official inspection of each burnt area and transmitted to the Valencian Community. The spatial pattern of wildfire starting points is gaining attention due to the important role ignition plays in fire regimes [60–65].

2.3. Data Analysis

Data analysis included a synchronic, descriptive examination of wildfire characteristics. Average burnt surface area per year and frequency of wildfires in the same location were calculated for each municipality of the Valencian community. Indicators include (i) burnt surface area in total municipal area and (ii) the ratio between the number of wildfires and the burnt area.

Spatial elaborations were carried out through the ArcGIS software (ArcGIS software (ESRI Company, Redlands, CA, USA). A shapefile representing roads and provided by the Valencian Community, was overlapped on a fire location map (representing the ignition point of each fire). Two buffers (100 m and 500 m radius) were designed around each ignition point to identify the specific conditions under which each fire took place. Spatial concordance between wildfires and human activities, particularly along roads, was documented in earlier studies [66]. The road network was derived from the shapefile delivered by the Valencian community, where each road is classified in the following types: motorway/highway, basic road, local infrastructure, municipal infrastructure, collecting way, auxiliary branch, service road, and road 'under construction'. A descriptive analysis of wildfire occurrence close to each of these road classes provides indications on the relevance of road density in both intentional and accidental fires. A correlation analysis was finally carried out to test the relationship between the distance from roads and fire size (ha). A Spearman non-parametric co-graduation coefficient was used to identify both linear and non-linear associations between variables, testing for significance at $p < 0.05$ irrespective of the normality assumption of the data.

3. Results

During 1993–2015, a total of 8725 wildfires occurred in the Valencian community, burning nearly 313,020 hectares of land (Figure 1). The largest number of wildfires (668) was recorded in 2005; however, the year 2005 did not record the largest surface area burned and the greatest number of people injured and killed. Overall, the worst years for firefighting in Valencia were 1993, 1994 and 2012, when respectively 42,984, 146,264 and 60,329 hectares were burnt. The highest number of dead and injured was recorded in the early years of the study, apart from a peak in 2012 (9 injured and 4 dead). The largest number of fires took place in the afternoon (2 p.m. and 6 p.m.) with a relative peak earlier in the morning (around 9 a.m.).

Most of the municipalities near the city of Valencia experienced (more or less intense) wildfires (Figure 2). Only a few municipalities, some of which are situated along the coast, were unaffected by fire during the entire study period. Wildfires primarily affected inner and central areas of the Valencian community. These municipalities have characteristic forests and scrubland, where a high presence of biomass load led to a higher incidence of fires. In some areas, fires occurred more than once in the same location. For instance, fires occured five times in a natural area surrounded by residential settlements within the municipalities of Cabanes and Torreblanca, suggesting that repeated burning in this context was related to biomass load (natural park) and increasing human pressure.

