

Commentary

Sustainable Land Management, Wildfire Risk and the Role of Grazing in Mediterranean Urban-Rural Interfaces: A Regional Approach from Greece

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Received: 21 December 2019; Accepted: 13 January 2020; Published: 14 January 2020



Abstract: Mediterranean regions are likely to be the most vulnerable areas to wildfires in Europe. In this context, land-use change has promoted land abandonment and the consequent accumulation of biomass (fuel) in (progressively less managed) forests and (non-forest) natural land, causing higher fire density and severity, economic damage, and land degradation. The expansion of Wildland-Urban Interfaces (WUIs) further affects fire density by negatively impacting peri-urban farming and livestock density. Assuming the role of grazing in controlling fuel accumulation in forests and non-forest natural land as an indirect measure of wildfire containment around large Mediterranean cities, our work focuses on the role of nomadic livestock, i.e., sheep and goats—the most abundant and traditional farm species in the area. The present study (i) investigates the relationship between fire frequency/extent and livestock decline at the regional level in Greece, (ii) explores changes over time in regional wildfire regimes, comparing Attica, a particularly vulnerable peri-urban region which includes Athens (the Greek capital city), with the rest of the country, and (iii) quantifies trends over time in livestock characteristics (population structure and dynamics) over a sufficiently long time interval (1961–2017) at the same spatial scale, with the aim to document the progressive reduction of nomadic livestock in peri-urban districts. A comprehensive analysis of statistical data, corroborated with a literature review, outlined the relationship between livestock decline over time and changes in specific wildfire characteristics at the regional scale, evidencing peculiar environmental conditions in Attica. In this region, a rapid decline of nomadic livestock was observed compared to in the rest of Greece, leading to a higher wildfire risk. The results of this study suggest that nomadic livestock contributes to sustainable management of peri-urban land, stimulating grazing that may prevent fuel accumulation in fringe woodlands.

Keywords: wildfires; peri-urban area; sheep; goats; Mediterranean landscape

1. Introduction

A complex interplay of natural and anthropogenic factors shape wildfires in affected and vulnerable areas [1]. In agriculture, fire was traditionally used to facilitate different land management options, such as converting forests to open land for pasture and farming purposes [2]. In the last century, the progressive decline of forests in advanced economies has been often linked with crop intensification [3]. While anthropogenic-driven fires have been historically used as a land management system in order to adapt natural settings to agricultural (or residential) use [4–6], wildfires combined with human activity have reinforced the development of fire-adapted forest ecosystems [7]. In Europe, biophysical and socioeconomic conditions supporting a dynamic balance between land-use allowed for keeping wildfires as a largely controlled phenomenon up to the 1950s [8]. In the following decades, a progressively unbalanced distribution of population along urban-rural gradients, the spatial polarization in intensive and extensive cropping systems, land abandonment and recovery of (mainly unmanaged) forests in marginal districts, and the disappearance of some rural activities (e.g., traditional livestock with sustainable grazing) all altered the landscape-wildfires equilibrium. A significant increase of fire frequency and extent has been observed in recent decades, indicating that the resulting rural contexts have been more prone to wildfires [5].

Mediterranean countries are the countries most threatened by wildfires in Europe. The so called “fireclub” involves countries such as Greece, Italy, Spain, Portugal, and France, where wildfires burned about half a billion hectares per year, with an average of 50,000 fires registered annually in the last two decades [9]. The temporal distribution of wildfires showed a seasonal outline where fires range from small (<1 ha) to large (>1 km²) [10,11]. However, fire risk was increasing rapidly in countries of Eastern, Central, and Northern Europe, becoming a problematic issue at the continental scale. At the same time, intense landscape transformations have affected many European areas in recent decades, and the Northern Mediterranean basin is one of the main land-use change hotspots in Europe [12,13]. Depopulation, land abandonment, and livestock decline shaped new landscapes with a progressive recovery of woodlands—often non-managed or badly managed—and with a consequent increase in vegetation accumulation on the ground, offering fuel for combustion [14,15]. As a matter of fact, fire spread more widely and aggressively in these contexts, causing substantial economic and environmental damage [15], negatively impacting land resources, ecosystem services, and biodiversity, and affecting activities such as tourism, especially in coastal areas [3]. In such contexts, the spatial distribution of fires changed rapidly over time [16–20]. Increased spatial variability makes fire prediction a particularly difficult task [21]. Moreover, winter fires are becoming more frequent compared to (the more traditional) summer fires [3,11,22–24]. The increased variability in fire regimes over time and space is a particularly relevant issue in sustainable land management [15,19,20]. Although fuel and landscape heterogeneity can help to slow fire spread, due to fuel breaks, spatio-temporal heterogeneity in fire regimes may halt suppression measures [25]. More unpredictable fire regimes make prevention and preparedness actions less effective, often determining an increase in management costs [8,19,26,27].

