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Recent Trends in Fire Regimes and Associated Territorial Features in a Fire-Prone Mediterranean Region

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Abstract: Fire regimes in Mediterranean countries have been shifting in recent decades, including changes in wildfire size and frequency. We sought to describe changes in fire regimes across two periods (1975–1995 and 1996–2018) in a fire-prone region of central Portugal, explore the relationships between these regimes and territorial features, and check whether these associations persisted across periods. Two independent indicators of fire regimes were determined at parish level: fire incidence and burn concentration. Most parishes presented higher values of both indicators in the second period. Higher values of fire incidence were associated with lower population densities, lower proportions of farmland areas and higher proportions of natural vegetation. Higher levels of burn concentration were associated with smaller areas of farmland and natural vegetation. These associations differed across periods, reflecting contrasting climatic and socio-economic contexts. Keeping 40% of a parish territory covered by farmland was effective to buffer the increased wildfire risks associated with different management and climate contexts. The effectiveness of higher population densities in keeping fire incidence low decreased in the last decades. The results can improve the knowledge on the temporal evolution of fire regimes and their conditioning factors, providing contributions for spatial planning and forest/wildfire management policies.

Keywords: wildfires; fire regimes; population features; land management; Mediterranean Europe; Portugal

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1. Introduction

Fire regimes can be understood as the average fire conditions (frequency, density, intensity, severity, seasonality, etc.) in a particular area and over a long period [1–3]. Past and present fire regimes are crucial for understanding fire spatial and temporal behavior and for estimating future changes [1,4–6]. This is particularly important in Mediterranean Europe, one of the most fire-prone regions worldwide due to its climate and vegetation characteristics [7,8].

Fire regimes are affected by land use/land cover (LULC), human activities, climate, and topographical context (e.g., [6,7,9–18]). Understanding and modeling these factors, in particular how they interact with each other to influence fire regimes, remains a key challenge [6,19,20]. LULC has a crucial role on driving fire regimes, by regulating moisture content and the availability, continuity and flammability of fuel loads [21,22]. In fact, several studies demonstrated that fires are selective regarding land cover (e.g., [22–24]), and in the case of the Mediterranean region, scrublands, forest plantations (mainly maritime pine (*Pinus pinaster*) and eucalyptus (*Eucalyptus globulus*)), grasslands and woodlands are the most fire-prone, while built-up surfaces, farmland areas and agroforestry systems are less likely to burn [22–26]. The continuity/contiguity of fuel load is also strongly dependent on LULC patterns. A diverse and heterogeneous landscape is capable of modifying the fuel characteristics and conditions in space, hampering wildfire propagation and reducing the fire extent and its capacity to cause damage [13,24,27,28]. On the contrary, a more homogeneous landscape is less fire-resistant and promotes a higher wildfire hazard [22].

Population is another major driver of fire regimes. Fire ignitions are often associated with human presence, agricultural activity, and livestock grazing [7,9,16,20,22,29–34]. Intentional or negligent/accidental ignitions frequently result from using fire for agricultural and grazing purposes, i.e., harvest waste removal and brushwood/abandoned land clearance [20,30]. On the other hand, the abandonment of rural areas and consequent population loss has caused the decline of traditional land uses (farmland, silviculture, and livestock), enabling the growth of unmanaged forests and scrublands, promoting fuel accumulation and resulting in more frequent and larger wildfires [7,12,30,35–39].

Finally, the temporal trends of wildfires and how they spread over landscapes are greatly influenced by annual variations in temperature, rainfall and relative humidity, with wildfire occurrence and severity being favored by long-term droughts and heat waves [5,9–11,15,40–44].

The effect of LULC and human population on fire regimes is therefore likely to vary across periods in the magnitude of decades, due to temporal changes in climatic factors and socioecological context [6,45]. For example, some authors state that the fire regimes in the western Mediterranean have already shifted from fuel-limited to drought-driven, which led to larger burned areas [7,12,46,47]. However, the temporal changes in fire regime drivers and their relationship with fire incidence have been considered in few studies [1,10,11,37,48], and are not yet fully understood.

Here, we examine how spatial patterns of LULC and population density are associated with local fire regimes in a wildfire-prone region of central Portugal, and how different periods influence these relationships. Portugal stands out among the European countries, recording the highest wildfire density and percentage of burned areas in the last decades [16,29,47,49–52]. We expected that the effects of LULC changes, rural abandonment, and lack of land management in this region affect the severity of the fire regime across time. To address this, we compared LULC and population density associations to fire regimes across two periods with similar durations (1975–1995 and 1996–2018), ensuring a representative number of years in each period. Environmental and socioeconomic changes are progressive along time, so we expected that this simple division would contrast the average values and trends of features in these two periods. Specifically, we aimed: (1) to characterize and describe changes in fire regimes and their associated territorial features (LULC and population) across periods; and (2) to model how LULC and population were associated with local fire regimes, and to what extent the impacts of these drivers changed between the two periods. The obtained results provide insights on the temporal evolution of fire regimes and their conditioning factors, with implications for spatial planning and forest/wildfire management policies.

2. Materials and Methods

2.1. Study Area

The study area (Figure 1) is located in central Portugal, a highly wildfire-prone region, and covers 15,242 km^2 and 568 civil parishes, our unit of analysis that corresponds to the smallest administrative units in the country. The average area of these parishes is 27 km^2 (range = 2–172 km^2). The climate is Mediterranean (Köppen classes Csa and Csb), with dry and hot/warm summers. Rainfall is mainly concentrated in the autumn and winter months (around 70% of the annual values), although the spring months represent on average 20–25% of the annual values. Elevation ranges between 1993 m a.m.s.l. in the central section of the region and 23 m a.m.s.l. in the south. In 2015, more than 3/4 of the landscape was occupied by forests, in which maritime pine (*Pinus pinaster*), scrublands and eucalyptus (*Eucalyptus globulus*) stand out, representing 28%, 20% and 14% of the study area, respectively. Built-up areas are mostly scattered and interspersed with wildland, corresponding only to 3% of the study area. In 2011, ca. 730,000 people lived in the region (48.1 inhabitants/km^2), but the population has been declining and aging over recent decades, along with progressive rural abandonment. During the 1975–2018 period, the total burned area reached 2,113,528 ha (1.39 times the study area's surface).

