fire

Article

Pastoral Burning and Its Contribution to the Fire Regime of Alto Minho, Portugal

Emanuel Oliveira [1,*] and Paulo M. Fernandes [2,*]

[1] Department of Agro-Forestry Engineering, International PhD School (EDIUS), University of Santiago de Compostela, Rúa Benigno Ledo, 27002 Lugo, Spain
[2] CITAB—Centre for the Research and Technology of Agro-Environmental and Biological Sciences, University of Trás-os-Montes and Alto Douro, 5001-801 Vila Real, Portugal
* Correspondence: emanuel.r.s.oliveira@outlook.pt (E.O.); pfern@utad.pt (P.M.F.)

Abstract: Alto Minho (in northwestern Iberia) is one of the European regions most affected by fires. Many of these fires originate from rangeland management of Atlantic heathlands, and, while being illegal, often are not actively suppressed. In this study, pastoral fires (autumn-to-spring fires unrecorded by authorities), spring wildfires, and summer wildfires were independently mapped and dated from remote sensing. Alto Minho burned at a mean annual rate of 5.0% of the territory between 2001 and 2020. Pastoral burning totalled 40,788 hectares during the period, accounting for 20% of the total burnt area. Rangeland burning occurs mostly from December to April, the rainiest months that guarantee the conditions for pasture renewal and fire self-extinction. The mean fire return interval of pastoral burning is slightly higher than that of wildfires (13 years vs. 11 years), except in part of the inner mountains where it dominates fire activity. Pastoral fires are more frequent and largely prevail over wildfires in the parishes with higher livestock quantities. Conversely, the largest wildfires and higher summer burnt areas correspond with very low livestock and nearly non-existing pastoral fires. Traditional fire knowledge should not be overlooked by fire management, as it contributes to more sustainable fire regimes and ecosystems.

Keywords: fire use; fire frequency; rangeland management; traditional fire knowledge

check for updates

Citation: Oliveira, E.; Fernandes, P.M. Pastoral Burning and Its Contribution to the Fire Regime of Alto Minho, Portugal. *Fire* **2023**, *6*, 210. https://doi.org/10.3390/fire6050210

Academic Editor: Grant J. Williamson

Received: 2 April 2023
Revised: 5 May 2023
Accepted: 16 May 2023
Published: 19 May 2023

1. Introduction

Alto Minho, located in the northwest of the Iberian Peninsula, is one of the regions in Portugal that has been more affected by fires in recent decades [1,2]. While Holocene fire expansion in southern Europe was initially conditioned by high climatic seasonality, the use of fire by the first agrarian societies in the Neolithic promptly shaped the fire regime [3]. The frequency of fires increased with population increase, as new agricultural areas, areas for grazing, and new settlements were established [4–6]. As in other regions of southern Europe, fire has marked the structure and functioning of ecosystems that have adapted over thousands of years to a human-shaped fire regime, as the primary causes of fires in the territory are anthropogenic [6,7].

The Atlantic heathlands of NW Iberia have been traditionally maintained by a combination of grazing, shrub cutting, and burning [8]. The use of fire, rather than an isolated practice, was integrated into the ancestral agro-silvo-pastoral system that lasted until the mechanization of agriculture and the introduction of inorganic fertilisation in the second half of the 19th century [9,10]. The abandonment of agricultural activity in NW Portugal contributed to increased fire occurrence and burnt area [11]. Traditional pastoral fires, mainly in shrubland, contribute to create and maintain mosaic-structured landscapes [12]. The abandonment of small-scale farming and traditional practices such as grazing dissolves the traditional mosaic and reinforces the connectivity between homogenous and extensive high fuel-load patches derived from contemporary afforestation and rewilding [6]. However, a number of studies point to a relationship between wildfires and the traditional use of fire, particularly for range management purposes [13–15]. This type of fire use may constitute a negligent or intentional cause of wildfire, depending on each country's legislation [16]. Other studies associate the replacement of agriculture by extensive livestock production and the need to use fire as a tool for pasture maintenance as the origin of the increase in wildfire frequency [17,18].

The impact of large wildfires in the Mediterranean Basin, including Portugal, fostered studies linking components of the fire regime to weather and climate [19–21], and examining how fire incidence relates with land use and biophysical variables [22–25] and anthropogenic causes [13,26,27], including social conflicts and recreational and leisure activities [10]. A global study showed that farmlands are prone to recurrent fire, which, given the human agency involved, is less affected by weather variability than in other land cover types [28]. In Portugal, fire density is at its maximum in densely populated regions but it also increases with elevation, in part because of pastoral burning of shrubland [22]. Recently, the first classification and mapping of fire regimes in mainland Portugal was published [27], covering the period from 1980 to 2017 at the parish scale, and highlighting the existence in northern and central Portugal of frequent fire regimes with a marked autumn-to-spring component, revealing of pastoral burning activity.

Wildfire causality studies in Portugal have relied to date on official data from the Institute for Nature Conservation and Forests (ICNF), which has inconsistencies because of variation in mapping methods, database completeness, limitations in satellite image processing, and insufficient field validation [2,29,30]. Here we seek to understand the relationship between extensive livestock production and the use of fire, whose practice is currently a remnant of the agro-silvo-pastoral system that has modelled Alto Minho and other European Atlantic landscapes over the centuries, e.g., [31]. Based on rigorous and detailed fire mapping using several cartographic sources and historical series of satellite images and orthoimagery, we examine (i) the contribution of pastoral burning to fire activity in Alto Minho, and (ii) whether there is a relationship between pastoral burning and livestock in the region.

2. Materials and Methods

2.1. Study Region

The study region is the entire Alto Minho, located in the extreme northwest of Portugal (Figure 1). To the north and east, it is bordered by the autonomous community of Galicia (Spain), to the south by the district of Braga, and to the west by the Atlantic Ocean. Alto Minho coincides with the Viana do Castelo district, occupying an area of approximately 2217 km^2, and is divided into ten municipalities. These municipalities are further subdivided into smaller administrative units—parishes—which were our sample units (n = 208).

Approximately 18% of Alto Minho is occupied by agriculture and 72% corresponds to forests and shrublands, of which 52% are common lands (DGT, 2020). Portuguese common lands were extensively afforested with pine in the 20th century, only to subsequently revert to Atlantic heathland through fire [32]. The terrain is predominantly mountainous, with elevations exceeding 400 m, up to over 1000 m, with the exception of the coastal zone and the main valleys of the Minho and Lima rivers [33]. The annual temperature range is generally low, with average annual temperature between 14 °C and 16 °C [34]. Mean annual precipitation exceeds 1000 mm and varies markedly from the coast to the interior, where it can reach 2400 to 2800 mm at higher elevations. Similarly to other northwest Iberian regions, the use of fire in the Atlantic heathlands of Alto Minho is intrinsic to the ancestral agro-silvo-pastoral system, both in ploughing, soil fertilisation, renewal of pastures, and the burning of heaps and stubbles [35], and is also thought to be a relevant wildfire cause.

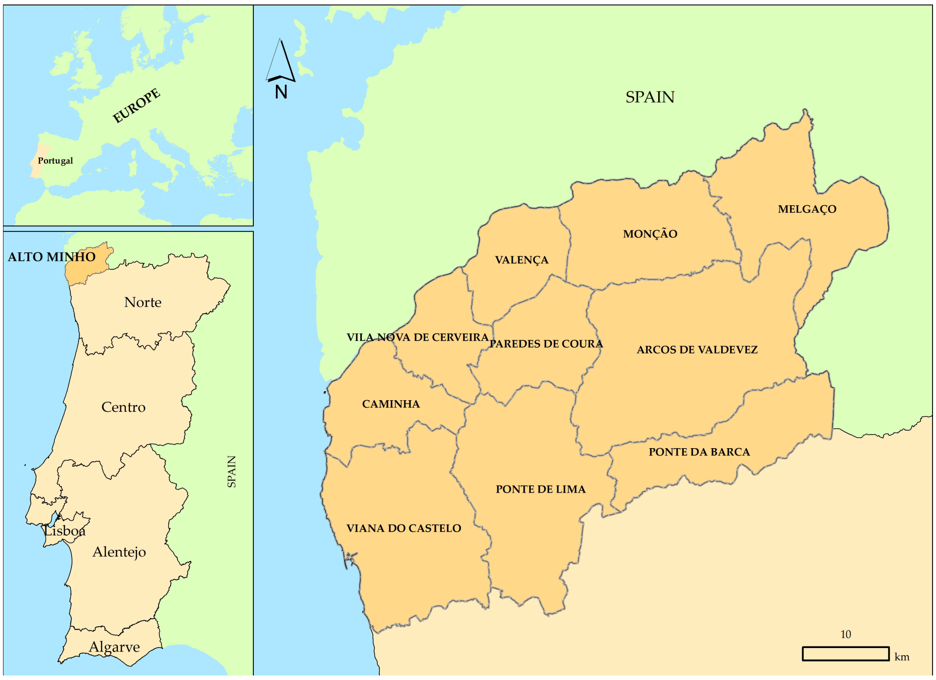

Figure 1. Geographic context of the study region, Alto Minho. Source: Official Administrative Map of Portugal, Directorate General of Territory—DGT (2020), Administrative Limits of Spain, National Geographic Institute of Spain—IGN (2019).