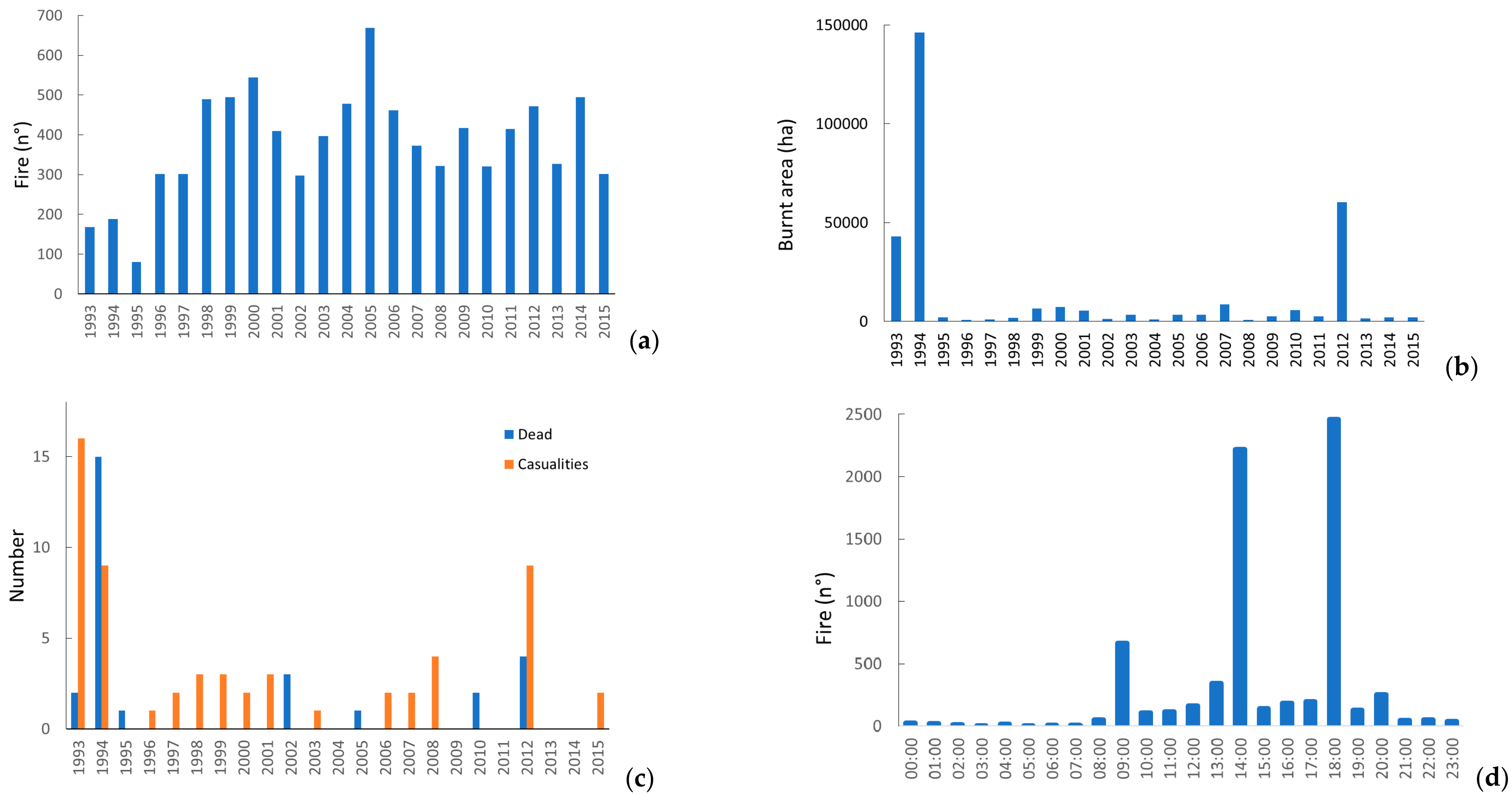

Figure 1. Number of fires (**a**), hectares of burnt surface area per year (**b**), number of fatalities (**c**) and daytime intervals when fires occurred (**d**) in the Valencian community, 1993–2015.

A spatial analysis of ignition points reveals geographical locations more prone to fires in the Valencian Community. In past decades, larger wildfires occurred especially in the central area of the region (Massís del Caroig), which experienced the largest forest fire that had ever occurred in Spain (1979). A high incidence of fires was also recorded in recent years (2012) in mountainous and inland municipalities (Figure 2c). While 19% of fires occurred during holidays, most fires were recorded on working days (3% on a day before a public holiday and 13% on Saturday). Most fires on the southeastern coastline were often fueled by strong winds, which made suppression increasingly difficult. Figure 2d illustrates the total number of fire days during the study interval (from 1993 to 2015) at the municipal scale. Fire events lasted longer than the average in both eastern and southern municipalities and in some hinterlands (areas located in municipalities north of Valencia).