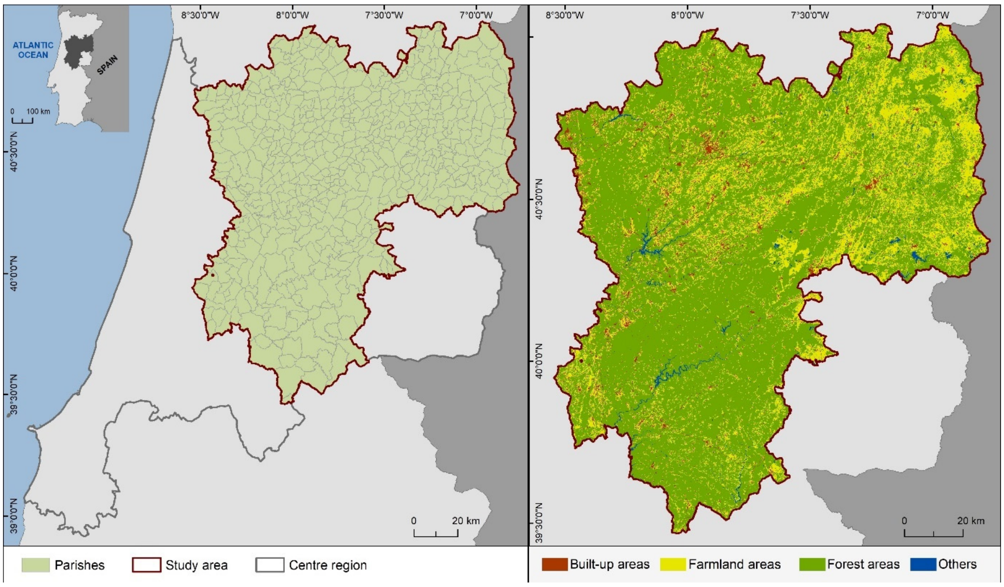

Figure 1. Study area in central Portugal, civil parish boundaries and land use/land cover (LULC) of 2015 in the region. LULC source: Portuguese Directorate-General for Territory.

2.2. Fire Regime Characterization

Fire regimes were characterized from a set of seven variables expressing how fire affected each of the parishes across time and space during each of the two considered periods: 1975–1995 and 1996–2018 (Table 1). These were estimated based on maps of yearly burned area, obtained in vector format from the National Forests Service (Portuguese Institute for the Conservation of Nature and Forests—ICNF) (Lisbon, Portugal). ArcMap 10.7.1 (ESRI Inc.) (Redlands, CA, USA) software was used for all spatial analysis operations.

The total burned percentage describes the accumulated burned area during each period, expressed as percentage of the parish area. It was used as an indicator of the extensiveness of wildfires. The proportions of years in which a parish burned 25%, 50% and 75% of its area were likewise used as complementary indicators of fire extent.

Mean and maximum times burned were used as indicators of the frequency of burning. They were obtained by dividing each parish into 25 m pixels and calculating the mean and the maximum number of times that the pixels within each parish burned during each period.

Finally, we used a variable to describe the temporal distribution of wildfire damage within the fire regime. This was the Gini concentration index (Gini), applied to the yearly burned areas of each parish over each period. This index quantifies (between 0 and 100) the temporal concentration of the total burned area for each parish, allowing the differentiation of parishes where most of the burned area is concentrated in a small number of years (higher values) from those where the burned area is more regularly distributed over time (lower values). It was originally developed in the field of economics [53] and it has been used to measure the concentration of wildfire damage over wildfire events [54] or as the basis for concentration indices with the same purpose [55–57].

Table 1. Median, mean, and range (min–max) for the fire regime variables estimated for each parish, in each of the two periods.

Variable	Description	First Period (1975–1995)	Second Period (1996–2018)
Total burned percentage	Total accumulated burned area expressed as % of the parish area.	49.3/58.1 (0.1–259.3)	73.8/80.1 (0.3–329.5)
Gini	Gini index of the yearly distribution of the total burned area	81.5/81.1 (58.8–95.2)	87.7/85.4 (53.9–95.7)
Mean times burned	Average number of years a pixel inside the parish was burned	0.49/0.58 (0.0–2.6)	0.74/0.80 (0.0–3.3)
Max times burned	Maximum number of years a pixel inside the parish was burned	3/3.5 (1.0–8.0)	3/3.6 (1.0–10.0)
Prop years 25%	Proportion of years that a parish burned over 25% of its area	0/0.02 (0.0–0.24)	0.04/0.04 (0.0–0.22)
Prop years 50%	Proportion of years that a parish burned over 50% of its area	0/0.0 (0.0–0.14)	0/0.02 (0.0–0.13)
Prop years 75%	Proportion of years that a parish burned over 75% of its area	0/0.0 (0.0–0.05)	0/0.01 (0.0–0.09)

2.3. Territorial Features

Population density in each parish for each period was calculated from the average of two national population censuses (1981 and 1991 for the first period; 2001 and 2011 for the second period), produced by Statistics Portugal (Table 2).

Table 2. Median and range for territorial variables estimated for each parish in each of the two periods.

Variable Name	First Period (1975–1995)	Second Period (1996–2018)
Population density (inhabitants/km^2)	45.1 (7.4–810.6)	35.3 (4.2–741.1)
Proportion of area covered by farmland (%)	26.4 (1.8–79.3)	22.4 (0.7–75.3)
Proportion of area covered by plantations (%)	41.5 (0–92.2)	39.1 (0–88.8)
Proportion of area covered by natural vegetation (%)	24.8 (0.6–79.8)	28.9 (0.9–91.3)

LULC was estimated considering three main categories (Table 2): farmland (including annual crops, permanent crops, and pastures), tree plantations (including pine and eucalypt plantations), and natural vegetation (including scrublands and oak forests). For each parish, the proportional cover by these three categories was estimated from detailed LULC maps provided by the Portuguese Directorate-General for Territory in 1995 (used to characterize the first period) and 2015 (used to characterize the second period). The date of the first LULC map (1995) is the criterion for the division between periods in 1995/1996. The LULC maps were created through the interpretation of digital orthorectified aerial photos, with a minimum cartographic unit of 1 hectare.