2.2. *Methodology*

2.2.1. Obtaining and Processing Satellite Images

Images were acquired from Landsat 5 (TM), Landsat 7 (ETM+), Landsat 8 (Operational Land Imager—OLI) and Sentinel-2 (Multispectral Instrument—MSI) satellites for the 2001–2020 period. These images were obtained from the Semi-Automatic Classification Plugin (SCP) application developed by Congedo [36] for the QGIS software and directly via the U.S. Geological Survey platform—Earth Explorer. Approximately 400 images, cloud-free or with minimum cloud cover, spanning from 2001 to 2020 were collected from the satellites to identify seasonal patterns of burnt areas in Alto Minho. This allowed for maximum coverage of each year and accurate analysis of fire patterns.

All images were pre-processed for atmospheric correction using the SCP for QGIS. Burnt areas were subsequently identified using the NBR index and the RGB false colour composition [36]. The year 2000 fire scars were identified to avoid their potential inclusion in the burnt areas of the following year.

2.2.2. Obtaining the Perimeters of Burnt Areas

The fire perimeters were digitised from the NBR and RGB false colour images. The process was entirely manual and supervised, supported by ancillary information such as high-resolution orthophotos, to avoid interpretation errors resulting from changes in land cover that might alter the final result [37–39].

The manual digitisation process considered the resolution of the images from different satellites, ranging from a scale of 1:25,000 to 1:3000. The use of historical orthophoto series also allowed the identification and correction of the fire perimeters, increasing the accuracy and detail of mapping.

2.2.3. Dating and Classifying Fire Perimeters

Once the digitisation phase was concluded, the fires were dated and classified. To do so, the georeferenced hotspots from the MODIS and VIIRS sensors were overlaid, after download from the archive on the NASA Fire Information for Resource Management

System (FIRMS) website (https://firms.modaps.eosdis.nasa.gov/, last accessed on 15 October 2022) in vector format (point).

Annual data on individual fire occurrences from 2001 to 2020, provided by ICNF, were imported and georeferenced. Temporal and spatial cross-referencing between ICNF data and remotely sensed information enabled the matching of fire records and fire perimeters. Similarly, institutional cartographic information in vector format (polygon) with respect to prescribed fire was overlaid. The overlay of the different sources related to the fires allowed dating the perimeters and classifying them according to their origin.

The fire perimeters were classified as "wildfire" when matching an official database record, i.e., fires that involved the dispatch of suppression resources. We distinguished between summer season fires, classifying them as "summer wildfire" (WFSUM), and fires occurring in other seasons, classifying them as "autumn-winter-spring wildfire" (WFAWS). The remaining fire perimeters were either classified as "autumn-winter-spring fires" (FAWS) or "prescribed burning" (PB). The former were identified from the chronological sequence of satellite images and hotspots dates, and correspond to fires absent from the official database, therefore indicating that suppression operations were not undertaken. The reasons for such non-response may vary, from no detection or lack of suppression resources to awareness and acceptance of the land management goals of those fires. Fires transmitted from outside the study region were included in the burned area estimates but were not typified.

2.2.4. Other Data

The agrarian nature or motivation of autumn-to-spring fires in Alto Minho recommends an analysis of the evolution and distribution of livestock. Livestock data concerning extensive and semi-extensive production at the parish level, in particular, ruminants and horses, was sourced from the decennial Agricultural Censuses of 1999, 2009, and 2019 (National Statistical Institute—INE) and adapted to the Official Administrative Map of Portugal (DGT, 2020).

Additional context for the fire-livestock analyses was given by retrieving the area occupied by forest and shrubland in each parish.

2.3. Data Analyses

Burnt areas per fire type (FAWS, WFAWS, WFSUM) were summed for each year and globally for the study period and month of the year. Fire frequency (or the mean annual burn probability of each pixel) was calculated and mapped for each fire type as the number of times it burned in the 2001–2020 period divided by 20. Five fire frequency classes (and their corresponding fire return intervals, see Results) were considered to summarize cumulative burnt area distribution across the three fire types. Similar statistics were separately calculated for the Union of Parishes of Castro Laboreiro and Lamas de Mouro, Melgaço, where the frequency of pastoral burning is the highest in Alto Minho.

In order to detect relationships between fire and livestock production, the burnt area was summed and distributed by fire type for several groups of parishes, defined by the mean number of extant animals across the study period, namely 0–250, 250–500, 500–1000, 1000–1500, and >1500 animals. Finally, a K-means cluster analysis was carried out to identify groups of parishes with similar livestock numbers and fire frequencies per fire type, as well as similar territorial contexts in terms of shrubland fraction. For this purpose, the reference to calculate fire frequency was the area of forest and shrubland in the parish.

3. Results

3.1. Fire in Alto Minho

The cumulative burnt area resulting from all types of fires during the 2001–2020 period was 221,854 hectares (Table 1), or 5.0% of the Alto Minho region as an annual average. The fire type distribution shows that 60.8% of the cumulative area is the result of summer wildfires. Autumn-to-spring wildfires and autumn-to-spring fires have similar shares, respectively 19.9% and 18.6% of the total burnt area in the period. Prescribed fire accounts for a very minor component of the fire regime, comprising just 0.7% of the total burnt area (Table 1). However, interannual seasonal variation is high: summer wildfire can be almost absent, and autumn-to-spring fire activity can account for more than 80% of the annual burnt area, as in 2009, 2011, 2017, and 2018, with FAWS comprising a maximum of 57.2% of the burnt area in the mild fire weather year of 2014.

Table 1. Annual burnt area (ha) distribution by fire type in Alto Minho (2001–2020), respectively autumn-to-spring fire (FAWS), autumn-to-spring wildfire (WFAWS), summer wildfire (WFSUM), and prescribed fire.

Year	FAWS	WFAWS	WFSUM	Prescribed Fire	Total Burnt Area
2001	4371	1824	5724	-	11,920
2002	2098	856	9505	-	12,459
2003	10	653	549	-	1212
2004	2890	1489	2708	-	7086
2005	2685	3299	26,578	-	32,562
2006	2631	367	14,701	-	17,699
2007	1266	3006	193	-	4464
2008	548	510	48	-	1105
2009	1946	4831	1525	52	8354
2010	1587	1723	23,570	444	27,324
2011	3432	3938	1747	43	9160
2012	2512	2978	65	67	5622
2013	2128	2642	10,111	103	14,984
2014	1322	916	11	63	2312
2015	2302	3903	6636	113	12,955
2016	2308	696	26,051	108	29,163
2017	3952	7607	1017	137	12,713
2018	895	1361	148	53	2457
2019	1603	1090	942	364	3999
2020	757	371	3164	10	4302
Total	41,244	44,060	134,994	1557	221,854
Mean	2062	2203	6750	130	11,093

The monthly distribution of precipitation based on the climatological normal of 1981 to 2010 (Portuguese Institute of Sea and Atmosphere—IPMA, 2022) reveals June to August to be the driest months of the year, corresponding to a drought period lengthy enough to result in a distinct wildfire activity peak in August but also implying that the window for significant fire activity is short in the oceanic climate of Alto Minho (Figure 2). FAWS are more prevalent from December to April and during these months their extent is higher than that of wildfire.