Analysis of the percentage share of burnt surface area in municipal areas indicates the most susceptible locations to wildfires in recent years (Figure 2e). The mountainous areas of the Valencian Community were seriously affected by fire, likely due to dry climatic conditions that may control vegetation recovery and fuel accumulation (300 mm/y rainfall and 1300 mm/y potential evapotranspiration). Southern municipalities and marginal municipalities bordering Catalonia experienced a particularly high number of small fires (Figure 2f); wildfires occurring in the central part of the region were less frequent but larger. Wildfires occurred preferentially in forests (47%), cropland (19%) and along road systems (13%).

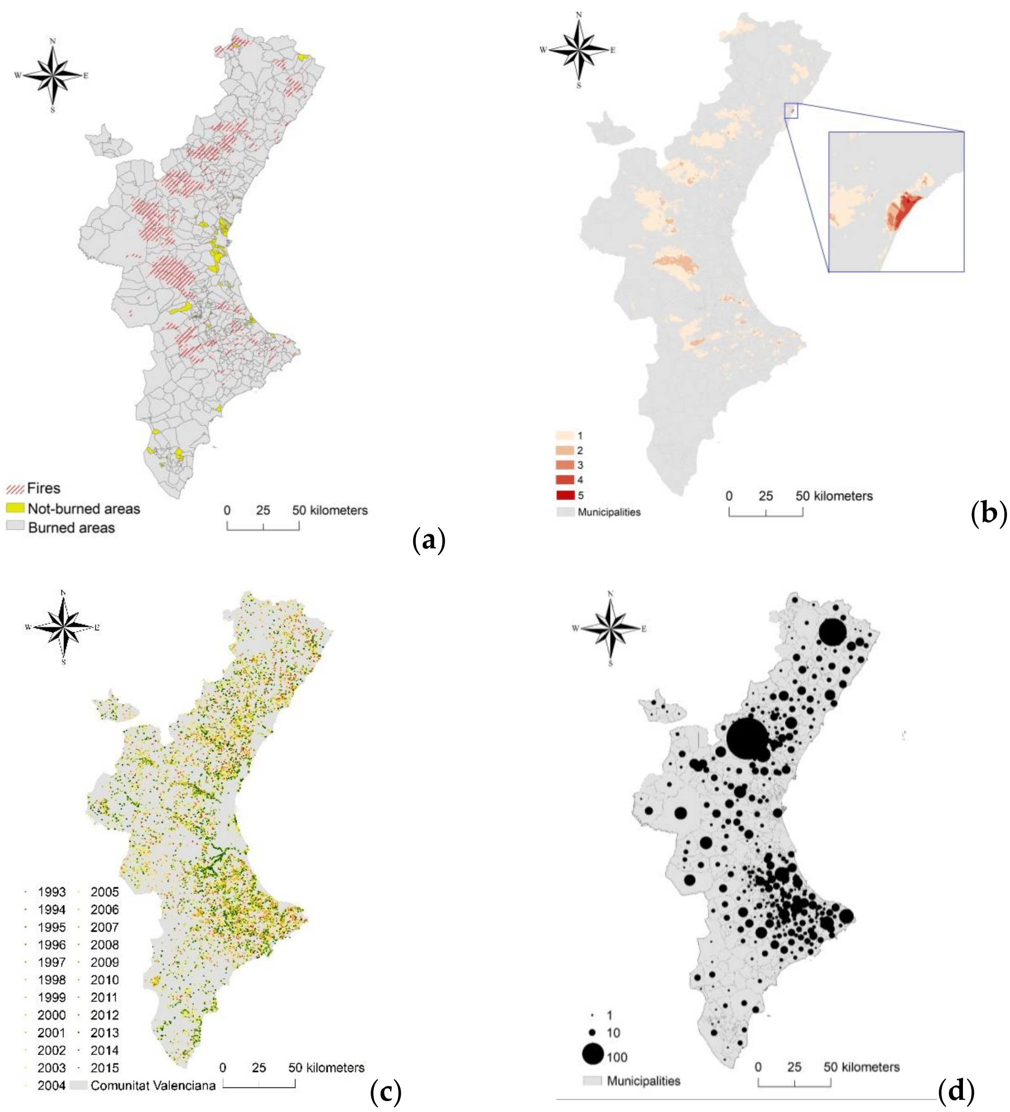

Figure 2. *Cont.*

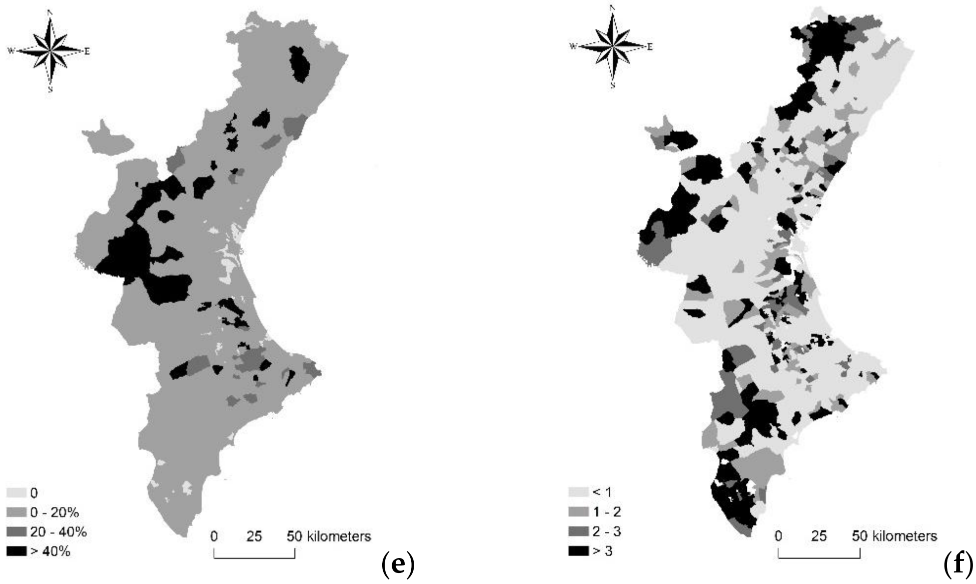

Figure 2. Burned and not-burned areas (**a**); number of times when a fire occurs at the same location (insert highlights the most exposed area) (**b**); time series of fires per year (**c**); duration of fires (in days) in the last years (**d**); burnt surface in municipal surface area (**e**); and the ratio of number of fires to burnt areas (**f**).

The most frequent cause of a fire was negligent behavior and accidents (41%), even though a large proportion of intentional acts was recorded (32%), of which 25% were perpetrated by people who have been recognized as mentally ill (Figure 3). One fire out of five was caused by lightning, especially in northern and inland areas during summer. On public holidays, the main causes were smokers (31%) and unknown causes (22%). On working days, the main causes were landfill exhaust, garbage burning, fire reproduced and other negligence. Accidental and intentional causes occurred mainly in areas close to the coast and along secondary roads.

More than 97% of fires affected protected rural areas. Causes of these fires include intentional negligence (15%), accidents (54%) and lightning (22%). Furthermore, most fires potentially started near the road system. Results of the spatial overlap of an ignition points map and the road system network in the Valencian Community are presented in Table 1. Confirming our initial hypothesis, the outcomes indicate an effective correlation between the appearance of fire and the proximity of a road. Especially, there is a relevant chance that a fire can occur in correspondence to a specific type of road. However, a non-parametric Spearman correlation analysis between fire size and distance to the road network from the related ignition point ($r_s = 0.35$, $p < 0.05$) indicates that distance from the road increases with fire size. In other words, smaller fires are more likely to occur close to the road network than larger fires.