The Castelo Branco rain gauge, located in the southeast of central Portugal, was used to determine the average annual values of temperature and rainfall for the study area. This rain gauge belongs to the Portuguese Institute for Sea and Atmosphere (IPMA) and is the only one whose temperature and rainfall data cover the entire studied period.

2.4. Data Analyses

All analyses were performed using R software [58]. We used principal component analysis (PCA) [59] to summarize the main trends in fire regimes. Each parish was characterized in both periods so that resulting parish coordinates in the PCA could be comparable across time. Differences across periods were visualized using kernel density plots to show the probability density function of coordinate distribution using the ggplot2 package [60]. The significance of the observed differences was tested using linear mixed models with parish ID as a random effect. The package lme4 [61] was used for fitting these models.

The PCA derived two main axes representing two indicators of fire regime. The relationship between these indicators (as response variable) and LULC variables, population density (log-transformed) and period were analyzed using linear mixed models using parish ID as a random effect. Before running the models, collinearity between explanatory variables was assessed using correlation and variance inflation factors (VIF) using the usdm package [62]. The proportion of natural vegetation and proportion of plantations were highly correlated ($r = -0.82$); therefore we discarded the latter, after which no variable showed collinearity problems, with all VIF smaller than 2 [63]. The two-way interaction between period and each of the other variables was included in an initial full model that was simplified by discarding nonsignificant variables (and interactions), using the step function, until all remaining variables were significant. Predicted values were visualized using the package jtools [64], controlling for the effects of other variables in the model (by keeping them at their mean values or base level for categorical variables). A few parishes ($n = 15$) did not burn in any of the two periods and were discarded from the analyses.

3. Results

3.1. Fire Regimes

Yearly burned area in the region between 1975 and 2018 averaged 48,000 ha (41,739 ha in the first period and 53,783 ha in the second period), ranging from a minimum of 1866 ha (in 2018) to 383,000 ha (in 2017), one of the worst fire years in the country due to the occurrence of two extreme events (June and October). The three worst fire years occurred in the second period (Figure 2). The sum of the three years with the largest burned area (2003, 2005 and 2017) reached 677,263 ha, which means that almost a third of the total burned area in 44 years was concentrated in just three years.

The PCA yielded two principal components with eigenvalues > 1, which accounted for 81.3% of the total variance (Table 3). PC1 (hereafter designated "fire incidence") represented a gradient of increasing total burned area and fire frequency, with increasing parish PC scores representing increased total accumulated burned area, higher average number of years a pixel was burned, and a higher proportion of years when a parish was burned in at least 25% or 50% of its total area. PC2 (hereafter designated "burn concentration") expressed mainly the Gini index, i.e., represented a gradient of increased temporal concentration of the total burned area (regardless of its extent), as opposed to a more homogeneous distribution of burned area throughout the period. It therefore expresses the likelihood that a parish will be significantly affected in specific years, rather than being progressively burned at regular intervals. Associated with this variable, parishes with higher PC2 coordinates also had a higher proportion of years where they burned at least 75% of the total area.

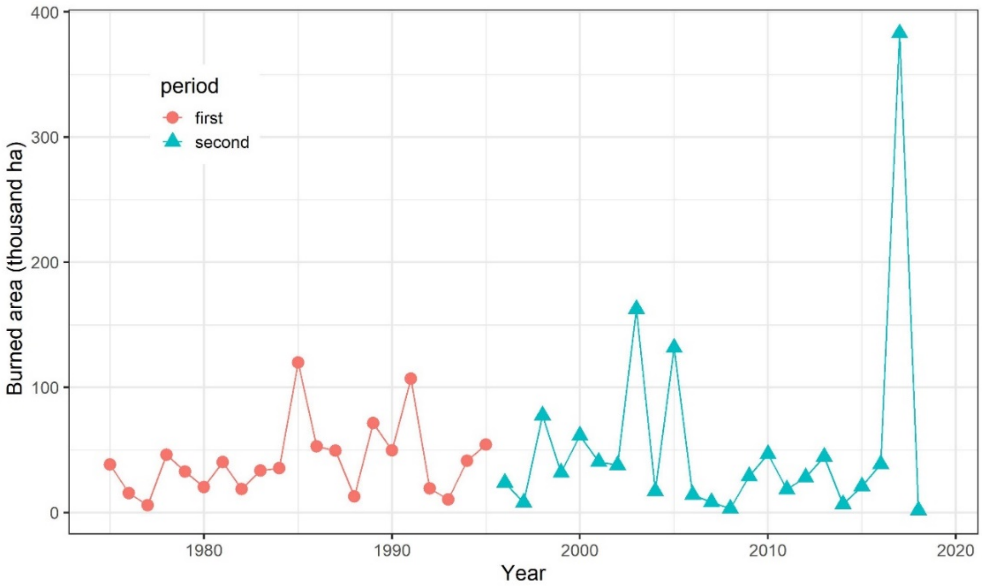

Figure 2. Variation in the total annual burned area (in thousand hectares) across the two studied periods (first = 1975–1995; second = 1996–2018).

Table 3. Variable loadings for the two extracted principal components (PC) and explained variance.

Variable	**PC1**	**PC2**
Total burned percentage	**0.98**	−0.05
Gini	−0.29	**0.88**
Mean times burned	**0.98**	−0.06
Max times burned	0.64	**−0.67**
Prop years 25%	**0.83**	0.17
Prop years 50%	**0.70**	0.56
Prop years 75%	0.46	**0.59**
Explained variance (%)	*53.9*	*27.4*

A graphical representation of the values of both PCs for both periods (Figure 3) shows that the range of PC2 values was wider for parishes with higher PC1 coordinates, regardless of the period. This demonstrates that a higher variability in the temporal concentration of total burned area is associated with parishes with higher fire incidence. At the same time, the figure shows that the second period is marked by increased variability in the values of both PCs. It is worth highlighting the upper right quadrant of the Figure 3, which reveals the most severe situation, where the parishes with higher scores of fire incidence and burn concentration are represented. It should also be noted that the second period dominates this quadrant.

This contrast between both periods can also be seen when considering the distributions of the PC score values in each period (Figure 4) with coordinates in both PC1 and PC2 less concentrated and shifted towards the right in the second period, showing an increasing trend in both fire incidence and burn concentration. In the case of PC2, the second period is also marked by the increased number of parishes with relatively high burn concentration (peak at PC2 scores higher than 2).

