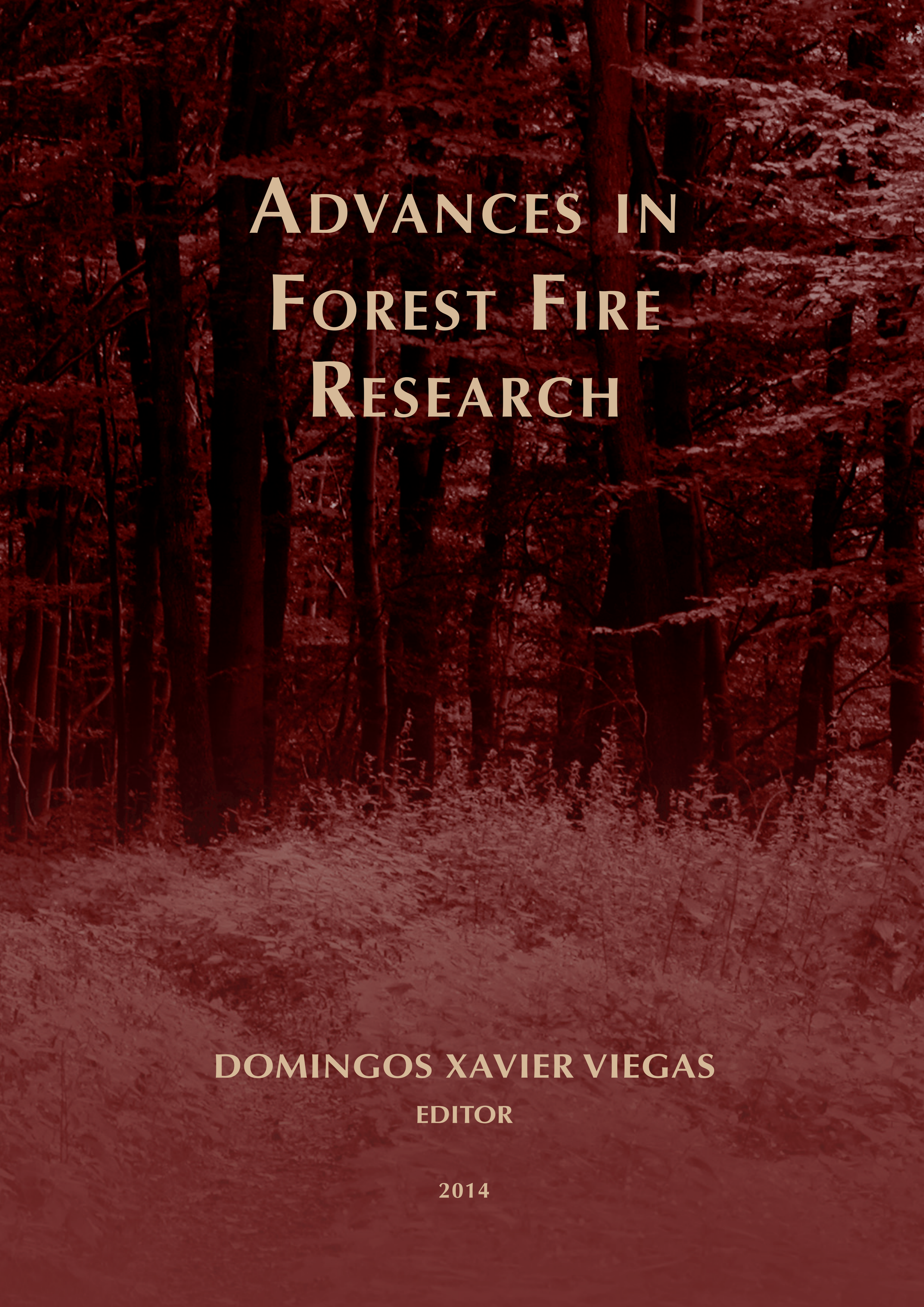

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Modelling socio-economic drivers of forest fires in the Mediterranean Europe

Lara Vilar[a], Andrea Camia[b], Jesús San-Miguel-Ayanz[b]

[a] *Centre for Human and Social Sciences, Spanish National Research Council (CSIC), C/Albasanz 26-28, 28037 Madrid, Spain, lara.vilar@cchs.csic.es*
[b] *Joint Research Centre of the European Commission, 21027 Ispra (VA), Italy, andrea.camia@jrc.ec.europa.eu, jesus.san-miguel@jrc.ec.europa.eu*

