Spatial distribution of human-caused forest fires in Galicia (NW Spain)

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Abstract

It is crucial for fire prevention policies to assess the spatial patterns of human-started fires and their relationship with geographical and socioeconomic aspects. This study uses fire reports for the period 1988-2006 in Galicia, Spain, to analyze the spatial distribution of human-induced fire risk attending to causes and underlying motivations associated with fire ignitions. Our results show that there are four distinctive types of municipalities in this region according to the incidence of intentional agricultural-livestock fires, pyromaniacal behavior, negligence, and unknown causes. They highlight that study of the spatial properties of the human causes and motivations of forest fire activity can provide valuable information for detecting the presence of non-random clusters of fires of various causes in particular locations, where fire management planning should be evaluated more in depth.

Keywords: forest fires, intentionality, negligence, Galicia.

1 Introduction

Forest fires can have devastating effects on forest ecosystems. The major impacts include loss of wildlife habitat; destruction of the vegetation and biomass; worsening of soil productivity and erosion; heating of water and increased sedimentation, with significant effects on aquatic organisms; and damaging atmospheric emissions including smoke and carbon. Forest fires may be the result of natural phenomena (i.e., mainly lightning), human negligence,

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accidents (often lumped into a category called "accidental"), and human intentional behavior (i.e., those ignited with malice or set with illegal intent, typically labeled "arson"). The South of Europe - Portugal, Spain, France, Italy and Greece - has been seriously affected both economically and environmentally by these kinds of human-ignited wildfires. In 2008 alone, these five countries registered more than 36,000 wildfires of all causes, burning roughly 160,000 ha, and approximately 70% of these wildfires correspond to Spain and Portugal (European Commission [1]). Because the vast majority of wildfires in the region are not natural, most of the fire activity in Southern Europe is connected to human starts. In other words, fires can be understood as a human mediated event process (Martín [2]). For example, Spanish data show that 4% of the forest fires are caused by lighting; 36% are caused by human-negligence or accidents; and 42% are human intentional actions. In Portugal, intentional fires represent 42% and accidents or negligence represent 58.6% of the human-caused fires. The high rate of human-caused fires in the region imply that positive actions taken by wildland managers to prevent such starts through education could be of great benefit. With enhanced understanding of the underlying drivers or correlates of human-caused fires, the effectiveness of wildfire prevention programs could be further enhanced, allowing for targeted interventions. However, a prerequisite of such enhanced programs is expanded research and development.

Worldwide, agricultural activities have made use of forest firesetting, as a common practice for centuries (Gamst [3], Doolittle and Lightsey [4], Vélez [5], Kuhlken [6]). In addition, social motivations such as revenge against a landowner, as an act of protest, as an attempt to cover up another crime, or as vandalism have been pointed to as underlying drivers of illegal firesetting. However, this human component of the risk of fire occurrence is quite complex to model, and it is therefore rarely included in the statistical analysis of fire danger. There are significant differences in the temporal and spatial scale of biophysical (e.g., weather, fuel conditions) and socio-economic processes (e.g., ownership, labor market conditions) that influence the risk of fire occurrences. In addition, a large share of human-caused fires is intentional, incorporating complex individual motivations. The multifaceted nature of these fires has constrained the number of quantitative studies of them. This paucity of studies stands in the face of evidence of the potential negative economic and ecological effects of these fires in both southern Europe and elsewhere and the concerns of both forest managers and law enforcement organizations that seek to limit such firesetting.

In the US, arson fires account for up to 80% of all fire ignitions in some states. Although there are some negative trends in the rates of such fires, these fires account for a steady or rising share of all area burned in many locations, including US national forests (Prestemon and Butry [7]). Arsonist firesetting has been documented extensively in the United States (Bertrand et al. [8], Gamst [3], Bertrand and Baird [9], Doolittle and Lightsey [4], Kuhlken [6], Maingi and Henry [10]). Recent research has shown that these fires are clustered in time, i.e., they usually occur in concentrated periods (Prestemon and Butry [11]). They also cluster in space, and in a space-time dimension (Doolittle and Lightsey [4], Butry and Prestemon [12]). In this line of research, Genton et al. [13] show that arson and lightning are the leading causes of wildfires in Florida and that fires ignited by trains, lightning, and arsonists are spatially more clustered than ignitions by other accidental causes.