Autumn-to-spring fire activity is dominated by fire return intervals greater than 10 years and, especially, greater than 20 years (Table 2). However, fire frequencies higher than 0.05 year^{-1} are more represented in summer wildfires, where the 0.1–0.2 fire frequency class is only slightly less represented than the two lower frequency classes, implying that summer fires are more frequent over much larger areas. Autumn-to-spring wildfires have lower burnt area in the higher frequency classes and a much higher accumulated area in the lower frequency class when compared with pastoral fires. Overall, the approximate mean fire return intervals for the WFSUM, FAWS and WFAWS fire types are respectively 11, 13, and 20 years, and 13 years on the whole.

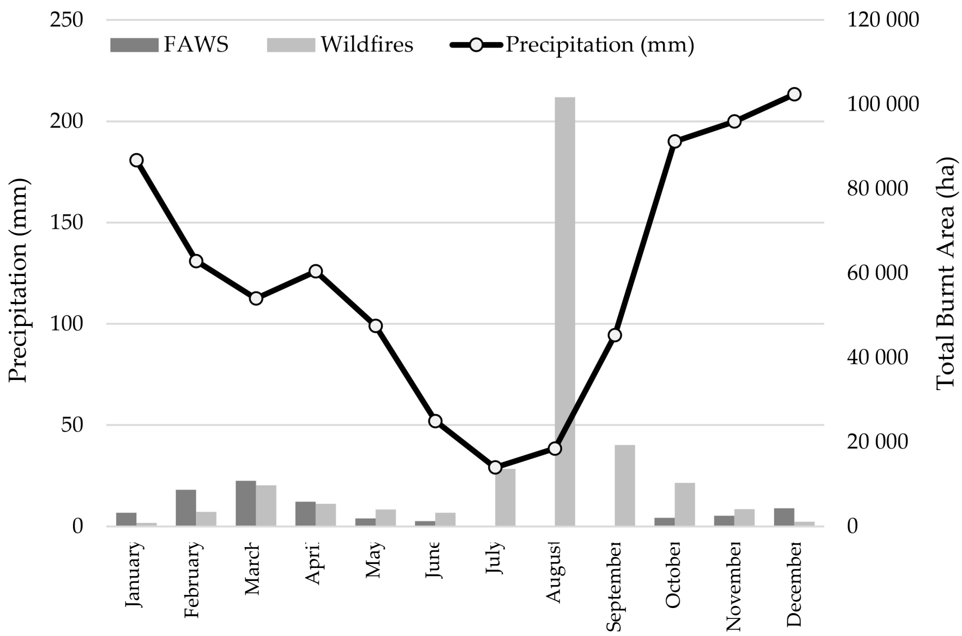

Figure 2. Total monthly burnt area (2001–2020) by autumn-to-spring fires (FAWS) and by wildfires in Alto Minho, and precipitation (mm) according to the 1981–2010 climatological normal from the weather station of Viana do Castelo (Meadela).

Table 2. Absolute (hectares) and relative (%) burnt area (2001–2020) by fire frequency/fire return interval class and fire type in Alto Minho, respectively autumn-to-spring fire (FAWS), autumn-to-spring wildfire (WFAWS), and summer wildfire (WFSUM).

Fire Frequency (Year^{-1})	Fire Return Interval (Years)	FAWS	WFAWS	WFSUM
0–0.05	>20	17,090 (41.9)	28,075 (63.7)	44,137 (32.7)
0.05–0.1	10–20	12,098 (29.7)	11,722 (26.6)	43,564 (32.3)
0.1–0.2	5–10	10,864 (26.6)	3964 (9.0)	41,429 (30.7)
0.2–0.3	3–5	691 (1.7)	277 (0.6)	5653 (4.2)
0.3–0.4	2–3	45 (0.1)	24 (<0.1)	237 (0.2)
Total Burnt Area		40,788	44,061	135,019

The spatial patterns of fire extent and recurrence also vary by fire type (Figure 3). Pastoral burning is mostly located in the inner mountain region, with greater relevance in the Melgaço municipality, where rural communities still use fire as a tool for pasture renewal. Conversely, coastal mountains in Caminha, Viana do Castelo, and Ponte de Lima are more affected by large summer fires, including relatively large high-frequency patches. It is also clear that autumn-to-spring wildfires (Figure 3b) are generally smaller than summer fires (Figure 3c) and larger than pastoral fires (Figure 3a), which also feature substantially higher dispersion.

3.2. The Particular Case of Castro Laboreiro and Lamas de Mouro

The Union of Parishes of Castro Laboreiro and Lamas de Mouro, Melgaço, occupies 10,602 ha within the Peneda-Gerês National Park. Resident population was 874 inhabitants in 2001 (Census 2001, INE), but is now around 503 people (INE, 2022). Approximately 95.5% of the parish is under communal land tenure, with shrubland predominating (78.5% of the parish); forest occupies little more than 17% of the territory. It is one of the six parishes of Alto Minho with more than 1500 livestock animals. According to the Agricultural Census of 2019 (INE, 2021), 2001 animals were present, namely cattle (48.8%), sheep (36.3%), goats

(9.4%), and horses (5.4%). Livestock is mostly kept in an extensive regime of heathlands of *Erica* sp., *Pterospartum tridentatum*, *Ulex* sp. and *Cytisus* sp.