Factors underlying an increased fire risk during the most recent decades are multifaceted and differentiated at the geographical scale, evolving rapidly over time [15,28,29]. Sustainable land management is fundamental in these circumstances [1,30–34]. For instance, abandonment of forest and non-forest natural land including pastures, led to increased vegetation biomass which is no longer managed by humans or used by animals [7,35]. An excess of biomass leading to increased fuels in both forest and non-forest land has been considered to be a key driver of wildfire risk [22,23,36,37]. Fuel management oriented towards fire risk reduction is crucial in densely populated contexts near forest and non-forest landscapes progressively abandoned or less used than in the past [1,38–43]. Such areas include Wildland-Urban Interfaces (WUIs) and have more recently received consideration due to the rapid increase of wildfires near highly populated districts [15,35,43–53]. A WUI comprises a mixed landscape where houses, crop, and forest (as well as non-forest) natural vegetation often coexist [51,54]. Once low-density urban fabrics expand into forests, wildfire begins to threaten settlements bordering natural areas [55].

In Mediterranean countries, dispersed urbanization significantly increased the surface area and the perimeter of WUIs, expanding the length of contact points between settlements and wild land and thus enhancing the risk of more severe wildfires [56,57]. In this regard, the most recent evolution of peri-urban areas fueled land abandonment and spontaneous “re-naturalization” processes around cities, resulting in accelerated biomass accumulation in progressively less managed areas [35]. In other words, WUIs produce a spatial setting in which wildfires can easily spread from forest fuel to human settlements [58]. While requiring major investments, measures aimed at reducing the contact point between forests and settlements, e.g., creating buffers (or physical barriers) among buildings and vegetation, seem to be appropriate in such contexts [7,59–62]. For instance, the European Commission invested more than 3.2 billion Euros per year in fire suppression with the aim of restraining the socioeconomic impact of wildfires [8,10]. However, policies entirely based on widespread fire suppression have evidenced signs of failure in different European regions [11]. By contrast, fuel management is an appropriate tool to mitigate fire risk [33,38–42,48,63]. Combined fuel management plans for fire prevention and mitigation seem to be appropriate tools to reduce the impact of harmful and costly wildfires on natural environments [25,34,38].

Together with land-use change and farmland abandonment, a decline of livestock activities and grazing in peri-urban areas indirectly led to the accumulation of vegetation biomass in fringe natural land. Being strictly connected with the (increasing) urban market, animal husbandry around large cities has traditionally represented a natural control of vegetation, e.g., through nomadic sheep, goats, and cattle farming [7,64–69]. Up to a sustainable carrying capacity, pasture and forest systems may support a high density of grazing animals. Sheep and goat nomadic livestock are considered to be traditional elements of Mediterranean semi-arid landscapes in particular, as they are rather common around cities and towns in the past [59,60]. Assuming a multi-driver fire risk profile in Mediterranean countries, the present work debates the progressive reduction of livestock activities in peri-urban areas as a factor enhancing fire risk. A case study was based in a largely vulnerable Mediterranean peri-urban area (Attica, Greece) with the aim of discussing possible solutions to support traditional (wild) livestock activities at the fringe of large cities [70]. Land-use dynamics in Attica, a region including the Greek capital city of Athens, are representative of the abandonment of traditional agricultural systems that are typical of Mediterranean urban agglomerations [71]. Assuming land abandonment as a driver of fuel accumulation in natural landscapes and nomadic pastoralism as a means to control biomass and thus reduce fire risk [72–74], this work debates a more holistic management system for Mediterranean peri-urban landscapes, integrating sustainable land planning and fire-risk measures.