A spatial analysis was finally adopted to investigate fire characteristics considering the percentage of road length by type around each ignition point. Two buffers (100 m and 500 m radius from the ignition point) were considered. While highways had only a few meters affected by fire, more than 50% of fires had their origin alongside local and municipal streets. This is a well-known issue because in Spain protective zones exist only along highways, while most fires started close to secondary roads. Wildfires along local and municipal roads were more frequent during the day, particularly between 1 p.m. and 6 p.m. The largest fires had ignition points close to local roads; fires occurring within 0.1 km of local roads burned 23 ha of land on average, while fires occurring near highways had a smaller average surface area (slightly more than 1 ha).

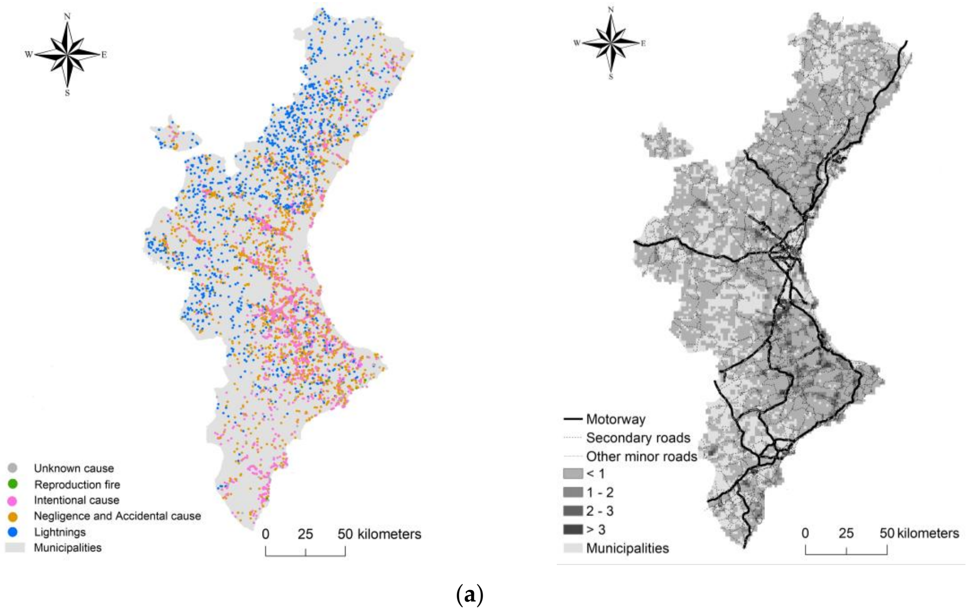

Figure 3. Spatial distribution of wildfires by type of cause (**a**) and density of the ignition points overlapped with the road system (**b**).

Table 1. Road length (per cent share in total network length) by type, within a buffer of 0.1 and 0.5 km from the origin of the fire (i.e., ignition point) by type of cause.

Road Type	Percentage Share in Total Length of Road Affected by Wildfires						Average
	Unknown	Reproduction Fire	Intentional	Negligence Accidental	Lightning	Total	Fire Size (ha)
0.1 km buffer							
Highway	8.4	26.8	9.0	14.3	5.3	11.3	1.2
Basic	15.5	6.4	10.4	12.7	8.3	11.5	0.3
Local	52.9	57.5	46.0	44.3	55.0	46.5	23.3
Municipal	16.5	0.0	25.3	20.4	27.3	22.5	1.9
Collecting way	0.0	0.0	0.3	0.0	0.0	0.1	0
Auxiliary branches	5.1	2.2	4.4	4.6	1.4	4.2	0.2
Service road	1.6	7.1	4.6	3.7	2.6	3.9	1.8
Under construction	0.0	0.0	0.0	0.0	0.0	0.0	0
0.5 km buffer							
Highway	10.8	20.0	13.3	15.7	8.6	13.9	1.5
Basic	13.0	11.7	11.7	12.3	9.8	11.9	0.9
Local	41.3	56.0	39.9	39.3	51.4	41.0	7.1
Municipal	22.3	8.7	22.0	20.9	21.3	21.3	0.8
Collecting way	0.3	0.0	0.3	0.1	0.0	0.2	0.2
Auxiliary branches	10.1	0.7	7.8	6.5	5.5	7.0	0.6
Service road	2.0	2.8	5.0	5.1	3.3	4.7	2.5
Under construction	0.0	0.0	0.0	0.0	0.0	0.0	0.2