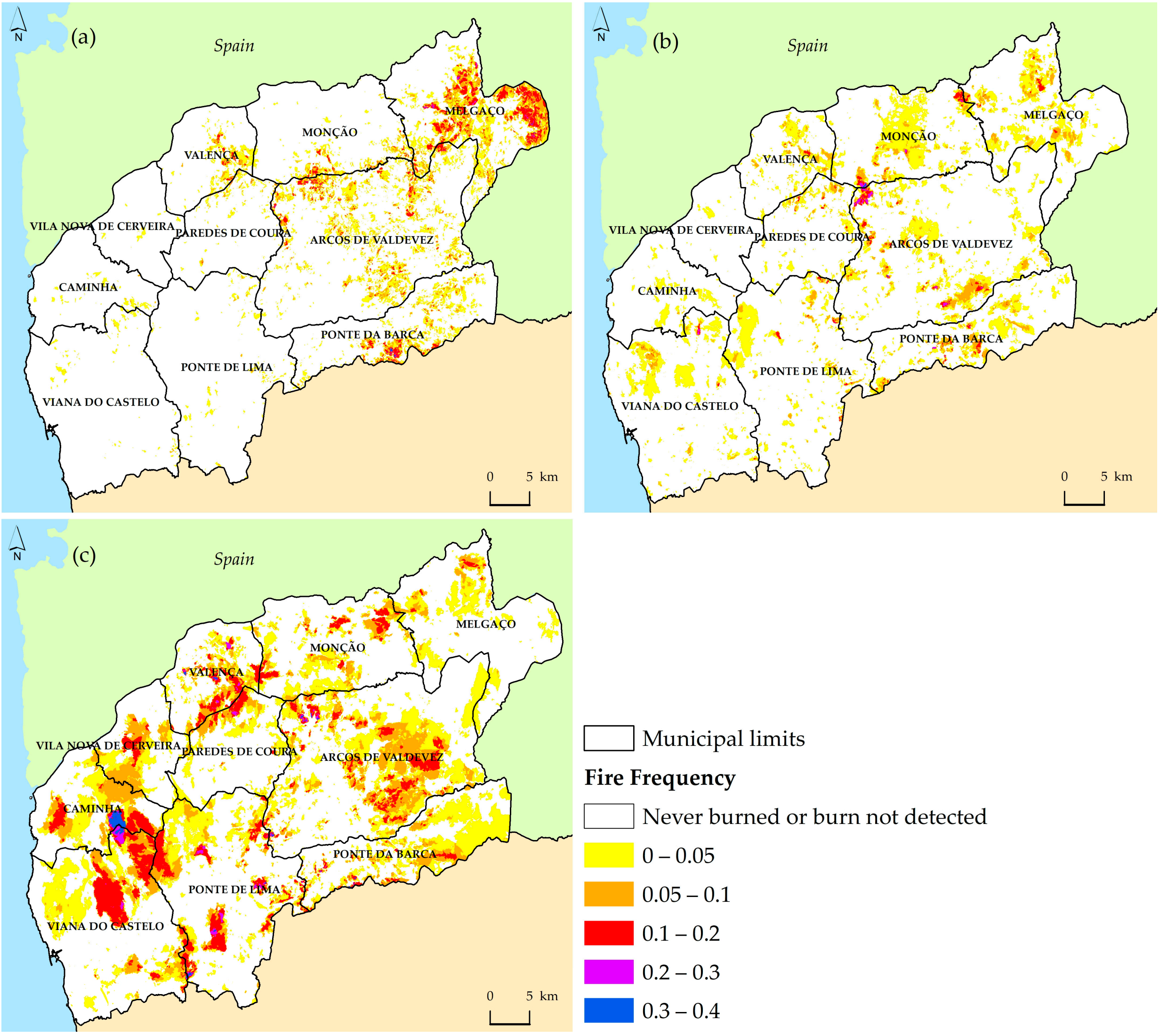

Figure 3. Map of fire frequency in Alto Minho: (**a**) autumn-to-spring fires (FAWS); (**b**) autumn-to-spring wildfires (WFAWS); (**c**) summer wildfires (WFSUM).

Approximately 81% of the Union of Parishes of Castro Laboreiro and Lamas de Mouro parish did burn at least once between 2001 and 2020, as manifest in Figure 4. Cumulative burnt area from 2001 to 2020 reached 13,980 ha, of which 74.2% were FAWS, and these fires occurred mostly (68% of the cumulative area) from December to March. Autumn-to-spring wildfires, summer wildfires, and prescribed burning amounted respectively to 16.1, 9.5, and 0.3% of the total burnt area. The temporal patterns of the three non-institutional fire types are quite distinct: while pastoral burning mostly occupies the 5–20-year fire return interval range, wildfires predominantly (autumn to spring) or almost totally (summer) recur at intervals >20 years (Table 3). Approximate mean fire return intervals for the FAWS, WFAWS, and WFSUM fires are, respectively, 11, 23, and 38 years.

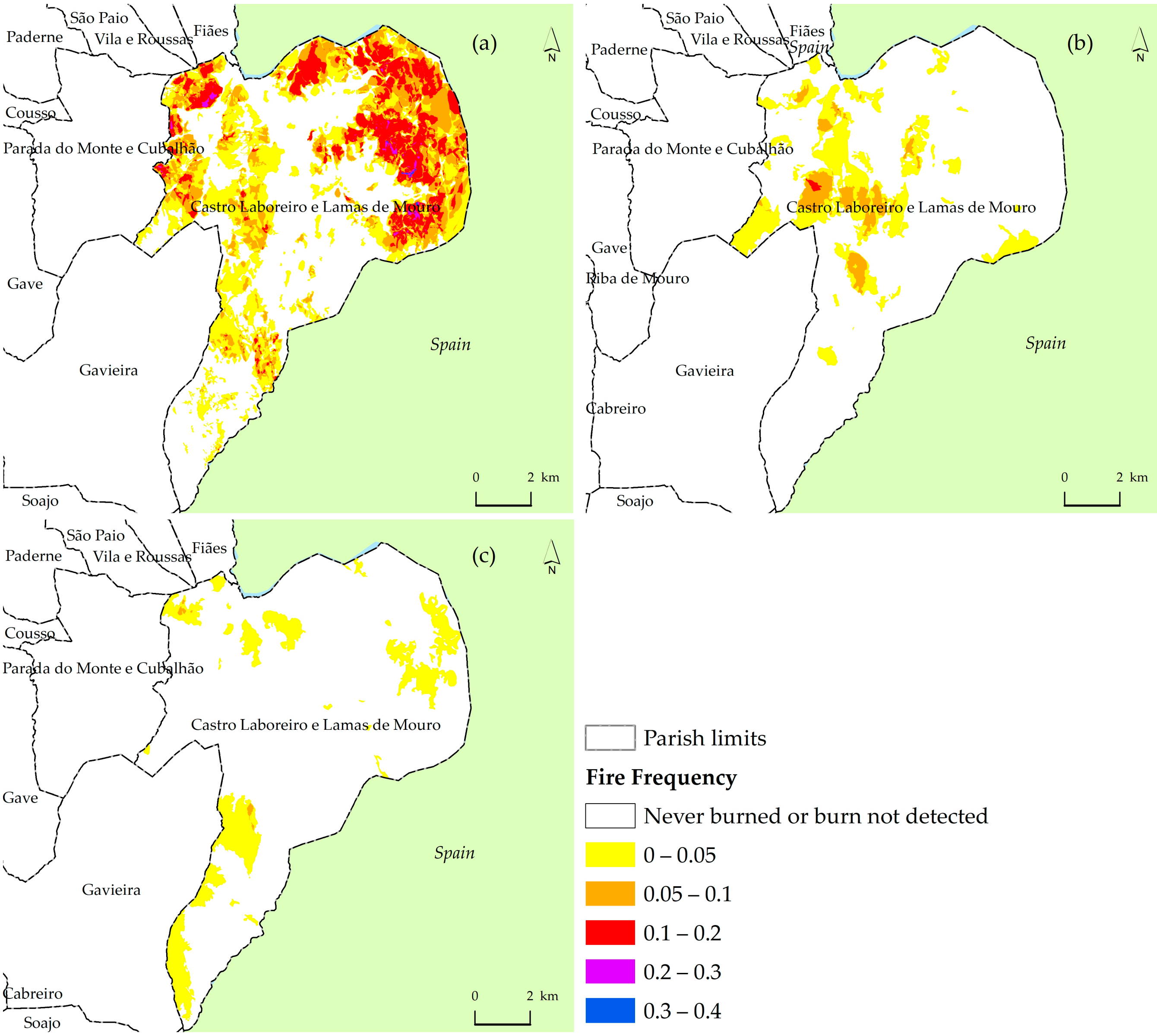

Figure 4. Fire frequency map for the different types of fires in the Union of Parishes of Castro Laboreiro and Lamas de Mouro between 2001 and 2020: (**a**) autumn-to-spring fires (FAWS); (**b**) autumn-to-spring wildfires (WFAWS); (**c**) summer wildfires (WFSUM).

Table 3. Absolute (hectares) and relative (%) burnt area (2001–2020) by fire frequency/fire return interval class and fire type in the Union of Parishes of Castro Laboreiro and Lamas de Mouro, respectively autumn-to-spring fire (FAWS), autumn-to-spring wildfire (WFAWS), and summer wildfire (WFSUM).

Fire Frequency (Year^{-1})	Fire Return Interval (Years)	FAWS	WFAWS	WFSUM
0–0.05	>20	2485 (24.7)	1462 (65.0)	1289 (97.6)
0.05–0.1	10–20	3249 (32.3)	751 (33.3)	32 (2.4)
0.1–0.2	5–10	4074 (40.6)	35 (1.6)	
0.2–0.3	3–5	234 (2.3)		
Total Burnt Area		10,042	2249	1321

3.3. Livestock and Fire

Livestock under an extensive exploitation regime is a relevant feature of Alto Minho. However, a generalized loss of livestock occurred from 1999 to 2019 in all Alto Minho municipalities, with an overall reduction of 43% in the number of animals (Table 4). Only 20 parishes have more than 1000 animals each, concentrating 30.5% of the total mean livestock (1999–2019) in about 26% of Alto Minho.

Table 4. Evolution and distribution of livestock in the municipalities of Alto Minho between 1999 and 2019.