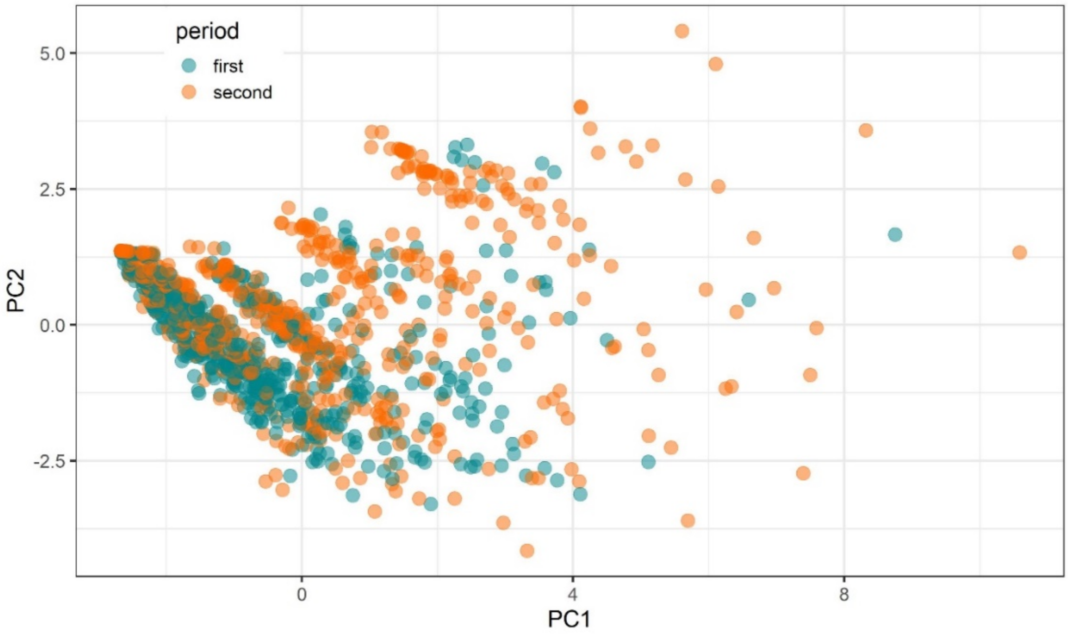

Figure 3. Plot of the values of the two extracted principal components (PC) by parish for the two studied periods (first = 1975–1995; second = 1996–2018).

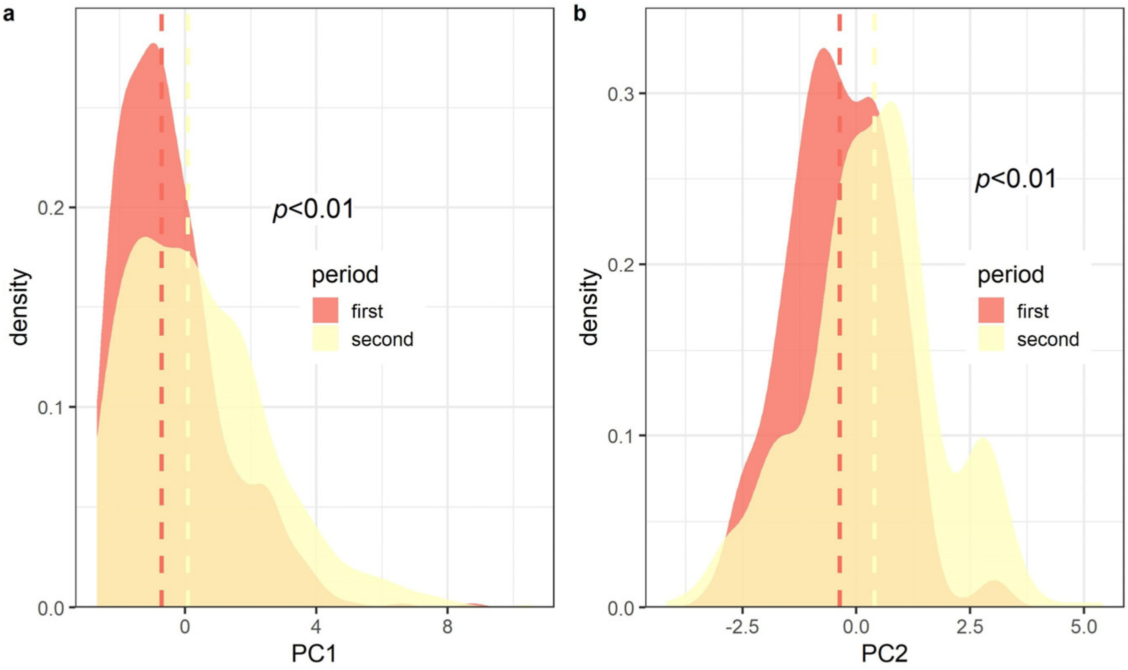

Figure 4. Kernel density estimates of PC1 (**a**) and PC2 (**b**) scores in the two periods (first = 1975–1995; second = 1996–2018). Vertical lines represent median values for each period.

The spatial distribution of fire regime indicators is shown in Figure 5. The increase in fire incidence across periods was widespread in the whole area, although particularly concentrated in the center and southern sectors. The increase in burn concentration was mostly found in the western and southern sectors of the study area, with a reduced expression in its eastern limit.