Abstract
Forest fires in the Mediterranean Europe are mostly related to human activities. More than 90% of fires are originated from either deliberate or involuntary causes. Socio-economic changes occurring in Europe in the last decades (e.g., abandonment of agricultural lands, depopulation of rural areas, changes in agriculture and forestry policies, etc.) have driven landscape transformations affecting fire risk levels through processes like e.g., increase of unmanaged lands, dead and live biomass accumulation, new uses of the forest and natural lands. In this work we analysed and attempted modelling the influence of socio-economic factors and their change over time on forest fire occurrence in the Mediterranean Europe (EU-Med).
Three 6-year time periods were considered (1988-1993, 1998-2003, 2004-2009). Fire data was extracted from the European Fire database of the European Forest Fire Information System (EFFIS). Our analysis was performed in the most fire-affected area of Europe, the European Mediterranean region covered by Portugal, Spain, France, Italy and Greece. Fire data were analysed according to their main fire cause (accident-negligence and deliberate). Both, fires and socio-economic variables, which represent anthropogenic factors related to fire activity, were mapped on a 10 km x10 km grid. Models of forest fire density were derived separately for each period and per cause category using ordinal regression statistical methods. The best predictors by period and fire cause category were assessed and differences between time periods analysed. Our result show that the variable wildland-urban interface (WUI) is related to higher ratings of fire density. This result was consistent for all periods and for the two type of fire cause analysed in our study. The overall fit of the models was 40-50%.for accident-negligence and 50% deliberated caused fires. Despite the relatively homogeneous socio-economic characteristics of the Mediterranean Europe, differences are found at regional level and by fire cause category. The anthropogenic drivers of forest fires are a challenging yet fundamental factor to understand and model the European Mediterranean fire environment.

***Keywords**: fire density, fire causes, socio-economic drivers, Europe, EFFIS*

1. Introduction

Mediterranean ecosystems cannot be fully understood without the role of fires. Natural fires have been essential to maintain biodiversity. Fire has also been a widely used tool to manage territory. In Mediterranean Europe fire regimes have been set directly and indirectly by humans for thousands of years (Pyne, 2009). However, in the last decades, natural fire regimes have experienced significant alterations (fire frequency, intensity and severity), which have aggravated their negative ecological, social and economic consequences (Westerling *et al*., 2006; FAO, 2007). In Mediterranean Europe nowadays, fire does not form a significant part of traditional systems of life; however it continues to be strongly tied to human activity (Leone *et al*., 2009). Socio-economic changes which are occurring in Europe (abandonment of agricultural land, depopulation of rural areas, priority shifts in forestry policy, etc.) result in an increase of unmanaged shrubs and biomass, which increases fire risk (Vélez Muñoz, 2007). Fire risk is also aggravated by the climate conditions in these Mediterranean areas (e.g. hot and dry summers) (Leone *et al*., 2009). Furthermore, research on climate change has indicated that increased fire hazard is likely to arise from global warming (Westerling *et al*., 2006).

Forest fires in the Mediterranean Europe are mostly related to human activities. More than 90% of fires of known cause are originated from either deliberate or involuntary causes (Ganteaume *et al*., 2013).
Fire data were extracted from the European Fire database of the European Forest Fire Information System (EFFIS). EFFIS is the European Commission (EC) focal point for information on forest fires in Europe (San-Miguel-Ayanz *et al*., 2012). It was established by the Joint Research Centre (JRC) and the Directorate General for Environment (DG ENV) of the European Commission to support the services in charge of the protection of forests against fires in the EU and neighbour countries, and also to provide the EC services and the European Parliament with information on forest fires in Europe (San-Miguel-Ayanz *et al*. 2013). Following the recommendations of the European Parliament to further develop the European Forest Information System (EFFIS), a common classification scheme of fire causes was established. This harmonized classification scheme was accepted in 2012 and is currently being adopted by the countries as a common means to record fire causes when reporting national data to EFFIS (Camia *et al*., 2013). This classification was used in our analysis. .
We analysed and attempted modelling the influence of socio-economic factors and their change over time on forest fire occurrence in the Mediterranean Europe (EU-Med). Data from the European Fire database in the European Forest Fire Information System (EFFIS) related to three 6-year time periods were considered: 1988-1993, 1998-2003 and 2004-2009. These three periods will be referred to in the text as 1990s, 2000s and 2006s. Fires were mapped on a 10 km x 10 km grid starting from their location at NUTS3 (Nomenclature of territorial units for statistics, level 3 - province) level resolution using GIS tools. NUTS regions are used by the countries to report national information to the European Commission. Fire density was separated into two cause categories, accident-negligence and deliberate. Socio-economic variables representing anthropogenic factors related to fire activity were also mapped using the same 10 km x 10 km grid.