Municipality	Municipality Area (ha)	Common Lands (%)	No. of Animals			% Variation 2019–1999
			1999	2009	2019	
Arcos de Valdevez	44,727	50.8	20,326	18,665	19,918	−2.0
Caminha	13,640	41.6	3660	2861	1847	−98.2
Melgaço	23,808	62.0	8683	7867	6437	−34.9
Monção	21,115	28.3	16,752	14,448	8933	−87.5
Paredes de Coura	13,808	23.7	12,308	12,444	8074	−52.4
Ponte da Barca	18,198	52.9	5745	4873	3437	−67.2
Ponte de Lima	32,000	21.2	18,797	16,946	14,398	−30.6
Valença	11,703	30.0	6220	6031	3243	−91.8
Viana do Castelo	31,875	16.4	12,460	9220	8323	−49.7
Vila Nova de Cerveira	10,838	47.7	3573	3099	1444	−147.4
Total	221,711	37.3	108,524	96,454	76,054	−42.7

The parishes at the extremes of livestock quantity are distinct regarding the relevance of the different fire types. Lower animal numbers (<250) correspond with residual pastoral burning and more than 70% of the fire extent occurring in summer (Figure 5a). In contrast, nearly half of the burnt area is of type FAWS in the parishes with the highest livestock quantity (>1500), exceeding summer wildfire area. Figure 6 juxtaposes livestock quantity and FAWS frequency, indicating that the largest patches of pastoral burning (and at higher recurrence), coincide with the highest livestock quantities. The three intermediate livestock classes have similar fire type distribution. Autumn-to-spring wildfires account for similar shares of burnt area across the livestock quantity range, suggesting (as we assumed) that these fires are unrelated to pastoral activity. Patterns of burnt area as a land fraction (Figure 5b) are similar, except that low livestock quantity does not amount to the highest share of summer fire. Overall, the amount of fire in the landscape as a fraction of parish area has an increasing trend with increased livestock.

Further systematization of the understanding of fire–livestock relationships through cluster analysis produced eight groups of parishes, of which one (cluster 5) is excluded from Table 5 as it comprised a single outlier parish with an abnormal burn likelihood as a result of fire exported by neighbour parishes. As expected, the lowest frequency of pastoral burning occurs at low livestock levels, combined with low fractions of shrubland, corresponding to four clusters (1, 4, 7 and 8) that include 89% of the total number of parishes, including the two clusters with the highest rates of summer wildfire. Cluster 2 has the maximum livestock but a low fraction of shrubland and minimal pastoral burning. Cluster 3 is characterized by a moderately high shrubland fraction and its pastoral burning frequency is the second highest (but lower than summer wildfire), even if livestock quantity is low. Finally, cluster 6, which includes the Castro Laboreiro and Lamas de Mouro parish, has very high livestock, the highest fraction of shrubland, and the maximum and minimum frequencies of pastoral burning and summer wildfire, respectively. The clusters are not spatially coherent, i.e., they are dispersed, except for cluster 6 and, to a lesser degree, clusters 1 and 4 (Figure 7).

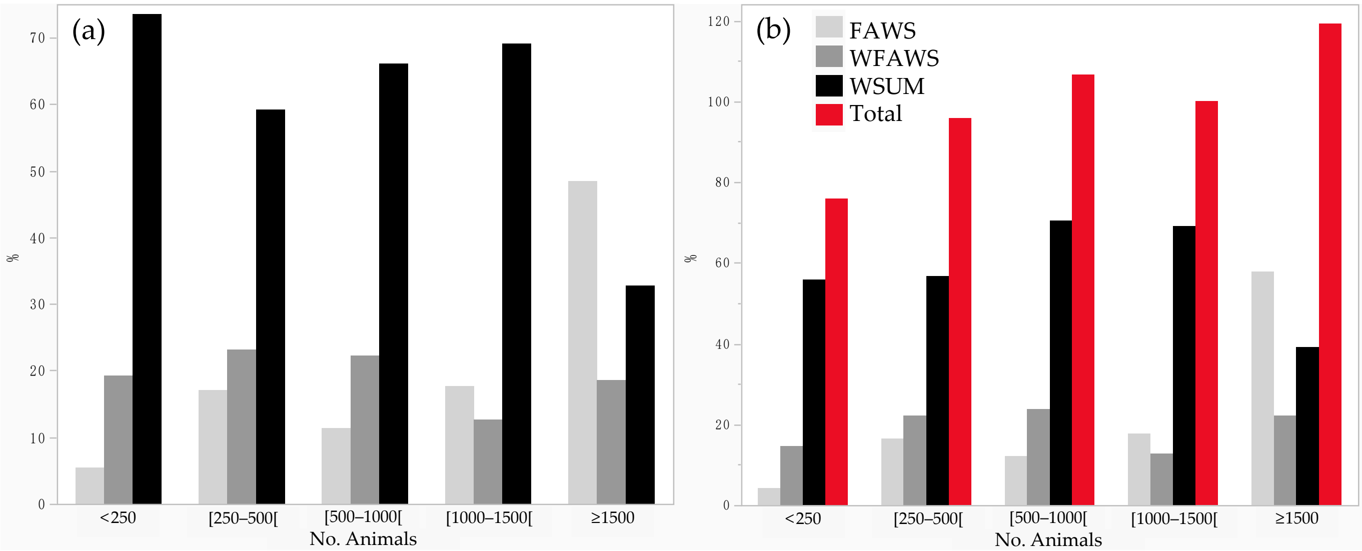

Figure 5. Cumulative burnt area in Alto Minho (2001–2020) distribution (%) in each class of number of ruminants and horses, respectively by fire type (**a**) and by fire type as a percentage of parishes area (**b**).

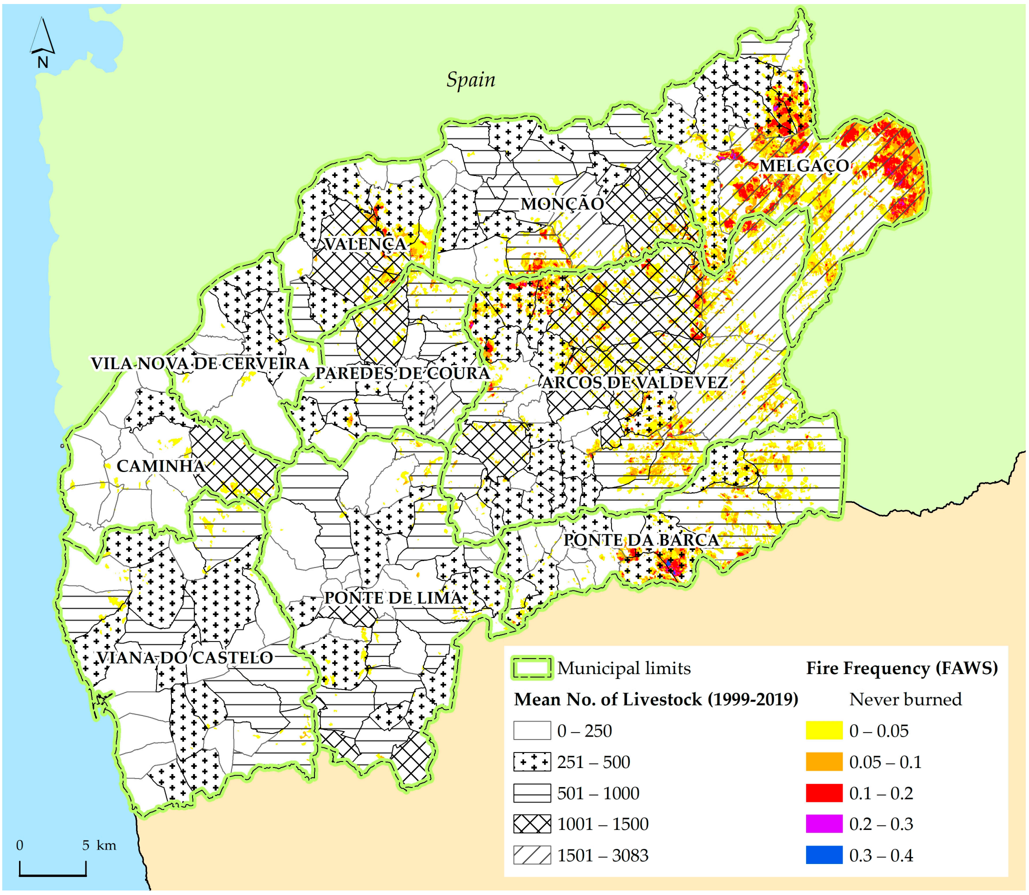

Figure 6. Mean fire frequency of autumn-to-spring fires (FAWS) in Alto Minho (2001–2020) and mean total livestock by parish (1999–2019).