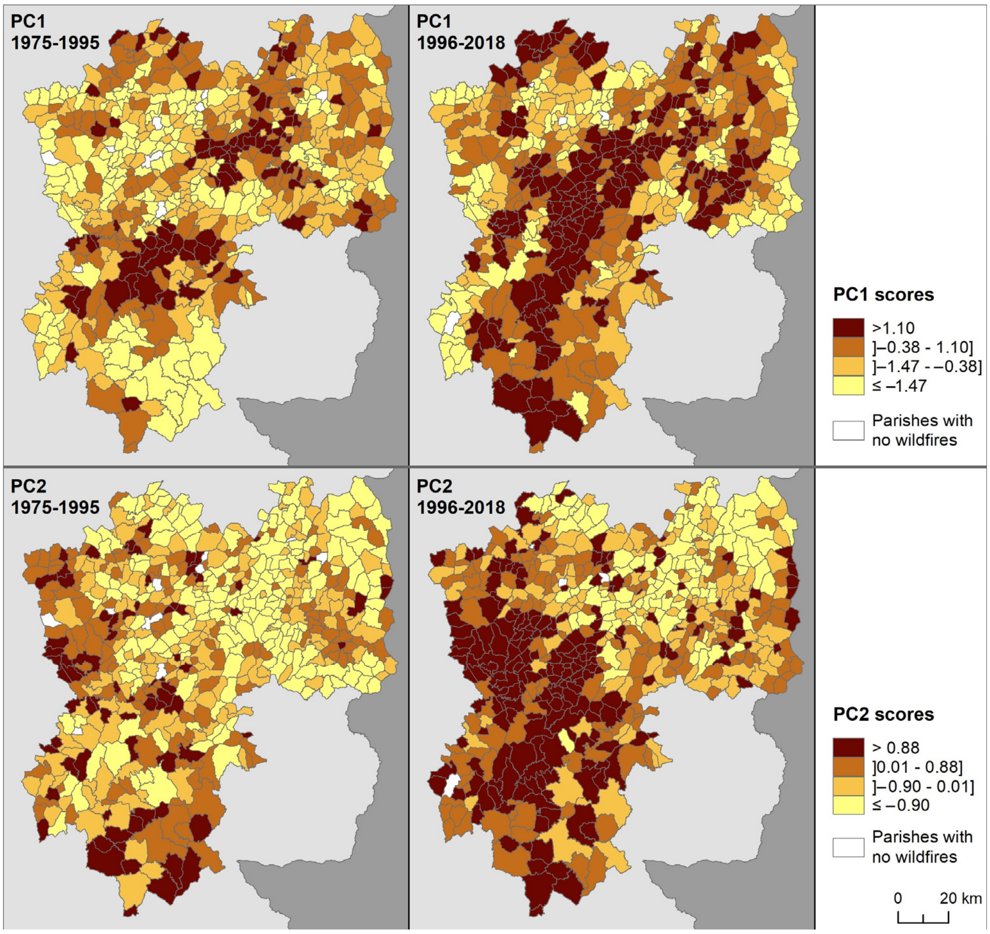

Figure 5. Spatial patterns of parish coordinates in the PCA axes, across periods. Above, PC1 (fire incidence), below, PC2 (burn concentration). Color codes represent the quartiles of the PC scores values.

3.2. Territorial Features Associated with Study Periods

Basic statistics on landscape features across periods are shown in Table 2 and Figure 6. Population density was quite variable within the region, but with a significant declining trend (ca. 10 inhabitants/km^2) when comparing the two periods (Figure 6a). The main land cover (on average, ca. 40% of parish area) was pine and eucalypt plantations, which suffered a small (although significant) 3% decline across time (Figure 6b). Both farmland and native vegetation (oak forests and scrublands) covered ca. 25% of the parishes, with significant but inverse trends across time: a 4% decrease in the former (Figure 6c) and a similar increase in the latter (Figure 6d).

3.3. Influence of Period and Territorial Features on Fire Regime Indicators

The intersection between the cumulative burned areas and LULC classes in both periods is shown in Table 4. Plantations and scrubland together represented ca. 80% of the total burned areas in both periods, while oak forests and farmland accounted for 11% and 8%, respectively. Burned areas increased in the second period for all LULC classes, but their proportions of total burned areas remained practically unchanged between periods. The second period also recorded higher values in the ratio between burned areas and the LULC class area, with emphasis on scrubland (157%; 37% more than in the first period) and plantations (80%; 26% more when compared to the first period). Oak forests recorded the smallest difference between periods (3% higher in the second period). These results confirm the higher propensity to burn of scrubland and plantations, and the lower propensity to burn of farmland and oak forests.