4. Discussion

The present study investigates the spatial distribution of wildfires in relation to the road network in the Valencian Community. Wildfires primarily affected inner and central areas, whose landscape is dominated by abandoned crops and Aleppo pine plantation (*Pinus halepensis* Mill.) recovery or afforestation, where a high presence of biomass justifies a high incidence of fires after years of land abandonment [60]. In some of these areas, e.g., the Massís del Caroig, wildfires have occurred more than once in the same location. Several studies demonstrated how human-caused fires started close to human settlements and roads [63,67–70]. However, an explicit relationship between type of road and ignition points was not clearly demonstrated until now; our study verifies that roads are an important factor influencing the spatial distribution of fire ignition points in the Valencian Community.

By means of an elaboration using the ArcGIS program based on the urban planning that defines land-use in the Valencian Community, 97% of fires mainly affect protected rural areas. However, fires do not appear to start in open rural fields and forest contexts, but mainly near the road network. Confirming our main hypothesis, outcomes indicate a correlation between fire probability and proximity to a given type of road. Most fires occurred mainly near villages, which are accessible by local roads. In fact, local and municipal roads are frequent places where fires start (e.g., due to negligence), but their role is crucial for fire suppression and civil protection operations, which are directly influenced by accessibility [71]. While the results of this study seem to demonstrate some obvious issues (e.g., the positive spatial relationship between fires and the road network), they also show less expected aspects. Rural depopulation and land abandonment are important factors of wildfires if associated with development of road infrastructure, as observed in many rural districts of Mediterranean Europe. Proximity to roads mainly stimulate small-size fires in agricultural fields, while large-size fires are mainly observed in more remote places with forest land-use. Moreover, descriptive statistics demonstrate a spatial concordance between location of a given ignition point and type of road near where fires occurred, in turn related to some anthropogenic activities, including agriculture. Human-caused fire ignitions are spatially concentrated, suggesting that roads are crucial determinants of spatial places of human-caused ignitions, especially in rural districts with mixed cropland and abandoned land [63,64,68–71]. More than 50% of fires have their origin mainly alongside local and municipal roads. Earlier studies in other climatic zones have revealed that roads are the preferred location for fire ignition [72]. Several authors [19,60,73] provided similar findings for Portugal, France and Catalonia, respectively. Density of the road network also influences the timeframe between fire ignition and detection. For instance, if lightning fires occur close to developed areas (e.g., a road system), they may be rapidly repressed, resulting in circumscribed and smaller fires [66].

Based on the results of this study, regulatory master plans and spatial development tools depicting scenarios to ensure sustainable development and regions more resilient to natural disasters, should limit urban sprawl and rural abandonment [10,40,44,57,74], protecting, at the same time, the most vulnerable areas to wildfires, especially those situated close to dense road networks. From this perspective, agriculture can be regarded as a factor promoting and reducing fire risk at the same time. Farming clearly induces anthropogenic pressures directly and indirectly leading to a higher fire risk. At the same time, a productive district with economic value can be better protected from fires and less abandoned, as for many areas inland with low population density and few economic activities.