In Europe, studies which focus on intentional fires using long-term series are scarce. In the particular case of Spain, Martínez and Chuvieco [14] study the spatial distribution patterns at the municipality level of fire properties (e.g. mean burned area, mean time of extinction, forest ownership), including if the fires were intentional, negligent or of an unknown cause. They are able to classify Spanish municipalities as falling into one of four types, according to these general forest fires properties. Other studies have focused on the differences in the spatial or temporal behavior between natural and human-caused wildfires (Vázquez and Moreno [15], Amatulli et al. [16], Benavent-Corai et al. [17]). For example, Amatulli et al. [16] find that fires due to human causes in Aragón are more spatially diffuse than lightning, observing many small hotspot areas. Benavent-Corai et al. [17] detect that human impact has important implication decreasing the inter-event interval and increasing the sparking frequency on forest-fire modeling.

This research analyzes the spatial distribution of causes and motivations of intentional fires that characterised wildfires in Galicia (Northwest Spanish region). Following Martinez and Chuvieco [14], it proposes a zonification of the Galician territory, clustering municipalities of homogeneous fire properties. However, we focus on the causes of fires and incorporate the underlying motivations behind intentional forest fires. The resulting typology of Galician municipalities according to the occurrences of different fires' causes and motivations can provide useful information that could enhance the effectiveness and efficiency of prevention activities. The paper is organised as follows. In the second section, we develop a cluster analysis of forest fire causes and underlying motivations. Following this, we introduce the database and the causality variables. Subsequently, we highlight the main causes and motivations of firesetting in Galicia and present the results of classifying these causes and motivations for homogenous geographical areas. The final section recapitulates the main points, and offers some conclusions.

2 Spatial clustering of forest fire causes and motivations

2.1 Data and methodology

This analysis uses wildfire data from Galicia, 1978-2006, provided by the General Statistics of Forest Fires compiled by the Spanish Forest Service and Consellería do Medio Rural (Xunta de Galicia). Spain has had a standardized forest fire database since 1968, making it one of the world's most comprehensive wildfire datasets. Although the reports have undergone several changes during all this years, the uniformity and continuity of the information has always been maintained (Martín [2]). The current version of these reports gathers general information regarding the fire (e.g. area burned, date and time of ignitiation, climatic conditions, causes and motivations, fire fighting measures) and detailed information on the forestland affected (e.g. ownership, forest biomass of the area, and estimated losses). Detailed information on the causes and motivations of intentional fires were not fully captured in these reports until the end of the 1980's. Therefore, the data used in this study range from 1988 to 2006 (19 years). This time period includes problematic events such as those experienced in 1989, when Galicia registered more than 8,000 wildfires, affecting about 200,000 ha.

Fires from the database were assembled into a dataset of counts of wildfires at the level of the municipality. For each municipality, counts of wildfires by causes and motivations were assembled. Fire policies and prevention efforts are organized at the level of forest districts. There are 19 forest districts, each of which compromises several municipalities. There are therefore too heterogeneous. We opt for the municipalities as the unit of our analysis. (e.g. Martínez and Chuvieco [14]). There are currently 315 municipalities in Galicia, with a mean size of 9,300 ha. Our number of observations however is 313, because several municipalities were studied together given that these were seggregated during the study period. This is the case of Burela and Cervo, seggregated in 1995, and Illa de Arousa and Vilanova de Arousa, seggregated in 1997. In order to be able to compare between information of different municipalities, a normalisation was done, expressing fire counts relative to area.