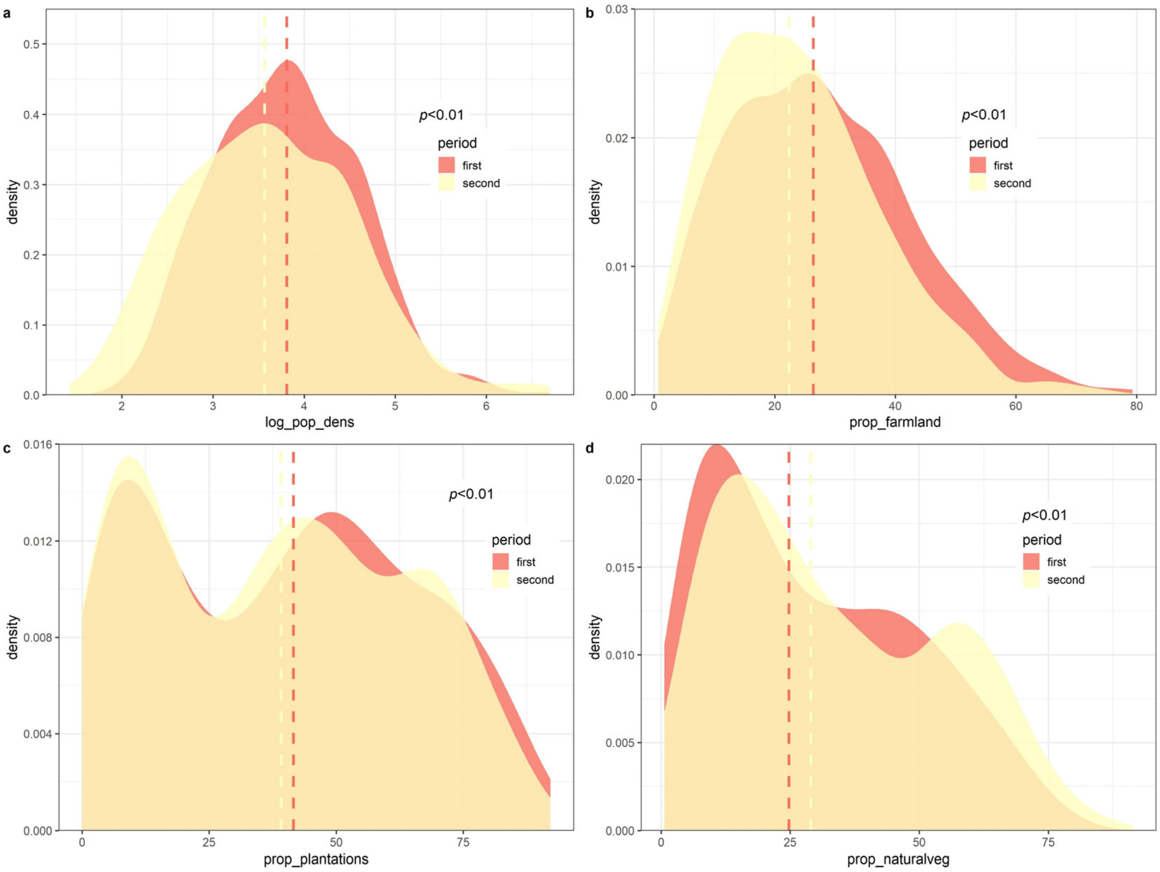

Figure 6. Kernel density estimates of territorial features in the two periods (first = 1975–1995; second = 1996–2018). (**a**) Population density (log-transformed); (**b**) proportion of farmland (%); (**c**) proportion of plantations (%); and (**d**) proportion of natural vegetation (%). Vertical lines represent median values for each period.

Table 4. Burned areas per LULC class in each of the two periods.

LULC Classes		**First Period (1975–1995)**					**Second Period (1996–2018)**				
		LULC Area		**Burned Areas**			**LULC Area**		**Burned Areas**		
		ha	**%**	**ha**	**% of Total**	**% of LULC Area**	**ha**	**%**	**ha**	**% of Total**	**% of LULC Area**
Farmland		368,570	24.2	70,940	8.1	19.2	308,420	20.2	98,370	8.0	31.9
Plantations		675,590	44.3	363,190	41.4	53.8	650,840	42.7	520,480	42.1	80.0
Natural vegetation	Oak forests	148,650	9.8	92,410	10.5	62.2	202,060	13.3	130,780	10.6	64.7
	Scrubland	281,860	18.5	338,950	38.7	120.3	298,250	19.6	468,680	37.9	157.1
Total (study area)		1,524,190	100	876,510	100	57.5	1,524,190	100	1,237,020	100	81.2

Fire incidence at parish level was related to four variables (Figure 7; Table 5): period, population density, and the proportion of farmland and natural vegetation.

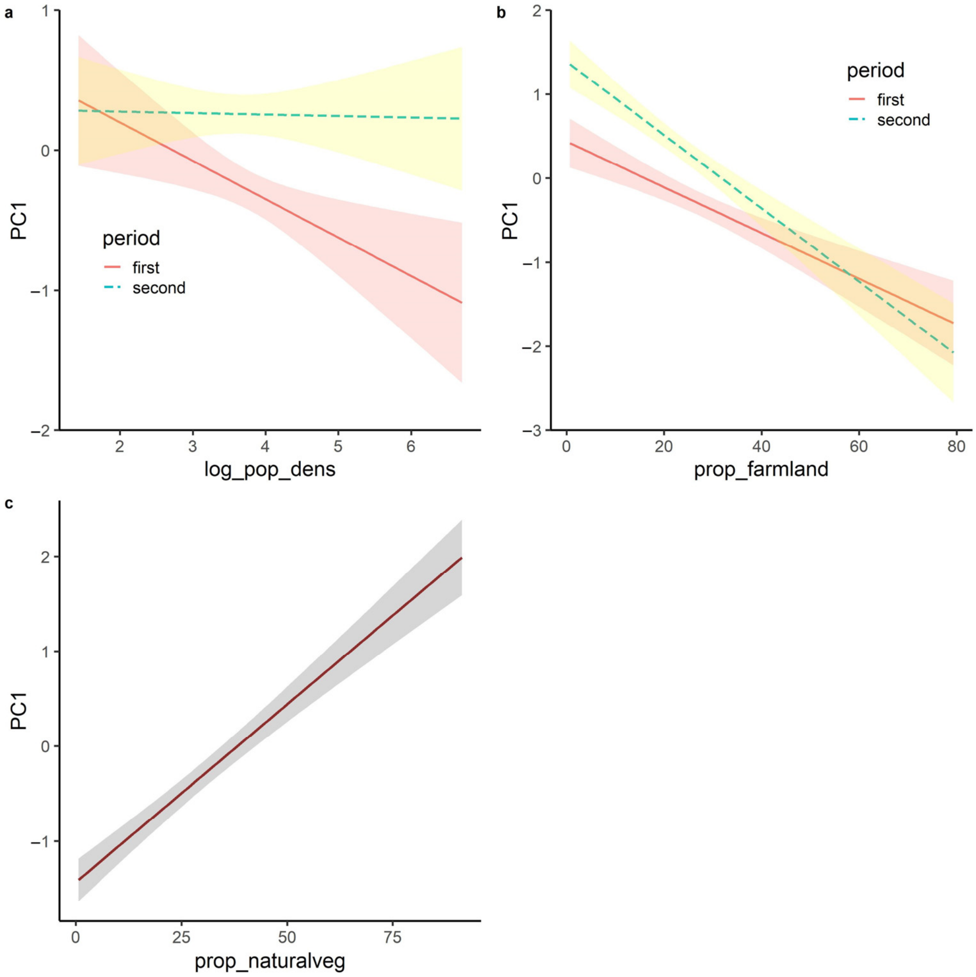

Figure 7. Predicted value (and 95% confidence intervals) of significant variables associated with PC1 parish coordinates, expressing fire incidence. For each variable, all the others are set to their mean (or base level) values. (**a**) Population density (log-transformed); (**b**) proportion of farmland (%); and (**c**) proportion of natural vegetation (%). See model detail in Table 5.

Table 5. Significance of variables and interactions included in final mixed model to predict PC1. Model fit information: AIC = 4306.89, BIC = 4352.06. Pseudo-R^2 (fixed effects) = 0.27. Pseudo-R^2 (total) = 0.49. See model predicted values in Figure 7.

Variable	F-Value	Significance
prop_naturalveg	174.2	<0.0001
log_pop_dens:period	7.00	0.0083
period:prop_farmland	7.48	0.0064

Parishes with higher population density were associated with lower fire incidence, but only during the first period, as the trend was no longer visible in the second period. Except for parishes with a very low population density, for any given value of density, fire incidence was always higher in the second period. Increasing proportional cover by farmland was associated with decreased fire incidence, although the effect was stronger in the second period. Above a threshold of ca. 40% cover by farmland, there was no difference in fire incidence across periods, but under this threshold fire incidence was higher in the second period. Parishes with higher fire incidence were also associated with a higher proportional cover by natural vegetation, regardless of the period.