Since identification of a direct relationship between livestock spatial distribution (or density) and regional/local wildfire regimes is a rather hard task, the present study provides indirect evidence contributing to a discussion on the importance of (nomadic) livestock in peri-urban fires containment. This assumes that exurban development, a widespread urbanization model in Europe and the Mediterranean basin, leads to a reduction in the local density of nomadic livestock (mainly sheep and goats) in forests and non-forest natural environments close to settlements. This decline is due to different environmental and socioeconomic causes and has paralleled a consistent decrease of cropland. With progressive land abandonment, forest/shrubland expansion may be more rapid and intense in previously cultivated areas. A rapid decline in the number of farms and a consistent reduction of (mainly nomadic) livestock indicate a reduced anthropogenic control of natural land cover, a less effective management and use of productive areas, and land abandonment, with the resulting accumulation of fuel biomass, especially in non-managed forests/woodlands and pastures. Implications of this environmental spiral reflect an increased risk of wildfires. While this environmental spiral has been relatively well documented for rural areas, empirical evidence describing the socioeconomic background context and the main (urban and agricultural) transformations is still required for peri-urban areas.

The present study is articulated in three steps: (i) investigating the relationship between fire frequency/extent and livestock decline at the regional level in Greece, (ii) exploring changes over time

in regional wildfire's regimes, comparing Attica with the rest of the country, and (iii) quantifying trends over time in livestock characteristics (population structure and dynamics of sheep and goats) over a sufficiently long time interval (1961–2017) at the same spatial scale, with the aim to document the progressive reduction of specific livestock components (especially nomadic livestock) in peri-urban districts. Despite being speculative and exploratory in its aims, the analysis proposed for Attica and, more generally, for Greece is particularly interesting since the area experienced intense land-use change toward farmland/pasture abandonment, a less effective forest management with fuel accumulation, forest degradation, dispersed urbanization, and increased human pressure from infrastructural development, landscape fragmentation, industrialization, and tourism concentration along the coastal rim. Within such a complex territorial background, a quantitative analysis of statistical indicators integrated with field surveys and an extensive literature review can provide a specific contribution to sustainable land management in peri-urban areas, evidencing the progressive decline of nomadic livestock (and spatial concentration in a few locations) as a powerful factor shaping fire risk—because of reduced fuel control in pastures, forests, and non-forest natural land.

2. Methodology

2.1. Study Area

This study investigated livestock dynamics in Greece (131,957 km²), with a specific focus on the Attica region, using official statistics that report changes in sheep and goat density over time. Attica is the most populated administrative region of Greece, hosting 35% of the total population in the country (Figure 1). Extending 3025 km² of land with a density of 1250 inhabitants/km², Attica includes the capital city, Athens, whose area covers nearly 430 km² with a population density of nearly 15,000 inhabitants/km² [71–73]. In the last few centuries, the population in Attica moved from upland areas to lowland areas and along the coastal strip [75,76], and embraced different development types, which led to a shift from agrarian (or pastoral) management to urbanization [77–79]. In 1960, forests and pastures were the dominant land-use methods in Attica, while urban areas accounted for less than 10% of the total regional area. Since then, forests and non-forest natural areas decreased substantially, following which urban areas amounted to 25% of total land area in 2015 [80]. However, despite urban expansion, a particularly complex landscape still survives in Attica, mixing traditional cropland (garden crops, olive and vineyards), evergreen Mediterranean forests and shrubland at lower elevation, most of which have been grazed by sheep and goats until recently [60–62,68,79].

2.2. Livestock in Greece

In 2010, the total amount of sheep and goats in the country was 9,995,000 and 1,231,000 units, respectively, while grazing land covered more than 40% of the total country area [81–83]. Greece ranks third and first within the 28 European Union countries as far as the total number of sheep and goats is concerned, respectively. While other species are quite scarce and sparse throughout peri-urban regions such as Attica, sheep and goats remained as widespread farm species bred in different modalities (e.g., resident flocks, short-range nomadic, transhumant), which was likely because livestock activities involving sheep and goats were heavily subsidized [68]. Sheep and goats are considered to be effective farm species for the removal of forest and bush biomass (thus containing fire risk) and for this reason, their spatial distribution and density was investigated extensively in the present study.

2.3. Data Sources and Variables

2.3.1. Wildfires

Basic indicators assessing wildfire characteristics were calculated over a sufficiently long time period (2000–2018) using a comprehensive dataset of individual fires recorded in Greece and disseminated by the Hellenic Fire Brigade, including more than 190,000 events over 19 observation

years. Fire density (number of events per km²), average fire size (ha), per cent share of medium-large fires (>100 ha) in total fires, and per cent share of burnt land by class of land-use (woodland, pasture, and cropland in total burnt land) were calculated for each Greek prefecture (n = 51), considering the entire set of fires in the study period. Population density (inhabitants/km²) was considered as an additional variable to estimate human pressure. A specific aim was developed to compare wildfire regimes in Attica and in the whole of Greece using the same indicators, augmented with fire selectivity (per cent burnt land in total available area by land use). These indicators were calculated separately for two consecutive time intervals (2000–2008 and 2009–2018) and two study areas (Attica region and the whole of Greece) with the aim to outline diverging trends in the average wildfire regime in a peri-urban district and at the national scale. Land-use in Greece and Attica (forests, woodland, pastures, cropland) were derived from official statistics disseminated by Hellenic Statistical Authority (ELSTAT).