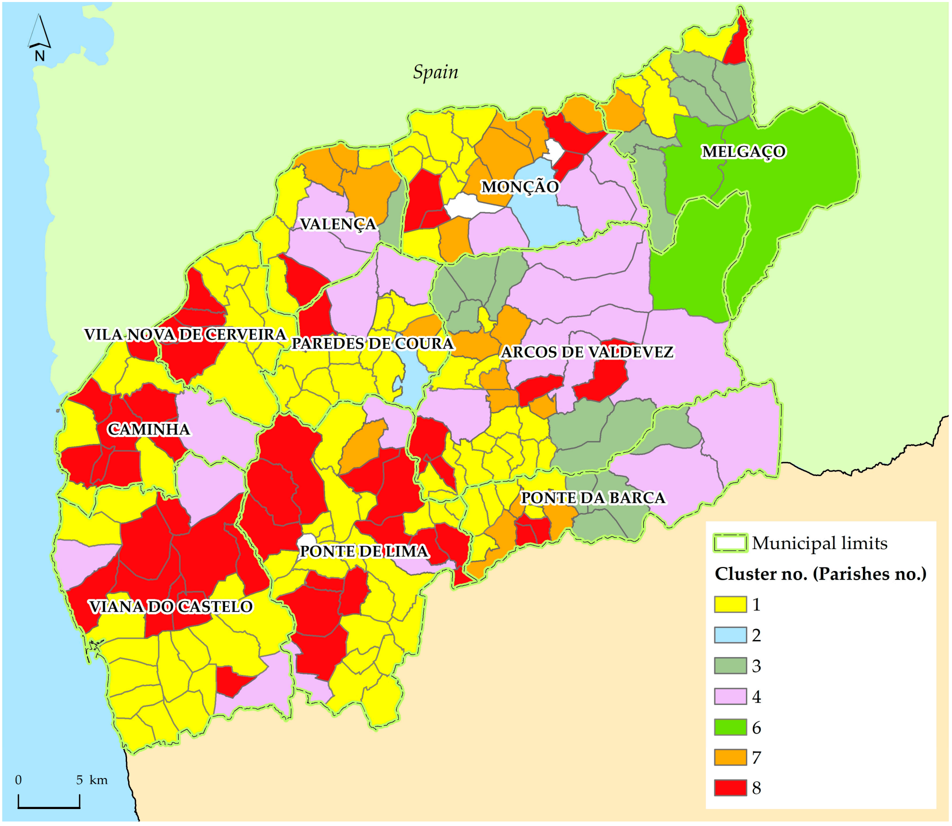

Figure 7. Classification of Alto Minho parishes by fire–livestock relationship cluster (Table 5). Clusters 3 and 6 correspond to substantial pastoral burning. Parishes in white denote either outliers or no fire activity.

Table 5. Mean characteristics of the Alto Minho parishes forming groups of distinct fire–livestock relationships as identified by K-means cluster analysis.

Cluster No. (Parishes No.)	Livestock No.	Shrubland Fraction	Fire Frequency (Year^{-1})		
			FAWS	WFAWS	WFSUM
1 (95)	341	0.061	0.001	0.005	0.018
2 (2)	2305	0.218	0.004	0.021	0.023
3 (16)	366	0.434	0.035	0.034	0.048
4 (22)	1041	0.422	0.010	0.013	0.054
6 (3)	1934	0.688	0.041	0.011	0.010
7 (20)	358	0.172	0.006	0.035	0.031
8 (47)	303	0.191	0.002	0.009	0.072

4. Discussion

The historical reconstruction by manually delineating perimeters and overlapping different fire-related data sources allowed classifying and quantifying the annually burnt areas in Alto Minho between 2001 and 2020 and identification of their seasonality. Besides wildfires (WFAWS and WFSUM), actively suppressed by definition, we were able to identify and map autumn-to-spring fires (FAWS) that were not the subject of firefighting actions. The official Portuguese fire atlas allows a general analysis of pyrogeography, but omissions and variable detail in delineating and classifying each burn patch decrease the rigour and accuracy of fire regime characterization in relation to the metrics of frequency, extent, seasonality, and size distribution, especially where out-of-summer fires are a relevant feature and at more local scales. This was particularly well illustrated in this study by the case of Castro Laboreiro and Lamas de Mouro, with a fire regime distinct from most of the rest of Alto Minho, which is not portrayed by the official fire atlas.

The annual mean burnt area in Alto Minho during 2001–2020 was double that of a previous study [2] for the 1975–2005 period, probably indicating a change in the fire regime but also reflecting our increased detection and mapping of autumn-to-spring fire activity. Note that 20% of all burnt area quantified in this study putatively corresponds to pastoral burning and that the fire return interval of 13 years estimated for the region is substantially lower than in previous studies, respectively 22 years [2] and 17 years [23]. FAWS thus dominates the fire regime in certain Alto Minho landscapes, expressing the persistence of traditional fire use practices for rangeland management, particularly where extensive livestock exists in higher quantity.

Contrary to what could be expected, we found that pastoral burning generally conforms to a longer cycle than summer wildfire, with respective return intervals of 13 and 11 years. However, the frequency of the former is higher in landscapes where pastoral burning is prevalent and summer wildfire is scarce, namely every 11 years in the Castro Laboreiro and Lamas de Mouro parish. Still, and considering the needs of rangeland renewal, this reflects a conservative and parsimonious practice, as the increase in nutritional quality of postfire shrub regeneration is short-lived [40].

Livestock quantity decreased substantially over much of Alto Minho between 1999 and 2019, continuing long-term trends starting in the 1940s [32,41]. Loss of livestock and the increasingly repressive legal restrictions to the use of fire by local communities might have reduced pastoral burning, mostly of low intensity and low severity [42], potentially contributing to an increase in the area disturbed by large and severe wildfires, as in the coastal and western parishes of the region. Pyrodiversity, the memory of antecedent fire creating more heterogeneous and finely grained spatial patterns in vegetation, has been shown to limit the development of large fires where pastoral burning is common in Portugal [43].

Fires associated with extensive livestock production, i.e., autumn-to-spring fires, were expected to be more frequent where animal load is higher, given the need to use fire to renew pastures of interest for animal fodder. The general trends observed in this study were (i) that less livestock corresponded to more summer wildfire and less autumn-to-spring fire, but the trend was mostly determined by the upper and lower extremes of livestock quantity, and (ii) that more livestock corresponded to increased overall burnt area. In fact, fire–ivestock relationships were more complex and nuanced than this, as shown by the cluster analysis. While pastoral burning is more prevalent where heathland occupies a higher fraction of the landscape, more heathland in the landscape does not imply more livestock and more pastoral burning. Likewise, high probability of burn by summer wildfire is restricted to low to intermediate livestock levels but can coincide with high pastoral burning levels.

The common perception of pastoral burning as the main cause for the increase in severe summer fires is unfounded. Pastoral fires occur in winter or precede the rainy season in early autumn, when fire spreads more effectively in shrublands dominated by species poor in elevated dead fuel, namely *Cytisus* sp. (pers. observ.). Maintenance of FAWS is conditional on maintaining extensive livestock production, and both have a considerable role in conserving the landscape and shaping the heathland mosaic and the distribution of species and habitats of pastoral or conservation interest, such as the Iberian wolf [44–47].

Despite the high loss of population between 2001 and 2021, traditional fire practices persist in Castro Laboreiro and Lamas de Mouro, indicating that the maintenance of agro-silvo-pastoral practices and, in particular, extensive livestock production, associated with traditional fire use, continues to be relevant in the conservation of the mosaic landscape. Institutional prescribed burning could replace pastoral burning, but its extent is irrelevant and is far from responding to the local communities' needs. Limitations to the use of prescribed burning in the parish may be related in part to the constraints resulting from the area belonging to the National Park of Peneda-Gerês. However, prohibiting the use of fire for pasture renewal by the community does not prevent it from being used illegally, as examples from other regions of the world show, e.g., [48]. The communities of Castro

Laboreiro and Lamas de Mouro were forced to adapt their use of fire, having abandoned the practice of "shepherding" (as they say locally) and monitoring the fire. Instead, they chose days with weather and fuel moisture conditions conducive to fire self-extinction. But pastoral fires can become significant wildfires under more fire-prone weather and the clandestine conditions under which they are carried out due to the force of law and bureaucracy. Nonetheless, as remarked in relation to pastoral fires in the Pyrenees [31], this does not imply that such escapes are environmentally detrimental, as long as the fire burns only the "right" type of vegetation.