Burn temporal concentration at parish level was related to three variables (Figure 8; Table 6): proportional cover by farmland, proportional cover by natural vegetation, and period.

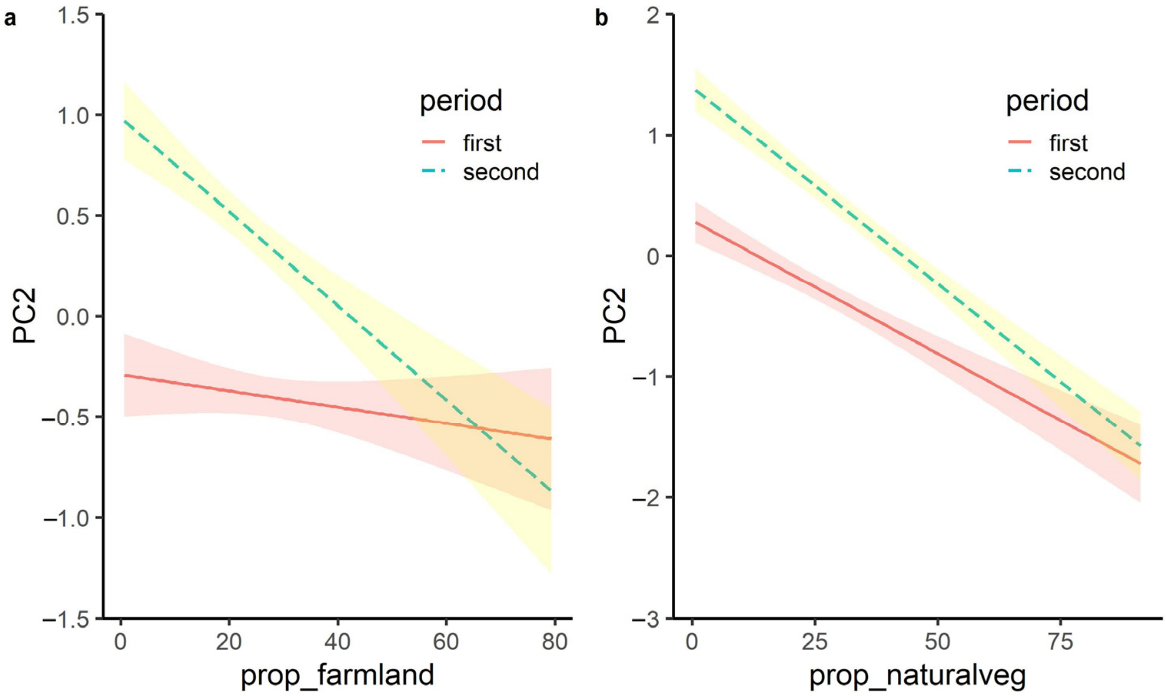

Figure 8. Predicted value (and 95% confidence intervals) of significant variables associated with PC2 parish coordinates, expressing burn concentration over time. For each variable, all the others are set to their mean (or base level) values. (**a**) Proportion of farmland (%) and (**b**) proportion of natural vegetation (%). See model detail in Table 6.

Table 6. Significance of variables and interactions included in final mixed model to predict PC2. Model fit information: AIC = 3528.18, BIC = 3568.33. Pseudo-R^2 (fixed effects) = 0.28. Pseudo-R^2 (total) = 0.52. See model predicted values in Figure 8.

Variable	F-Value	Significance
period:prop_naturalveg	13.1	0.0003
period:prop_farmland	21.6	<0.0001

The strong interaction between period and proportional cover by farmland was reflected in the fact that the latter variable was strongly associated with a decline in burn concentration, but only in the second period, this effect being negligible in the first period (Figure 8a). Consequently, above a threshold of ca. 50–60% cover by farmland, the period variable did not have a strong effect on this indicator. At smaller values, however, burn concentration was much higher in the second period.

Higher cover by natural vegetation was associated with lower levels of burn concentration, i.e., a more equal distribution of the total burned area across years (Figure 8b). The second period usually registered higher burn concentration, and the difference between periods was higher for parishes with lower cover by natural forests and scrublands. Overall, for the same amount of cover by natural vegetation, burn concentration was higher in the second period.

4. Discussion

4.1. Changes in Fire Regime and Territorial Features

The PCA summarized the used fire regime variables for the 1975–2018 period into two major independent indicators that we designated fire incidence and burn concentration. Fire incidence indicated the overall amount of area burned over a certain period, separating parishes with high and low fire prevalence (expressed in total area burned and fire frequency). Burn concentration expressed how the total burned area accumulated over the period (regardless of being high or low) was distributed over time, i.e., whether it was concentrated in a few years versus dispersed over the whole period. This use of the Gini coefficient provided a relevant view of an important aspect of fire regime, as parishes with total burned area concentrated in fewer years tended to have a higher proportion of years in which their total surface was more than 75% affected by wildfires, which may be an indication of higher severity [55,65] and higher socioecological damage [11,66–68]. Parishes with higher wildfire hazard are expected to be the ones with both higher fire incidence and higher burn concentration, which in our case are more prevalent in the western and southern sectors of the region (Figure 5), regardless of the period. For the second period, this could be explained by the large wildfires of 2017, which affected mainly these sectors.

There was a trend for both fire incidence and burn frequency at parish level to increase across time. This is concordant with most studies in the Mediterranean region describing changes in fire regimes across time, and is likely linked to differences in climate and territorial features [2,6,7,12–15,46]. For climate, a series of studies report trends of rising temperature and decreasing rainfall in the Iberian Peninsula and Mediterranean basin [7,69,70]. This is also registered for central Portugal [71,72]. In the Castelo Branco rain gauge, both the average annual temperature and the average annual rainfall increased in the second period: from 15.8 °C to 16.2 °C and from 724 mm to 789 mm, respectively. However, 2017 is simultaneously the year with the highest average annual temperature (17.5 °C) and the lowest average annual rainfall (418 mm) during the 1975–2018 period in this rain gauge, and that year also showed the largest burned areas (383,000 ha) in the study area. Thus, more detailed data would be necessary to identify significant changes in climate between the two studied periods and to draw definitive conclusions about its possible effects on fire regimes.