2. **Methods and materials**

2.1. **Study area**

The Mediterranean Europe (EU-Med) area considered for the analysis includes the EU countries Portugal, Spain, Italy, Greece and the Southern provinces of France, with a total area of more than 1 million km^2. Figure 1 shows the area analysed by NUTS3 administrative level (province) and by fire regions agreed by expert knowledge (Camia A, personal communication). Landscape differences between the Mediterranean Basin and the rest of Europe are mainly related to climate, the long and intense human impact and the role of fire (Pausas and Vallejo, 1999). Reflecting the prevailing climate, Mediterranean forests are frequently characterized by fire climax species, i.e. those dependent on the presence of fire in the reproductive cycle (FAO, 2007). Forests, including shrub formations and other semi-natural categories (e.g. transitional woodlands, sclerophyllus vegetation) occupy about 50% of the area. The area is populated by about 137 million people (Eurostat, 2011).

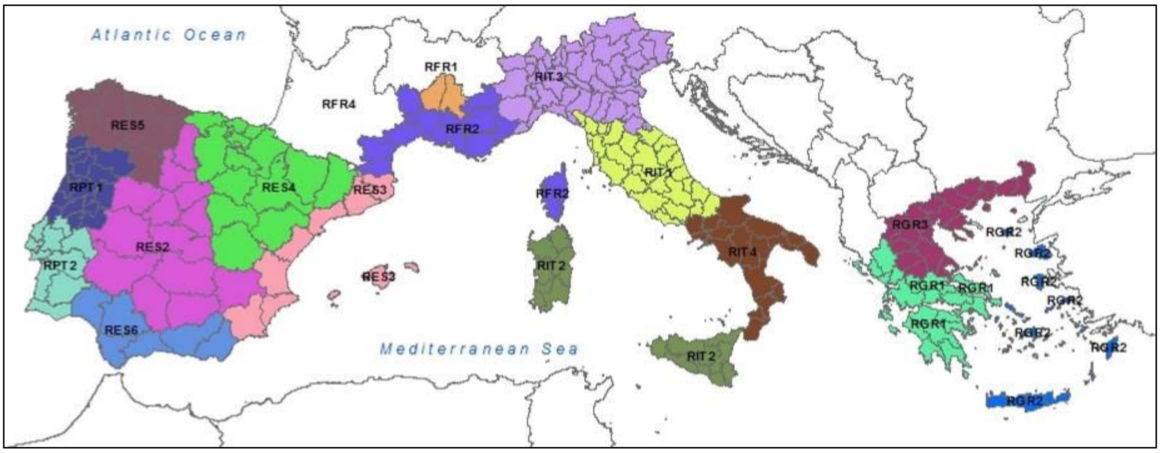

Figure 1- Extent of the analyzed area, separated by NUTS3 administrative level boundaries and fire regions

2.2. **Data**

2.2.1. *Fire occurrence data*

Fire occurrence data was obtained from the European Forest Fire Information System (EFFIS). Three 6-year periods of time were extracted: 1988-1993 (1990s), 1998-2003 (2000s) and 2004-2009 (2006s). The fire records were at NUTS3 (province) level, and included fire occurrence data for months March to November. Fire data was analysed by main fire cause category (accident-negligence and deliberate). Fires of unknown cause were assigned to a known cause on the basis of the proportion of known caused fires in each NUTS3. Also, the number of fires was referred to the wild-land area in the NUTS3. After the pre-processing and selection, the fire data were mapped on a 10 km x 10 km grid (LAEA projection reference grid) following the INSPIRE specifications (EC and EP, 2007). This resulted in fire density values by cause (accident-negligence and deliberate) by grid cell and by period (1990s, 2000s and 2006s). These variables were used as response variables in our modelling. Figure 2 shows as an example the fire density (fires/km^2) by 10 km x10 km grid of deliberated fires in 2000s.