The data were analyzed using cluster analysis (Romesburg [18]). This allows us to classified the Galician municipalities in different groups in order to find data associations and relationships in such a way that the degree of similarity (or homogeneity) among municipalities within a group is stronger than among municipalities of different groups based on the causes and motivation variables. In general, the greater the homogeneity within a group and the greater the difference between groups, the more distinct the clustering. The most common technique used is hierarchical clustering. However, this technique is unsuitable for this study because it has an elevated number of observations. We use *k*-means clustering, which involves splitting the municipalities in a predetermined *k*-number of groups. We compute a stopping-rule index, in particular the Calinski-Harabasz (Calinski and Harabasz [19]) pseudo-F index, for each cluster solution to determine the *k*-number of cluster. Higher values of this index indicate more distinct clusters. Discriminant analysis was also applied to check and improve the classification obtained with the application of the cluster technique. Discriminant analysis classifies municipalities into one of several mutually exclusive groups, which are given by the results previously obtained with cluster analysis, based on their values for the a set of predictor variables (i.e., the causality variables). Statistical software used was STATA 11® and SPSS V. 15.

Municipalities are classified according to the forest fire causes and underlying motivations identified in the Galician forest fire reports. These reports distinguished among six general causes of forest fires, which could be dissagregated into about forty different specific causes. In addition, human-intentional wildfire ignitions are classified according to twenty-four social motivations. Table 1 presents the classification of the causes following the forest fire reports. It only includes the relevant causes for the Galician case study (i.e., those causes for which there are observations available for Galicia in the study period). Agricultural and rangeland burning are either negligent or intentional forest fires depending on weather or not the responsible person undertakes the neccesary cautious measures established by law and has the corresponding burning permission. This means that firesetting in agricultural and livestock activities is not always considered as a criminal use of fire. In contrast, the rest of motivations of intentional fires in Table 1 are illegal activities because they cannot be authorized in any case.

2.2 Results

In the study period (1988-2006), 82% of the fire ignitions are classified as intentional while the fires caused by negligence and accidents only represent approximately 5%. Fires with unknown causes is 9%. These fires have been decreasing significantly since the begining of 1990’s in Spain (Castedo et al. [20]), presumably as a result of efforts to overcome this shortage. However, the proportion of the unknown caused-fires in Galicia is, in fact, among the lowest of Spanish regions, where this percentage can be over 40% (Martín [2]). In the negligence and accidental forest fires, agricultural burning and forestry activities such as elimination of shrubs for afforestation are the main causes of negligent fires, 14% and 12% respectively. Rangeland burnings to enable pasture regrowth and rubbish tip escapes are next in importance, at 7% each. Less common

Table 1: Causes classification based on Galician forest fire reports.

Forest fire causes	Specific type of cause	
Lightning		
Negligence and accidental I	Agricultural burning	(a)
	Rangeland burning	(b)
	Forestry work	(c)
	Burning bush shrub	(d)
	Bonfires	(e)
	Smokers	(f)
	Debris fire escapes	(g)
	Other negligent causes (e.g. fireworks)	(h)
Negligence and accidental II	Railway	
	Electric lines	
	Motors and machines (e.g. accidents, heavy and light vehicles)	
	Military manuevers	
Intentional	Type of Motivations: Agricultural burning; rangeland burning; pyromania; hunting; vandalism; get salaries; change land use; revenge; dispute against a fines; resentment against reforestation; drive away animals; watch forest fire fighting; distract the police; rituals; cancel contracts with administration; resentment against subsidies; etc.	
Unknown		
Reproduced		

remaining causes include campfire escapes, smoking, electric power lines, and railway lines. The so-called other negligent causes not clearly identified account for 33% of all intentional wildfires

Intentional fires are a serious concern for policy makers, because they cause great damage. They often occur in inaccesible locations, and several of them can start at the same time in different places. For the study period, the percentage of intentional fires with a registered motivation is 54%, while the rest has unspecified motivations (13%). The motivations of people that start these types of fires vary widely. The most important include agricultural and shrubland burnings (31%). Intentional rangeland burning to regrow pastures is the second most commonly identified motivation (11%), while pyromania is the third (9%). The rest of the cases (4%) are divided into motivations related to hunting, revenge due to land use and property, vandalism, rejection of land use limitations derived from afforestation and protected areas, attempts to modify land use into building land, low timber prices, etc.