The two periods also differed in some key territorial features, whose effects on fire regimes cannot be clearly separated from climate effects. Population density declined, a trend also occurring at the country level [36,47,73]. Farmland areas also decreased, a likely consequence of the loss of population involved in the primary sector and the low economic profitability of marginal agricultural areas, leading to land abandonment [22,30,36–39,51]. The area covered by pine and eucalypt plantations, the dominant land cover in the region, also declined in the second period, likely due to the impact of wildfires on these plantations and their replacement by secondary succession vegetation, mainly scrubland or regeneration plantations with scrubland-like physiognomy. This could explain the increase in the surface occupied by oak and scrubland found for the second period (Table 4).

4.2. Changes in Territorial Features—Fire Regime Associations across Period

Three territorial features were correlated with the two fire regime indicators: population density, proportion of parish area covered by farmland, and proportion of parish area covered by natural vegetation. However, the way these were associated with fire regimes differed between periods.

Parishes with higher population density usually had lower fire incidence, but this association was only visible in the first period. Higher population density has traditionally been considered an important indicator of the intensity of landscape management (including in existing farmland or forests) that may lead to decreased fuel accumulation and fire hazard [9,13,16,46,74,75]. Additionally, it is also an indicator of the likelihood of early detection and more effective suppression of wildfires, in spite of the higher human-caused ignition probability [10,26,36,42,48]. However, this association was no longer visible in the second period. At first sight, this could suggest that the impact of human management on fire incidence in the territory has decreased. However, it is more likely that the lack of association could be due to changes in the population itself, such as aging (impairing its ability to intervene in the territory) or a reduced level of engagement with farmland and forest management, as suggested by prior studies [47]. In fact, the decrease in importance of farmland and forest for the employment and income of the rural population between the first and second periods has been largely documented [76–78], impacting that engagement for the same population density. Therefore, and except for parishes with a very low population density, fire incidence was always higher in the second period. Studies [10,79] stated that human factors are losing importance in driving fire regimes when compared to climate/weather factors and fuel moisture. Adverse weather and moisture conditions also favor the occurrence of extreme fire events [9,80–83], whose size and magnitude exceed the human capacity to suppress them [84,85]. In this sense, and according to the obtained results, population density at a parish level revealed: (1) a nonsignificant relationship with burn concentration (PC2) in both periods, confirming that this variable does not have a relevant association with expected fire severity; and (2) a negligible association with fire incidence (PC1) during the second period, when the fire regime was characterized by a few major events that contributed to an increase in overall burned area. However, the year 2017, which was marked by the occurrence of two extreme fire events (in June and October), but also the events of 2003 and 2005, certainly prevented a stronger relationship between population density and fire incidence in the second period.

The increased proportion of farmland in the parish area was strongly and negatively associated with both fire incidence and burn concentration. With regard to fire incidence, this result is in accordance with the low fire selectivity for farmland already observed by several authors [24,86–89]. Regarding burn concentration, the effect of farmland can be interpreted in two complementary ways. On the one hand, farmland areas are likely to have an increased human presence in comparison to forest or scrubland, which will promote early detection and response to ignitions, promoting smaller fires over time and leading to the temporal dispersion of area burned. On the other hand, it is likely that the increased percentage of farmland has caused a greater fragmentation in the second period for non-farmland LULC classes within a parish, such as scrubland and forest, constraining fire propagation and the occurrence of large fires that would lead to higher burn concentration. These associations were stronger in the second period, mainly for burn concentration. The difference across periods was also more obvious for parishes with less farmland: the differences between periods became negligible above a threshold of ca. 40–50% of farmland. As previously, the interaction effect between period and farmland proportion may be explained by a mixture of climate differences (e.g., causing higher flammability to the same farmland land use) and management differences (e.g., increased flammability or human presence associated with transitions between crop types, or to transitions between more intensively managed annual crops and less intensively managed grasslands). Future studies should address these hypotheses, as well as a more detailed analysis of the impacts of landscape configuration (rather than simply composition) on fire regimes.

Regardless of the period, higher fire incidence was associated with parishes with higher proportions of natural vegetation (and therefore less pine and eucalypt plantations). Possible contributors to this pattern include: (a) an effect of wildfires on land cover—high fire incidence will promote fewer forests and a higher transition from forests to scrublands [22]. As the land cover information relates to a relatively late time frame in each period (the last year of the first period and 3 years before the end of the second period), it might express the land cover effects of fire regimes; (b) the elevated fire-proneness and high rate of postfire regeneration of scrubland [25,86,90,91], which will promote both extensive and frequent fires, even though this LULC class was aggregated in this study with the less fire-prone oak forests. The interpretation of the negative relationship between natural vegetation and burn concentration is not straightforward, as this LULC class includes both oak forest and scrubland. However, considering that areas with lower cover by this LULC have higher cover by tree plantations (these LULC classes are highly negatively correlated at a parish level), this pattern may show that areas with more plantations will have a higher burn concentration. Again, for the same cover by plantations, burn concentration will be higher in the second period (and the difference increases the higher the cover by plantations).

5. Conclusions

We described the temporal change in fire regime in a fire-prone region and registered a trend for increased fire incidence and burn concentration. Three main findings seem relevant for the implementation of wildfire management policies in this highly fire-prone region.

Firstly, the key role of farmland—in a context of farmland abandonment, keeping farmland in the territory is a big challenge, but it is the key tool to decrease fire incidence and burn concentration. Our results show that a minimum of 40–50% of a parish territory covered by farmland was highly effective to buffer the increased risks associated with different management and climate contexts of the considered periods.

Secondly, the challenge of keeping population active in the primary sector—the effectiveness of a higher population density on keeping fire incidence low—was much decreased in the latter period. We hypothesized that this was due to persisting population being less engaged in farmland and forest management. If this assumption is correct, policies to keep or increase population in these marginal territories may not by themselves solve the problem. Attracting people to these areas will not necessarily be reflected in a decreased fire hazard if these "new rurals" will only stay in larger urban centers with access to services (internet, schools, health care) and not devoted to activities in the primary sector. Therefore, fostering the socioeconomic viability of farmland in this region will require coordinated policies across different sectors [92].

Finally, the negative impact of large areas with tree plantations, which cause an increase in burn concentration, make a higher level of socioecological damage more likely.

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