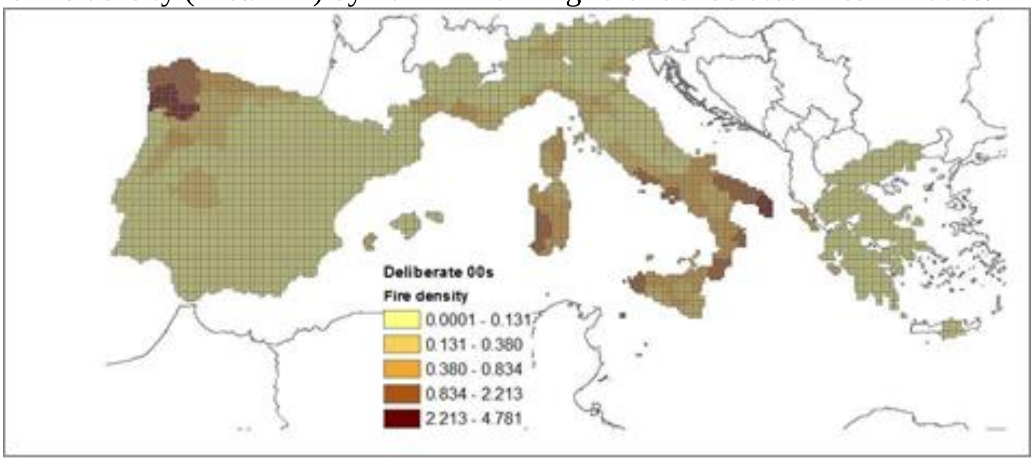

Figure 2- Fire density (fires/km^2) by 10 km x10 km grid. Deliberated fires in 2000s

2.2.2. *Socio-economic factors*

Fire density is influenced by socio-economic factors. These include socio-economic changes in rural and urban areas, traditional activities in rural areas, accidents or negligence, fire prevention activities and other factors that can lead to social unrest (e.g. land use disputes or high unemployment rates) (Martinez *et al*., 2009; Vilar del Hoyo *et al*., 2008; Leone *et al*., 2003). To analyze the impact of these factors on fire density in the EU-Med region, available spatially explicit socio-economic variables related to the different factors were obtained from different cartographic and statistical sources for the three selected periods of time (1990s, 2000s and 2006s).. All the variables were spatially referred and mapped on the 10 km x 10 km grid. Different spatial analyses were carried out using Geographic Information System (GIS) tools (ArcMap 10, ESRI 2011), including format conversion, re-projection, re-clasification, overlay, calculation of areas, buffer zones and other distance operations such as quantification of different land use interfaces. The variables considered in the analysis are shown in Table 1.

Table 1. Socio-economic variables tested as predictors in the models

Variables [abbreviation]	Unit
Population density [pop_den]	[number/km^2]
Density of labour force in economic sectors *(agriculture, industry, services)* [agri, indus, serv]	[number/km^2]
Agrarian holders older than 55 [holders55]	[number/km^2]
Road network *(road, motorway)* [road, motow]	[total lines/ km^2]
Wildland-Urban interface [WUI]	[km^2]
Number of heads of livestock [bovine, goat, sheep]	[number/km^2]
Full farm time workers (WT) [farmw]	[number/km^2]
Total AA (Agricultural area) Owner Farmed [ofarmed]	[km^2]
Grassland-forest interface [FGI]	[km^2]
Agricultural-forest interface [FAI]	[km^2]
Railway network [railway]	[total lines/ km^2]
Protected areas [NATURA00]	[km^2]
Landscape fragmentation [RPC_A] [RPC_W]	[-]

2.3. **Modelling the role of socioeconomic drivers of forest fires**

Scientific approaches which include human factors in fire risk assessment were commonly based on statistical models that attempt to explain historical, human-caused fires from a set of independent variables (Vilar del Hoyo *et al*., 2011). Logistic regression analysis was frequently used both to predict and also to explain human-caused fires (Martell *et al*., 1987; Vega-García *et al*., 1995; Chuvieco *et al*., 1999; Lin, 1999; Pew and Larsen, 2001; Vasconcelos *et al*., 2001; Martínez *et al*., 2004; Prasad *et al*., 2008; Martínez *et al*., 2009). Other statistical methods such as linear regression, classification regression trees, neural networks or Bayesian probability were also used in fire risk mapping to generate local risk models (Chao-Chin, 2002; Koutsias *et al*., 2004; Robin *et al*., 2006; Amatulli *et al*., 2006, 2007; Amatulli and Camia, 2007; Syphard *et al*., 2007; Vega-García, 2007; Yang *et al*., 2007; Romero-Calcerrada *et al*., 2008). The response variable in those models always refered to fire occurrence, commonly obtained from information available in forest fire databases.