2.3.2. Livestock

Descriptive statistics of livestock density referring to sheep and goats—likely the most traditional grazing species in Greece—were calculated from official data disseminated by ELSTAT and collected on behalf of the Annual Agricultural Survey at the spatial level of prefectures. Official data on sheep and goat density distinguishing three forms of livestock (domestic, in-flock, and nomadic) were derived from the survey with the aim to calculate specific indicators quantifying livestock decline between 2000 and 2017 for each prefecture of Greece. The time span investigated here corresponded with the period when detailed data on wildfires were available at the same spatial level (see Section 2.3.1). A total of 12 indicators were derived from aggregated data: density of sheep (2000, per km²), per cent share of in-flock sheep in total sheep, per cent share of nomadic sheep in total sheep, density of goats (2000, per km²), per cent share of in-flock goats in total goats, per cent share of nomadic goats in total goats, change over time in sheep density (2000–2017, %), change over time in goat density (2000–2017, %), change in sheep density, in-flock (2000–2017, %), change in goat density, in-flock (2000–2017, %), change in sheep density, nomadic (2000–2017, %), and change in goat density, nomadic (2000–2017, %). A specific focus on peri-urban contexts was carried out comparing official statistics (animal density at three different breeding types (domestic, in flock, nomadic) and population dynamics in terms of births by year and species over a longer time period (between 1961 and 2017) for Attica and Greece as a whole.

2.4. Data Analysis

A non-parametric Spearman rank correlation matrix was run with the aim to identify pair-wise relationships at the prefectural level between fire characteristics using seven indicators (wildfire density, share of burnt area in total burnt area, average fire size, share of medium-large fires in total fires, share of burnt woodland, share of burnt pastureland, and share of burnt cropland) and livestock characteristics using 14 indicators (density of sheep (2000, per km²): per cent share of domestic, in-flock, and nomadic sheep in total sheep, density of goats (2000, per km²), per cent share of domestic, in-flock, and nomadic goats in total goats, change over time in sheep and goat density (2000–2017, %), change in sheep density, in-flock and nomadic (2000–2017, %), and change in goat density, in-flock and nomadic (2000–2017, %)) augmented with population density as a proxy of human pressure. Significance was tested at $p < 0.05$ after Bonferroni's correction for multiple comparisons.



Figure 1. Study area illustrating the position of Attica in Greece (right insert), the position of downtown Athens in Attica, the location of recent, severe wildfires (July 2018) in the area (Kineta and Mati, Rafina), and the largest pastureland in green (Source: reference [76]).

3. Results

3.1. A Preliminary Analysis of Wildfire Regimes and Livestock Density in Greek Prefectures

Results of a Spearman non-parametric analysis identifying significant correlations between wildfires and livestock characteristics in 51 Greek prefectures are illustrated in Table 1. Population density was positively correlated with wildfire density, indicating a specific role of human concentration in fire frequency, which is directly associated with a higher risk of small and medium-small fires in Greece. The density of sheep and per cent share of domestic goats were in turn correlated positively with fire density. Conversely, the share of in-flock animals (both sheep and goats) in total livestock was negatively associated with fire density. These results clarify that, in general, livestock density was positively linked with fire frequency. In this context, shepherds frequently use fire (especially small and medium-small fires responsible for an increase of fire frequency at the local scale) for managing pastureland. However, more traditional practices, including the partly nomadic in-flock livestock (for both sheep and goats), are associated with a lower frequency of wildfires. Similar results were observed for fire extent (share of burnt area in total prefectural area). Fires were usually larger in local contexts where domestic (more intensive and residential) livestock were dominant and the reverse pattern was observed for contexts with more extensive and nomadic livestock. Interestingly, average fire size was not correlated with any livestock variable, being more likely affected by external factors. The per cent share of medium-large fires in total fires was negatively correlated with the density of sheep livestock. The per cent share of woodland in total burnt area increased in prefectures where density of sheep livestock (and especially in-flock sheep) decreased more rapidly between 2000 and 2017. As expected, density of sheep was positively correlated with the per cent share of pastureland in total burnt area, outlining the intimate relationship between (domestic, more intensive and residential) livestock and (medium-small) fires used for managing pastures. While this applied for the Attica region (the prefecture with largest peri-urban area in the country), there were peculiar values involving the remaining prefectures for most of the variables

tested in the correlation analysis, suggesting the importance of a specific focus on livestock density and wildfire features in this peri-urban area.