In summary, the variables selected to classified Galician municipalities according to the forest fire causes and intentional forest fires motivations are the following:

- Percentage of fires caused by negligences and agricultural activities: (a)+(b)+(c)+(d)
- Percentage of fires caused by other negligences and accidental causes: (e)+(f)+(g)+(h)
- Percentage of intentional forest fires motivated by agricultural burning.
- Percentage of intentional forest fires motivated by rangeland burning.
- Percentage of intentional forest fires motivated by pyromaniacs.

Other potential variables of interest that could also help to define the causes and motivations of forest fires were excluded from the statistical analysis either for (i) representing an insignificant proportion of the total fires occurrances (e.g., percentage of fires caused by negligence and accidental causes II); or (ii) for having a high correlation ($r \geq \pm 0.5$) with some of the variables considered above (e.g., the percentage of unknown causes is highly correlated with intentional forest fire).

The cluster analysis shows that Galician municipalities may be classified according to the causes of forest fires in six distinct clusters. After carrying out the discriminant analysis using the same causality variables, 92.4% of the municipalities are correctly classified in the original cluster analysis. This implies that only 25 municipalities had their classifications modified through discrimant analysis. There is therefore a high goodness-of-fit in the discriminant classification function. The final number of municipalities in each cluster is presented in Table 2. This table also shows the proportion of municipalities in each cluster with respect to the total number of analyzed spatial units. Other features displayed include the proportion of the forest area, burned area, and number of forest fires in each cluster with respect to Galician total forest area, total burned area and total number of forest fires, respectively, in the nineteen years of our study period.

Table 2: Number of municipalities in each cluster.

Cluster	Municipalities	% total municipalities	% Galicia forest area	% Galicia burned area	% Galicia nº of forest fires.
1	36	11.5	6.35	11.26	17.64
2	37	11.8	13.76	16.43	16.69
3	92	29.4	28.27	31.11	29.48
4	110	35.1	36.13	26.65	24.83
5	17	5.4	9.07	9.33	9.85
6	21	6.7	6.41	2.23	1.52
Total	313	100	100	100	100

Table 3: Mean and standard deviation of general properties of forest fires for the different clusters identified*.

Variables	Clusters					
	1	2	3	4	5	6
Forest area (ha)	3,594 (2,317)	7,577 (3,756)	6,261 (4,815)	6,630 (5,833)	10,871 (5,185)	6,221 (4,258)
Burned area (ha)	2,502 (2,161)	3,551 (2,524)	2,704 (2,569)	2,136 (1,990)	4,387 (2,802)	849 (877)
Nº of forest fires	870.8 (697.7)	801.8 (534.4)	569.6 (394.1)	397.6 (273.5)	1029.5 (632.0)	129 (99)
Risk index ***	0.27 (0.16)	0.11 (0.05)	0.11 (0.07)	0.08 (0.06)	0.10 (0.06)	0.02 (0.01)
Seriousness index ***	65.8 (43.2)	44.3 (22.8)	45.4 (31.8)	37.3 (23.6)	41.3 (23.9)	13.6 (9.4)
% Forest fires due to natural causes	0.20 (0.29)	0.80 (1.0)	0.8 (1.2)	2.2 (2.5)	0.8 (0.7)	1.8 (3.4)
% Forest fires due to agricultural negligence	2.3 (1.3)	1.3 (1.4)	3.6 (2.7)	2.8 (2.5)	2.8 (2.5)	16.7 (8.1)
% Forest fires due to other negligence or accidents	2.8 (1.8)	1.5 (1.0)	3.1 (2.3)	2.8 (2.2)	2.2 (2.2)	6.0 (3.5)
% Intentional forest fires	74.1 (8.9)	88.1 (4.8)	76.4 (10.3)	70.5 (13.1)	86.0 (8.3)	45.8 (15.5)
% Intentional forest fires motivated by agriculture burning**	13.1 (3.4)	37.6 (11.4)	13.0 (4.4)	2.4 (1.8)	16.1 (8.4)	3.6 (3.3)
% Intentional forest fires motivated by rangeland burning **	1.9 (2.8)	11.5 (4.6)	4.8 (4.6)	1.2 (1.5)	31.2 (10.5)	5.0 (5.8)
% Intentional forest fires motivated by pyromaniac behavior **	17.9 (6.4)	0.6 (0.6)	1.9 (2.6)	0.4 (0.8)	0.4 (0.8)	0.4 (1.1)
% Forest fires due to unknown causes	16.9 (7.5)	7.2 (3.8)	14.2 (7.6)	19.9 (11.9)	6.4 (4.0)	26.8 (14.7)

* Standard deviation in brackets. ** Calculate based on the total number of intentional forest fires. *** The risk index captures the density of forest fire per ha and seriousness index shows the percentage of burned area with respect to the total forest area.