5. Conclusions

The detailed reconstruction of burnt areas and the classification of the various types of fires are fundamental to developing a robust database allowing accurate fire regime characterization at scales meaningful for fire and land management. It is also essential to review the process of assigning the causes of wildfires, especially those related to the use of fire to renew pastures. E.g., season should be considered, because summer does not coincide with the period traditionally selected for pastoral burning. Legal instruments should be guaranteed that enable traditional communities to burn responsibly in autumn to spring, without the constraints they are currently subjected to and that lead to the use of "proscribed fire" that sometimes escapes and demands suppression action. In a time where fire management is increasingly challenged by global change, traditional fire users should be actively engaged and their knowledge taken advantage of rather than being marginalized by land management and emergency response agencies [49], namely in southern European mountains where traditional fire practices are deemed sophisticated [50].

Finally, it is important to acknowledge that eradicating fire from landscapes is not only impossible, but that it is also not desirable. Policies that advocate for total fire exclusion are actually selecting for the largest and most damaging wildfires, instead of managing low-intensity fires that fulfil land management goals and are part of sustainable ecosystems. Furthermore, the current minimum expression of institutional (prescribed) fire is not suitable for the needs of local communities. Given these compounded factors, it is the responsibility of decision-makers with technical expertise or political functions to carefully consider which type of fire should be maintained to conserve rural landscapes, reduce territorial vulnerability to climate change, and minimize the associated risks.

Author Contributions: Conceptualization, E.O. and P.M.F.; methodology, E.O. and P.M.F.; formal analysis, E.O. and P.M.F.; investigation, E.O.; writing—original draft preparation, E.O.; writing—review and editing, P.M.F.; supervision, P.M.F. All authors have read and agreed to the published version of the manuscript.

Funding: P.M.F. was funded by the Portuguese Foundation for Science and Technology (FCT) under Project UIDB/04033/2020.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: To the traditional communities of Northwest Iberia, in particular the rural communities of Alto Minho, and the Rural Laboratory of Paredes de Coura.

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

References

1. Pereira, J.M.C.; Carreiras, J.; Silva, J.M.N.; Vasconcelos, M.J.P. Alguns conceitos básicos sobre os fogos rurais em Portugal. In *Incêndios Florestais em Portugal—Caracterização, Impactes e Prevenção*; ISA Press: Lisboa, Portugal, 2006; pp. 133–158.
2. Oliveira, S.L.J.; Pereira, J.M.C.; Carreiras, J.M.B. Fire frequency analysis in Portugal (1975–2005), using Landsat-based burnt area maps. *Int. J. Wildland Fire* **2012**, *21*, 48–60. [CrossRef]

3. Connor, S.E.; Vannière, B.; Colombaroli, D.; Anderson, R.S.; Carrión, J.; Ejarque, A.; Gil-Romera, G.; González-Sampériz, P.; Hoefer, D.; Morales-Molino, C.; et al. Humans take control of fire-driven diversity changes in Mediterranean Iberia's vegetation during the mid–late Holocene. *Holocene* **2019**, *29*, 886–901. [CrossRef]
4. Vannière, B.; Colombaroli, D.; Chapron, E.; Leroux, A.; Tinner, W.; Magny, M. Climate versus human-driven fire regimes in Mediterranean landscapes: The Holocene record of Lago dell'Accesa (Tuscany, Italy). *Quat. Sci. Rev.* **2008**, *27*, 1181–1196. [CrossRef]
5. Pinto, B.M.L.; Aguiar, C.; Partidario, M. Brief Historical Ecology of Northern Portugal during the Holocene. *Environ. Hist.* **2010**, *16*, 3–42. [CrossRef]
6. Ganteaume, A.; Camia, A.; Jappiot, M.; San-Miguel-Ayanz, J.; Long-Fournel, M.; Lampin, C.; Ganteaume, A.; Camia, B.A.; Jappiot, M.; San-Miguel-Ayanz, B.J.; et al. A Review of the Main Driving Factors of Forest Fire Ignition Over Europe. *Environ. Manag.* **2013**, *51*, 651–662. [CrossRef] [PubMed]
7. Vázquez, A.; Moreno, J. Sensitivity of fire occurrence to meteorological variables in Mediterranean and Atlantic areas of Spain. *Landsc. Urban Plan.* **1993**, *24*, 129–142. [CrossRef]
8. Honrado, J.P.; Lomba, A.; Alves, P.; Aguiar, C.; Monteiro-Henriques, T.; Cerqueira, Y.; Monteiro, P.; Caldas, F.B. Conservation Management of EU Priority Habitats after Collapse of Traditional Pastoralism: Navigating Socioecological Transitions in Mountain Rangeland. *Rural. Sociol.* **2017**, *82*, 101–128. [CrossRef]
9. Carmo, M.C. Solo e Agricultura No Século XX Português. Um Problema Ambiental, Histórico e Epistemológico. Ph.D. Dissertation, Universidade de Lisboa, Lisboa, Portugal, 2018.
10. Meira Castro, A.C.; Nunes, A.; Sousa, A.; Lourenço, L. Mapping the Causes of Forest Fires in Portugal by Clustering Analysis. *Geosciences* **2020**, *10*, 53. [CrossRef]
11. Moreira, F.; Rego, F.C.; Godinho-Ferreira, P. Temporal (1958–1995) pattern of change in a cultural landscape of northwestern Portugal: Implications for fire occurrence. *Landsc. Ecol.* **2001**, *16*, 557–567. [CrossRef]
12. Pyne, S.J. Fogo no jardim: Compreensão contexto dos incêndios em Portugal. In *Incêndios Florestais em Portugal: Caracterização, Impactes e Prevenção*; Pereira, J.S., Pereira, J.M.C., Rego, F.C., Silva, J.M.N., Silva, T.P.d., Eds.; Instituto Superior de Agronomia: Lisboa, Portugal, 2006; pp. 115–131.
13. Parente, J.; Pereira, M.; Amraoui, M.; Tedim, F. Negligent and intentional fires in Portugal: Spatial distribution characterization. *Sci. Total Environ.* **2018**, *624*, 424–437. [CrossRef]
14. Sequeira, C.R.; Montiel-Molina, C.; Rego, F.C. Historical fire records at the two ends of Iberian Central Mountain System: Estrela massif and Ayllón massif. *Investig. Geográficas* **2019**, *72*, 31–52. [CrossRef]
15. Casau, M.; Dias, M.F.; Teixeira, L.; Matias, J.C.O.; Nunes, L.J.R. Reducing Rural Fire Risk through the Development of a Sustainable Supply Chain Model for Residual Agroforestry Biomass Supported in a Web Platform: A Case Study in Portugal Central Region with the Project BioAgroFloRes. *Fire* **2022**, *5*, 61. [CrossRef]
16. Tedim, F.; Leone, V.; Lovreglio, R.; Xanthopoulos, G.; Chas-Amil, M.-L.; Ganteaume, A.; Efe, R.; Royé, D.; Fuerst-Bjeliš, B.; Nikolov, N.; et al. Forest Fire Causes and Motivations in the Southern and South-Eastern Europe through Experts' Perception and Applications to Current Policies. *Forests* **2022**, *13*, 562. [CrossRef]
17. Pereira, H.M.; Domingos, T.; Vicente, L. *Portugal Millennium Ecosystem: State of the Assessment Report*; Centro de Biologia Ambiental, Faculdade de Ciências da Universidade de Lisboa: Lisboa, Portugal, 2004.
18. Bassi, S.; Kettunen, M. *Forest Fires: Causes and Contributing Factors in Europe*; (IEEP) Institute for European Environmental Policy: London, UK, 2008.
19. Carvalho, A.; Flannigan, M.; Logan, K.; Miranda, A.; Borrego, C. Fire activity in Portugal and its relationship to weather and the Canadian Fire Weather Index System. *Int. J. Wildland Fire* **2008**, *17*, 328–338. [CrossRef]
20. Carmo, M.; Ferreira, J.; Mendes, M.; Silva, Á.; Silva, P.; Alves, D.; Reis, L.; Novo, I.; Xavier Viegas, D. The climatology of extreme wildfires in Portugal, 1980–2018: Contributions to forecasting and preparedness. *Int. J. Clim.* **2022**, *42*, 3123–3146. [CrossRef]
21. Silva, P.; Carmo, M.; Rio, J.; Novo, I. Changes in the Seasonality of Fire Activity and Fire Weather in Portugal: Is the Wildfire Season Really Longer? *Meteorology* **2023**, *2*, 6. [CrossRef]
22. Catry, F.X.; Damasceno, P.; Silva, J.S.; Galante, M.; Moreira, F. Spatial distribution patterns of wildfire ignitions in Portugal. In Proceedings of Wildfire 2007, Sevilla, Spain, 14–17 May 2007.
23. Fernandes, P.M.; Loureiro, C.; Magalhães, M.; Ferreira, P.; Fernandes, M. Fuel age, weather and burn probability in Portugal. *Int. J. Wildland Fire* **2012**, *21*, 380–384. [CrossRef]
24. Nunes, L.J.R.; Raposo, M.A.M.; Gomes, C.J.P. A Historical Perspective of Landscape and Human Population Dynamics in Guimarães (Northern Portugal): Possible Implications of Rural Fire Risk in a Changing Environment. *Fire* **2021**, *4*, 49. [CrossRef]
25. Bergonse, R.; Oliveira, S.; Zêzere, J.L.; Moreira, F.; Ribeiro, P.F.; Leal, M.; e Santos, J.M.L. Biophysical controls over fire regime properties in Central Portugal. *Sci. Total Environ.* **2022**, *810*, 152314. [CrossRef]
26. Ribeiro, C.; Valente, S.; Coelho, C.; Figueiredo, E. A look at forest fires in Portugal: Technical, institutional and social perceptions. *Scand. J. For. Res.* **2015**, *30*, 317–325. [CrossRef]
27. Pereira, J.M.C.; Silva, P.C.; Melo, I.; Oom, D.; Baldassarre, G.; Pereira, M.G. *Cartografia de regimes de fogo à escala da freguesia (1980-2017)*; Centro De Estudos Florestai: Vila Real, Portugal, 2022.
28. Chuvieco, E.; Justice, C. Relations between human factors and global fire activity. In *Advances in Earth Observation of Global Change*; Springer: Dordrecht, The Netherlands, 2010; pp. 187–199. ISBN 9789048190843.