Table 1. Non-parametric Spearman rank correlation coefficients between wildfire characteristics and livestock density at the spatial level of Greek prefectures (bold indicates significance at $p < 0.05$ after Bonferroni's correction for multiple comparisons). Source: own elaboration from official statistics of the Hellenic Fire Brigade and Hellenic Statistical Authority.

Variable	Wildfire Density	Share of Burnt Area in Total Burnt Area	Average Fire Size	Share of Medium-Large Fires in Total Fires	Share of Burnt Woodland	Share of Burnt Pastureland	Share of Burnt Cropland
Population density	0.56	0.24	−0.11	−0.26	−0.08	−0.06	0.03
Density of sheep (2000, per km ²)	0.42	−0.09	−0.30	−0.36	−0.31	0.48	0.02
Per cent share of domestic sheep in total sheep	0.27	0.48	0.25	0.22	0.31	−0.21	−0.29
Per cent share of in-flock sheep in total sheep	−0.38	−0.45	−0.18	−0.17	−0.21	0.10	0.21
Per cent share of nomadic sheep in total sheep	0.20	0.22	0.12	0.02	0.09	0.12	−0.05
Density of goats (2000, per km ²)	0.29	0.17	0.01	−0.03	−0.02	0.09	−0.13
Per cent share of domestic goats in total goats	0.39	0.38	0.09	0.06	0.14	0.00	−0.22
Per cent share of in-flock goats in total goats	−0.42	−0.35	−0.06	−0.01	−0.11	−0.02	0.18
Per cent share of nomadic goats in total goats	0.13	0.11	0.06	−0.09	0.08	0.01	−0.02
Change over time in sheep density (2000–2017, %)	−0.11	−0.19	−0.06	−0.06	−0.34	0.17	0.30
Change over time in goat density (2000–2017, %)	0.00	0.01	0.07	0.04	−0.27	0.21	0.24
Change in sheep density, in-flock (2000–2017, %)	0.01	−0.10	−0.04	−0.03	−0.35	0.20	0.28
Change in goat density, in-flock (2000–2017, %)	0.24	0.10	−0.01	−0.08	−0.25	0.19	0.20
Change in sheep density, nomadic (2000–2017, %)	−0.26	−0.10	0.00	0.10	−0.10	−0.05	0.10
Change in goat density, nomadic (2000–2017, %)	−0.05	0.03	0.03	0.15	−0.20	0.15	0.17

3.2. Wildfire's Characteristics in Attica

Basic characteristics of wildfires in Greece as a whole and in the peri-urban region of Attica, including the capital city of Athens, were illustrated in Table 2. The number of events considered in this analysis amounted to 4799 and 191,583 fires, respectively, for Attica and Greece during a time span of 19 years covering 2000–2018. Fire density was lower in Attica than in the whole of Greece with a declining trend in both spatial partitions. Average fire size was relatively high in the most recent time interval (2009–2018) in Attica, but were lower and decreasing over time in the whole of Greece. Forest burnt area decreased over time in both spatial partitions, being slightly higher in Attica. The total burnt area of woodlands decreased in both partitions, being much higher in Attica than in the whole of Greece. Burnt pastureland increased continuously over time. Burnt cropland increased in Attica while decreasing in the whole of the country. Analysis of wildfire selectivity finally indicates that pastures burned more frequently than other land-use (in respect with the total available land) in Attica. The same was observed for forests and woodland. Fire selectivity was markedly lower for Greece, although pastures remained the most selected land-use class.

3.3. Livestock Dynamics in Attica

A descriptive analysis of (sheep and goat) livestock characteristics was proposed in Table 3 by comparing Attica with the whole of Greece at two time points (1961 and 2017). An almost stable population of sheep and goats over time was observed in Greece, with a density amounting to 67–68 sheep per km² and 30–35 goats per km². For livestock dynamics in Attica, animal density has halved, falling from 60.5 to 34.5 sheep per km² and from 32.5 to 14.5 goats per km². In 1961, the density of nomadic sheep was relatively high in Attica (17.2 per km²), declining to 0.1 per km² in 2017. A similar trend was observed for goats, with a density falling from 12.1 per km² in 1961 to 0.1 per km² in 2017.