Table 3 presents the mean and standard deviation of the forest fire causes and motivations for each cluster. It includes other relevant information to characterize the resulting clusters. For example, forest area, burned area, number of forest fires, risk index, and seriousness index.

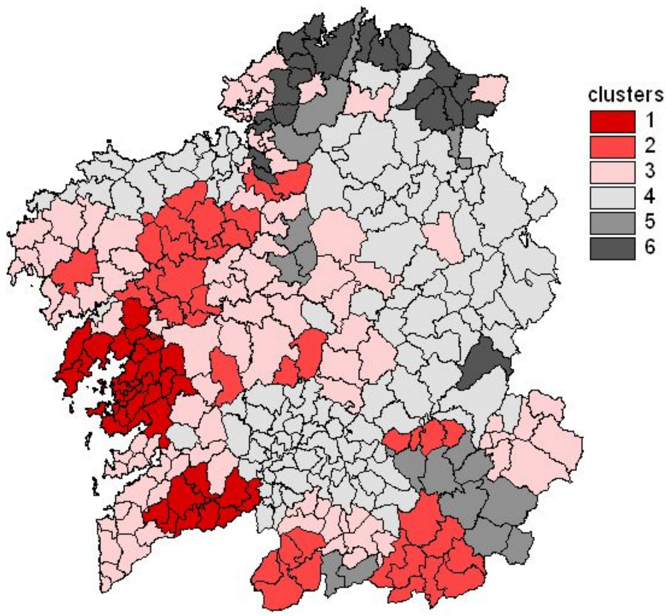

Figure 1: Spatial distribution of homogenous municipalities attending to causality properties of forest fires in Galicia (1988-2006).

Clusters present groups of municipalities with homogenous characteristics in relation to the causes and underlying motivation of forest fires. We expect the resulting classification to have not only a coherent typology in terms of the causality variables, but also a geographically meaningful dispersion in the Galicia territory. In other words, the groups of homogeneous municipalities are expected to have some cluster behavior in a spatial dimension. Figure 1 shows that there is a high level of spatial clustering in the homogeneous municipality groups derived from this analysis.

Based on these results, it is possible to classify Galician municipalities in four different types according to the causes and motivations of forest fires ignitions. These include:

Type 1 (clusters 2 and 5): Dominated by intentional forest fires associated with agricultural and rangeland activities.

In these Galician municipalities, there is a high percentage of intentional forest fires, nearly 90% of all reported fires, and the within-group dispersion of this variable is very small (Table 3). Forest fires that have unknown causes are the lowest of the whole region (6%-7%) (Table 3). Spatially, this type of municipality is clustered in two main blocks: one in the southeast, and a more dispersed one in northern Galicia. Intentional agricultural burning and rangeland burning dominate cluster 2 and 5, respectively. Uncontrolled burning of shrub and residues of agricultural activities motivate 37% of the intentional forest fires in municipalities of cluster 2 but just 16% of those fires in municipalities of cluster 5. On the other hand, rangeland burning to increase pasture productivity explains 11% of intentional fires in cluster 2 but 31% of those fires in municipalities of cluster 5 (Table 3). Intentional agricultural burning fires in cluster 2 represent 40% of the total Galician intentional forest fires; and intentional rangeland burning fires in cluster 5 represent 43% of the total Galician intentional forest fires. Prevention policies in municipalities in *Type 1* should mainly focus on the control of firesetting related to illegal agricultural and livestock burning.