The importance of roads in relation to fires is considerable for fire prevention and management, as roads are both points of fire ignition and transport/emergency corridors [69]. The spatial distribution of roads and their effects on the nearby areas should be more carefully investigated and more actively considered in fire management and planning. Advancing policies of fire protection and prevention, specifically in buffer areas along roads, should be integrated with policies for sustainable land management [75]. In addition to roads, other interacting drivers may complicate the valuation of wildfire expansion in forest and peri-urban areas exposed to increasing human pressure [76–78]. In this sense, analysis of micro-data derived from geo-spatial databases is particularly valuable to inform new strategies of landscape management [79] and for assessing changes over time in fire regimes [80–85]. Analysis of geo-spatial databases covering longer time periods gives fundamental indications for (i) operationally preventing large fires, (ii) intervening on smaller fires, (iii) identifying the main causes of wildfires, and (iv) understanding when (and at which location) fires occur in a way to limit them and take concrete mitigation actions. Empirical findings emphasized the importance of planning strategies explicitly planned for Mediterranean rural contexts affected by land abandonment [19,27,57,81,86–89].

Recent low-density urban expansion into rural, agro-forest areas at growing distances from the main cities may have long-term effects on landscape structure and composition that require further investigation particularly in environmentally-fragile areas [40,90–92]. Based on this assumption, the limits of the present study emerged in the lack of additional information on fire events, which may prevent a holistic understanding of fire regimes (Figure 4). Future research may allow a better understanding of spatial regimes of wildfires contributing to a more effective management of fragile areas. Further studies should specifically focus on intrinsic changes in the carbon cycle [93], the role of soils in the earth cycles [94] and the soil erosion cycle [95]. Additionally, most research carried out on forest fires has investigated plant composition, soil properties, soil erosion and runoff generation, and the restoration of soil and vegetation cover after fire [96–101]. Little attention was instead paid to identify the causes and the spatial distribution of forest fires, demonstrating, for example, that roads are a serious source of ignition. Our contribution will finally help to design forest managements that may reduce the risk of desertification, achieving a management strategy oriented toward land degradation neutrality [102].

Figure 4. Forest fire in Carcaixent. June 2016. View in September 2016. Quick recovery thorough the spotters such as thorny oak - *Quercus coccifera* (**a**); recently abandoned fields in densely populated areas results in fires (Carcaixent, June 2016) (**b**,**c**); and forest fire in Carcaixent, June 2016. One week after the fire (see dwarf palm - *Chamaerops humilis* already sprouting) (**d**); new plantations (citrus) and forest fires. The opening of new roads for the new plantations contributes to enhance fire risk (**e**); and fire was a tool for farmers. Less prescribed fires result in higher biomass and higher fire risk (**f**).

5. Conclusions

The present study indicates that wildfires are more likely to occur along specific types of roads. In the Valencian community, most severe fires were recorded in correspondence to secondary roads, where there are no buffer/protection zones as there are prepared along highways and high-distance national roads that can effectively prevent a fire from spreading. Moreover, severe and large wildfires sometimes had ignition points very close to local roads. They often occurred in small isolated villages, endangering the safety of their inhabitants and delaying rescue operations. Taken together, these results indicate the need of enhanced environmental/landscape planning along local roads, with the creation of buffer areas, with both natural cover and agricultural use, increasing road maintenance and reducing vegetation fuel along them. Vegetation along local roads should be considered a unique landscape type with heterogeneous fuel characteristics, and with relevant socioeconomic and environmental consequences for wildfire containment. Furthermore, due to recent and rapid changes along urban–rural gradients, research should focus more intensively on agro-forest fringe contexts, where recent low-density urban expansion at growing distances from the main urban centers may have unpredictable long-term impacts on local landscapes, particularly evident in environmentally-fragile areas [40,90–92].

Author Contributions: Conceptualization, I.Z. and P.S.; methodology, P.S.; validation, A.C., P.C. and S.P.; formal analysis, P.S. and A.C.; investigation, I.Z, L.S. and P.C.; writing—original draft preparation, I.Z., A.C., L.S. and P.S.; writing—review and editing, I.Z. and L.S.; supervision, A.C.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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