A comparison between the Attica region and the whole of Greece demonstrates the role of pastures for nomadic sheep and goats in peri-urban districts around Athens in 1961. The concentration of non-resident livestock in the area was remarkable at that time, declining over time because of urban growth and the conversion of pastures to settlements and intensive agricultural land.

Table 2. Basic characteristics of wildfires in the study area by time interval. Source: own elaboration from official statistics of the Hellenic Fire Brigade and Hellenic Statistical Authority.

Variable	Attica		Greece	
	2000–2008	2009–2018	2000–2008	2009–2018
Fire density (per km ²)	7.5	5.9	8.4	6.9
Average fire size (ha)	4.3	19.1	5.6	3.2
<i>Share of burnt land in total land by use (%)</i>				
Forests	20.9	15.6	23.2	13.8
Woodland	51.8	47.2	28.7	33.3
Pastures	15.2	17.6	13.5	20.5
Cropland	10.8	15.8	32.8	29.0
<i>Wildfire selectivity (%)</i>				
Forests	0.68	1.80	0.64	0.18
Woodland	0.47	1.51	0.49	0.27
Pastures	0.61	2.50	0.46	0.33
Cropland	0.11	0.57	0.40	0.17

Table 3. Density of sheep and goats (1961 and 2017) by grazing type in Attica and the whole of Greece. Source: own elaboration from official statistics provided by ELSTAT (the Hellenic Statistical Authority).

Variable	Sheep				Goats			
	Total	Domestic	In Flock	Nomadic	Total	Domestic	In Flock	Nomadic
Density per km ² , Greece (1961)	67.9	6.3	51.2	10.3	34.9	6.1	24.2	4.6
Density per km ² , Attica (1961)	60.5	9.4	34.0	17.2	32.5	8.8	11.6	12.1
Density per km ² , Greece (2017)	66.9	1.8	62.4	2.7	30.3	1.4	27.8	1.1
Density per km ² , Attica (2017)	34.5	0.6	33.8	0.1	14.5	0.9	13.6	0.1
Attica vs. Greece (%), 1961	2.04	3.38	1.52	3.81	2.13	3.32	1.10	6.04
Attica vs. Greece (%), 2017	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00

A descriptive analysis of demographic dynamics of sheep and goats in Greece indicates a progressive divergence between Attica and the whole of Greece (Table 4). While birth density of both sheep and goats has increased at the country level (from 48.0 to 59.7 births/km² and from 25.3 to 27.8 births/km², respectively, for sheep and goats in 1961 and 2017), these values decreased significantly in Attica during the study period (from 43.2 to 31.9 births/km² for sheep and from 24.9 to 15.9 births/km² for goats). Since the ratio of births to total population was quite stable over time for both sheep and goats, results of our analysis indicate a human-driven, progressive decline of livestock (and especially nomadic livestock) density because of increasing exploitation with no replacement from natural dynamics or immigration.

Table 4. Density of births for sheep and goats in Greece (1961 and 2017), with a focus on the Attica region. Source: own elaboration from official statistics provided by ELSTAT (the Hellenic Statistical Authority).

Variable	Sheep		Goats	
	Total Births	Births/Population	Total Births	Births/Population
Density per km ² , Greece (1961)	48.0	0.7	25.3	0.7
Density per km ² , Attica (1961)	43.2	0.7	24.9	0.8
Density per km ² , Greece (2017)	59.7	0.9	27.8	0.9
Density per km ² , Attica (2017)	31.9	0.9	15.9	1.1
Attica vs. Greece (%), 1961	2.07	1.0	2.3	1.1
Attica vs. Greece (%), 2017	1.23	1.0	1.3	1.2