Type 2 (cluster 1): Dominated by intentional forest fires caused by pyromaniacal behavior

Municipalities with this typology are located mainly in the South coast of Galicia. Here, intentional forest fires are highly relevant, with a 74% of the total fires within this group of municipalities and a 17% of total fires in Galicia (Table 3). Intentional forest fires caused by agricultural and livestock motivations are underrepresented. In this zone, only 13% and 2% of the intentional forest fires are associated with agricultural and livestock activities, respectively. Pyromaniacs explain 18% of the intentional fires in these municipalities, which represent 77% of the total intentional fires in Galicia by this motivation. Therefore, this area concentrates the malicious acts of pyromaniacs, because more than three-quarters of this type of event in Galicia occur here. Note that forest area in this zone represents 6% of the Galician forest area, but 11% of the burned area, and 17% of the total number of fires (Table 2). Risk and seriousness indices are the highest in the region (Table 3).

Type 3 (clusters 3 and 4): Dominated by intentional forest fires with unspecified motivations

It includes clusters 3 and 4, which have the highest number of municipalities (Table 2). They represent 64% of municipalities. In the municipalities of *Type 3*, the percentage of intentional forest fires is relatively high, with a mean value of 70%. However, there is higher within-group dispersion than in other groups. In cluster 3, intentional forest fires with agricultural, livestock and pyromaniacal motivations represent 13%, 5% and 2%, respectively. In cluster 4, these percentages take smaller values with 2.5%, 1.2% and 0.4%, respectively (Table 3). This indicates that only a small percentage of intentional forest fires in this zone can be explained with the motivations considered in this cluster analysis. We can therefore conclude that motivations that explained this type of forest fires are other or unspecified motivations. The properties of this zone indicate that in an important part of the Galician territory (cluster 3 and mainly cluster 4), stepped up efforts to identify motivations underlying intentional forest fires are needed as prerequisites to the development effective prevention policies.

Type 4 (cluster 6): Low weight of intentional forest fires, and higher importance of negligence and unknown causes

In the municipalities of this typology, the mean number of forest fires and the mean percentage of intentional forest fires are the lowest of Galicia (46%). Only 8% of these intentional fires are apparently motivated by agricultural and livestock activities (Table 3). However, the percentage of forest fires caused by negligence and accidental is on average 23%. These fires are caused mainly by careless behavior in agricultural activities (17%). There is also a high percentage of fires with unknown causes (27%) relative to the total number of fires ignited in these municipalities (Table 3).

3 Discussion and conclusions

This research has analyzed forest fires in Galicia in the period 1988-2006 using information from individual fires reports. Based on multivariate techniques, Galician municipalies are classified in six clusters. This allows us to divide the municipalities of this region into four distinct types according to their prevalances of the various causes and underlying motivations in forest fire occurence. *Type 1* is dominated by intentional fires motivated by malicious or illegal agricultural and rangeland burning. *Type 2* is characterized by pyromaniacal firesetting and a high fire frequency and burned area per forest area (i.e., it has the highest risk and seriousness indices). Intentional fires with unspecified motivations dominate *Type 3*. Finally, *Type 4* is characterized by fire ignitions associated with careless behavior and accidents, and with unknown general causes. The proportion of intentional fires in *Type 4* is the lowest, compared to the rest of Galicia. A straight forward extension of this work is to analyze this typology and zonification of forest fires causes and underlying motivations at a finer spatial scale (e.g. parish level with 3,801 parishes with an average size of 780 ha). Preliminary work shows no sensitivity of the results presented here to the spatial scale.

The analysis of the causes of fire occurrence is not an easy task because of the climatic, ecological, and socioeconomic variables that may simultaneously affect the probability of these events. For example, intentional fires often occur in very dry periods and in locations with high biomass inflamability. More detailed future analyses, which account for the interactions among natural and social factors and seasonality, and that explore how clusters differ when data are refined to smaller spatial units, could advance our understanding of such processes. Nevertheless, our study of the different causality typologies for the Galician municipalities based on cluster analysis shows that there are distintive spatial patterns of behaviors in forest fires ignitiations. This information could help in the development of more spatially targeted efforts of fire prevention and campaigns to enhance the awareness of local populations about the risks associated with the use and abuses of fire and the potential legal consequences of such activities.

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