29. Ferreira-Leite, F.; Bento-Gonçalves, A.; Lourenço, L.; Úbeda, X. Problemas metodológicos no estudo dos incêndios florestais em Portugal Continental: O caso dos grandes incêndios florestais. In Proceedings of the XIII Coloquio Ibérico de Geografia, Santiago de Compostela, Spain, 24–27 October 2012; pp. 848–857.
30. OTI; Castro Rego, F.; Fernandes, P.; Sande Silva, J.; Azevedo, J.; Moura, J.M.; Oliveira, E.; Cortes, R.; Viegas, D.X.; Caldeira, D.; et al. *O Planeamento da Defesa da Floresta Contra Incêndios (DFCI)*; Observatório Técnico Independente: Lisboa, Portugal, 2019.
31. Coughlan, M. Errakina: Pastoral Fire Use and Landscape Memory in the Basque Region of the French Western Pyrenees. *J. Ethnobiol.* **2013**, *33*, 86–104. [CrossRef]
32. Fernandes, P.M.; Loureiro, C.; Guiomar, N.; Pezzatti, G.B.; Manso, F.T.; Lopes, L. The dynamics and drivers of fuel and fire in the Portuguese public forest. *J. Environ. Manag.* **2014**, *146*, 373–382. [CrossRef] [PubMed]
33. Monteiro, A.; Ferreira, C.; Madureira, H. *Atlas Agroclimatológico do Entre Douro e Minho (2005)*; FLUP: Porto, Portugal, 2005.
34. CIM Alto Minho—Comunidade Intermunicipal do Alto Minho; Instituto Politécnico de Viana do Castelo PIAAC. *Plano Intermunicipal de Adaptação às Alterações Climáticas do Alto Minho—Contextualização e Cenarização Climática*; Instituto Politécnico de Viana do Castelo: Viana do Castelo, Portugal, 2017.
35. Díaz-Fierros, F. Forest fires in Galicia and Portugal: An historical overview. *Territ. Rev. Port. De Riscos Prevenção E Segurança* **2019**, *26*, 97–114. [CrossRef]
36. Congedo, L. Semi-Automatic Classification Plugin Documentation. *Release* **2016**, *4*, 29.
37. Tanaka, S.; Kimura, H.; Suga, Y. Preparation of a 1:25000 Landsat map for assessment of burnt area on Etajima Island. *Int. J. Remote Sens.* **1983**, *4*, 17–31. [CrossRef]
38. Chuvieco, E.; Congalton, R.G. Mapping and inventory of forest fires from digital processing of tm data. *Geocarto Int.* **1988**, *3*, 41–53. [CrossRef]
39. Ruiz Gallardo, J.R. Teledetección y SIG en la Asistencia de la Actuación Forestal Postincendio. Ph.D. Dissertation, Universidad de Castilla-La Mancha, Cuenca, Spain, 2007.
40. Rego, F.C.; Bunting, S.C.; Barreira, M.G. Effects of Prescribed Fire on Chamaespartium tridentatum ((L.) P. Gibbs) in Pinus pinaster (Aiton) Forests. *J. Range Manag.* **1988**, *41*, 410. [CrossRef]
41. Torres, F.; Fernandes, P.; Pinto, R.; Botelho, H.; Monzon, A. Regional livestock grazing, human demography and fire incidence in the Portuguese landscape. *For. Syst.* **2014**, *23*, 15–21. [CrossRef]
42. Manso, F.T.; Bento, J.; Botelho, H.; Pinto, R.; Ferreira, P.; Magalhães, M.; Gomes, M. Avaliação de características regionais e sazonais inerentes ao regime de fogo e ao pastoreio. *Silva Lusit* **2010**, *18*, 27–45.
43. Fernandes, P.M.; Monteiro-Henriques, T.; Guiomar, N.; Loureiro, C.; Barros, A.M.G. Bottom-Up Variables Govern Large-Fire Size in Portugal. *Ecosystems* **2016**, *19*, 1362–1375. [CrossRef]
44. Izco, J.; Amigo, J.; Ramil-Rego, P.; Díaz, R. Brezales: Biodiversidad, usos y conservación. *Recur. Rurais* **2006**, *2*, 5–24.
45. Pastro, L.A.; Dickman, C.R.; Letnic, M. Fire type and hemisphere determine the effects of fire on the alpha and beta diversity of vertebrates: A global meta-analysis. *Glob. Ecol. Biogeogr.* **2014**, *23*, 1146–1156. [CrossRef]
46. Lino, S.; Sillero, N.; Torres, J.; Santos, X.; Álvares, F. The role of fire on wolf distribution and breeding-site selection: Insights from a generalist carnivore occurring in a fire-prone landscape. *Landsc. Urban Plan.* **2019**, *183*, 111–121. [CrossRef]
47. González, T.M.; González-Trujillo, J.D.; Muñoz, A.; Armenteras, D. Effects of fire history on animal communities: A systematic review. *Ecol. Process.* **2022**, *11*, 11. [CrossRef]
48. Coughlan, M.R. Wildland Arson as Clandestine Resource Management: A Space–Time Permutation Analysis and Classification of Informal Fire Management Regimes in Georgia, USA. *Environ. Manag.* **2016**, *57*, 1077–1087. [CrossRef]
49. Huffman, M.R. The Many Elements of Traditional Fire Knowledge: Synthesis, Classification, and Aids to Cross-cultural Problem Solving in Fire-dependent Systems Around the World. *Ecol. Soc.* **2013**, *18*, 1–36. [CrossRef]
50. Vázquez-Varela, C.; Martínez-Navarro, J.M.; Abad-González, L. Traditional Fire Knowledge: A Thematic Synthesis Approach. *Fire* **2022**, *5*, 47. [CrossRef]