4. Discussion

Southern European countries have witnessed increasing frequency and severity of wildfires [10,11], and the increasing role of wildfires in peri-urban dynamics is a key issue in environmental risk [15]. Multiple factors were demonstrated to drive recent fire dynamics [15,28,29], with the consequent increase in the spatial heterogeneity of (both large and smaller) wildfires [16–20]. Spatial heterogeneity in wildfires reflects a low predictability of the most severe events, higher suppression costs, and less effective prevention and preparedness measures, especially in vulnerable districts such as the urban-rural interface [19,20,84]. As a matter of fact, a higher fire risk in Southern Europe [3,10,85] was demonstrated to be associated with an increasing frequency of less predictable events [3,15,19,24,25,27,34]. Land abandonment in rural areas has been shown to stimulate biomass accumulation. Since vegetation is not used by animals or managed by humans, spatial heterogeneity of natural landscapes increases, leading to more unpredictable fire patterns [7,35]. In these regards, sustainable land management is fundamental to containing wildfires [1,33,34]. More specifically, animal husbandry is considered an effective practice allowing for a natural control of vegetation [61,62]. The indirect control of sheep and goats—especially nomadic or when managed in flocks—was demonstrated to be particularly effective to control fuel accumulation in forests, maquis/bushland and non-forest natural land [66–69]. The empirical results presented in this study document a specific trend in a Mediterranean peri-urban area, traditionally devoted to pastoralism and now experiencing a decline in livestock density. In Attica, pastoralism was a traditional activity providing high-quality products (e.g., cheese, milk, meat) to a large (and increasing) urban market.

At the beginning of the study period, sheep and goats were managed in a nomadic fashion surrounding the Greater Athens area and in more remote rural places. In the following decades, livestock progressively disappeared because of urban expansion, land abandonment, and the expansion of industrial crops in pastureland. This process led to biomass accumulation especially in the most fragile sites, mainly along the urban-rural interface, where conflicts with urban land-use are more frequent and may determine a greater fire risk [36]. When compared with events observed at the country scale for a representative time horizon, the basic characteristics of wildfires in Attica indicate a moderate decrease in fire frequency (lower density of fire events in the last decade) and a substantial increase in fire severity (rising fire size). At the same time, pastures were increasingly burnt in respect to their availability in the landscape, suggesting an overall reduction of grazing and a progressive abandonment of this land type. Assuming that livestock grazing with wild animals is an effective tool mitigating fire risk [76,86–91], the continuous decrease in livestock density—and especially nomadic flocks—because of multiple drivers associated with urban growth and agricultural decline in fringe districts, as observed in Attica region, is an important factor shaping fire risk in peri-urban areas. In such contexts, moderate grazing was recognized to reduce fire severity, positively influencing fuel characteristics [39–43]. More specifically, sheep and goats contribute as an indirect fire management tool by abating fuel loads with a small diameter, which can have an impact on the rate of spread of a fire and flame height [60]. At the same time, monitoring of under store scrubs has revealed

the major impact of grazing goats and a valuable role for making use of the low nutritive value woody plants [61,76].

The abandonment of livestock farms in Attica was particularly noticeable in the last 50 years. While population dynamics were found to be rather constant over time, the overall density of livestock farms has been significantly reduced in Attica region compared to Greece. This is typically the case of peri-urban areas where pastoralism declines due to competition from more profitable agricultural activities (e.g., vineyards, garden crops, flowers) and other land-use (conversion of pastures into low-density settlements or fragmentation of a rural landscape matrix with pastures intermixed with cropland and woodlands). Pastoralism was also less intensively subsidized in peri-urban areas, with poor (or no) incentives at community scale. In this context, an intense decline in livestock farms was associated with (i) more severe wildfires, (ii) a higher incidence of fires burning woodlands, and (iii) a higher spatial heterogeneity of fire events, being motivated by multiple causes that include a lack of subsidies for livestock, conversion of forest and non-forest natural areas to urban settlements, poor forest management, and land abandonment [19,75,92].

Loss of pastoralism and the increasing spatial heterogeneity of wildfires were demonstrated to be associated with (rapid) changes in land-use, lack of subsidy for livestock activities and peri-urban agriculture, simplified (or no) forest management, and competitive urban land-use impacting fragile natural contexts [19,75,92]. Additional efforts aimed at (i) exploring fuel management for wildfire prevention in peri-urban districts and (ii) assessing efficiency of (pre- and post-)fire fuel management using advanced methodologies should be developed [34,44,48,93–96]. Forward-thinking indicators, such as spatial indexes quantifying where and what type of forests can be qualified for fuel removal in fringe districts, contribute to our understanding of which areas require a re-distribution of fuel removals to reduce fire risk [63]. Assuming that fuel management effectively changes the behavior of fires and their effects on forests and human systems [7,34,38–41], new wild livestock activities can be promoted in these areas. Unfortunately, the intimate linkage between fuel removal and a cost-effectiveness balance of preparedness actions is still incomplete in many regions of the Mediterranean basin, even though catastrophic fire events constantly occur every year in Southern Europe, especially in summer [10]. Understanding such a connection helps territorial planners and forest managers to progress their efforts in landscape management and accounting financial resources.

Severe fires were likely enhanced by ineffective territorial management, leading to a progressive decline of traditional agricultural and pastoral activities [60–62,68]. For instance, fuel accumulation and pastoralism decline were part of the causes for the 2018 catastrophic fires in Mati (Rafina) and Kineta, Attica. Drought and strong winds contributed to the rise in fire size, which led to nearly 20 km² of land being burnt. Kineta (2000 resident inhabitants) is a small resort town about 35 miles west of the capital city on a route used daily by more than ten thousand drivers to reach the Peloponnese peninsula. Rafina was the biggest town hit by the fires, with a population of over 13,000 inhabitants (2011). Mati, in Rafina district, is a popular location for local tourists, particularly older people and children at holiday camps. More than 100 victims were recorded in the Mati fire. A recent study documented how fire events are related to specific classes of land cover, above all agricultural areas and low-density built-up settlements [79]. Together with the increase of the WUI, such new landscape settings have led to increasing wildfire events in Mediterranean environments [15,97–99].

Since wildfires influence the structural characteristics of such environments [99,100], successful fuel management plans are required to evaluate (i) the expansion of wildfire suppression options and effectiveness, and (ii) the reduction of environmental and socioeconomic impacts of wildfires [1,8,10,11,23,81]. Active forest management with suitable and planned silvicultural interventions in peri-urban districts is required in Mediterranean cities, as it is one of the main tools against land abandonment and provides a reduced risk of wildfire [1,7]. Clearing of grazing land is among the most useful practices in terms of fire prevention [79]. Furthermore, under certain conditions, post-fire grazing status should be integrated with forest management, with the aim of achieving natural regeneration of burnt areas [7,101]. Although fuel removal (logging, mowing, and especially grazing)

in Mediterranean areas is used as a real fuel management preparation with the aim of assisting fire suppression strategies, financial resources are usually limited. Economic analysis can offer convenient material to support wildfire prevention agendas [38,40–42], suggesting that investments (e.g., cost of fuel removal) should be evaluated based on both monetary and non-monetary advantages [38–42]. Consequently, developing a comprehensive approach to assess the cost-effectiveness of fuel removal in peri-urban districts is essential [48], and the role of livestock grazing is particularly relevant for this matter.

5. Conclusions

Increasing fire risk was associated with landscape transformations that facilitate the spread of wildfires [1]. With the progressive disappearance of pastures in peri-urban districts, fuel accumulation, together with climate change and rising human pressure, is causing more severe wildfires affecting local economies and ecosystems [15,39–42,89,96,102–107]. Fire frequency and extent increased according to recent socioeconomic changes, including the expansion of rural-urban interfaces with mostly sparse settlements at the border of metropolitan regions, and the progressive abandonment of farmland and pastures [8,23,36,37,85]. Even if wildfires are a recurrent issue in Greece, land abandonment and livestock decline in fringe districts have led to a progressive expansion of forests and shrubland into farmland. Attica is a representative example of such dynamics [71]. Measuring environmental and socioeconomic factors causing increased fire risk together is essential from the standpoint of operational wildfire management agendas [38–42]. Nature-based solutions for wildfires, including grazing by nomadic livestock, require optimization of available resources and knowledge with the aim of achieving predictable results. Compared with the rest of Greece, our results suggest that nomadic livestock decline in Attica was noticeable and quite rapid over time. The loss of this traditional activity was likely associated with fuel accumulation in forests and non-forest natural areas (including pastures), thereby increasing the potential for wildfires [36]. A possible solution to counteract pastoralism loss is the implementation of specific subsidies to peri-urban livestock farms, with the aim of maintaining (wild) livestock across the urban interface [34]. In this way, a sustainable land management preventing (or containing) severe wildfires is promoted.

Author Contributions: Conceptualization, G.Q. and S.V.; methodology, A.C. and G.E.; software, R.T. and G.E.; validation, A.C. and S.V.; formal analysis, L.S. and S.V.; investigation, R.T. and G.E.; resources, G.Q. and G.E.; data curation, A.C., S.V. and R.D.; writing—original draft preparation, L.S.; writing—review and editing, G.E. and R.D.; visualization, G.E. and R.D.; supervision, A.C.; project administration, R.T. and R.D.; funding acquisition, G.Q. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

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

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