In order to identify the role of different socio-economic factors on the spatial variation of fire density, the relationships between this response variable and the spatialized socio-economic variables previously described were analized by using regression models for ordinal data, by means of cumulative link models (package ordinal, Christensen, 2012, for R, R Development Core Team, 2011). Fire density was divided into three equiprobable classes (low, medium, high). Models of forest fire density were derived separately for each period and per cause category. A 75% random sample of the input dataset was used to calibrate the models. In particular, the models were initially fitted by a constant and then the relevant socio-economic explanatory predictors were identified by performing a forward stepwise selection procedure, using the Akaike Information Criterion (AIC) as the criterion for variable inclusion. Finally the calibrated model was used to predict the expected fire density class on the 25% of the sample dataset excluded from calibration. The performance of the models was

evaluated by comparing the observed and predicted fire density classes. In particular, a crosstabulation analysis was conducted. This allowed calculating the accuracy by fire density class (user's and producer's accuracy) as well as the overall fit.
The best predictors selected by period and by fire cause category as well as the differences between time periods were analysed.

3. Results and discussion

Our results in EU-Med study area showed that, for the three periods of time analysed and for accident-negligence and deliberate caused fires, wildland-urban interface (*WUI*) was the variable invariantly selected with positive sign in all periods. For the two types of fire cause analysed the model predicts that the probability of belonging to a higher fire density class increases when *WUI* increases. Tables 2 and 3 show a summary of the results, indicating the significant variables of each model and their signs by period, and by fire cause (accident-negligence vs. deliberated), respectively.

Table 2. Summary of results of ordinal regression models for accident-negligence caused fires in EU-Med: period, variables in the model ordered by AIC step forward, sign and overall fit. In red colour, variables present in all periods with negative sign; in green colour, variables present in all periods with positive sign; in orange colour, variables present in all periods with changing sign

Accident-negligence					
1990s		**2000s**		**2006s**	
Variables (AIC Step forward order)	**Sign**	**Variables (AIC Step forward order)**	**Sign**	**Variables (AIC Step forward order)**	**Sign**
holders55	+	road	+	**bovine**	-
bovine	-	goat	-	**WUI**	+
pop_den	+	**bovine**	-	road	-
sheep	-	pop_den	+	**FGI**	-
FGI	-	agri	+	NATURA00	+
goat	+	RPC_W	-	FAI	+
WUI	+	**WUI**	+		
RPC_W	-	NATURA00	+		
RPC_A	-	RPC_A	+		
		FAI	+		
		FGI	+		
Overall fit	49%	Overall fit	47%	Overall fit	39%

Regarding fires caused by accident-negligence, the variable agriculture-forest interface (*FAI*) enters in the models with positive sign in 2000s and 2006s. This variable is related to vegetation management or agricultural burnings. It must however be noticed that other theoretically important variables show changing signs in the different periods (e.g. *FGI*), and also that high livestock presence (*bovine*) seems to lead to a reduction of expected fire density.

Table 3. Summary of results of ordinal regression models for deliberate caused fires in EU-Med: period, variables in the model ordered by AIC step forward, sign and overall fit. In red colour, variables present in all periods with negative sign; in green colour, variables present in all periods with positive sign; in orange colour, variables present in all periods with changing sign

Deliberate					
1990s		**2000s**		**2006s**	
Variables (AIC Step forward order)	**Sign**	**Variables (AIC Step forward order)**	**Sign**	**Variables (AIC Step forward order)**	**Sign**
holders55	+	**goat**	-	**holders55**	+
goat	-	**holders55**	+	**WUI**	+
sheep	-	agri	+	**sheep**	+
WUI	+	**sheep**	+	**FAI**	-
road	+	**WUI**	+	**goat**	-
bovine	-	**FAI**	-	NATURA2000	-
FAI	-	**road**	+	**road**	-
RPC_W90	+	RPC_A	-		
agri	+	FGI	-		
		NATURA2000	-		
		pop_den	-		
Overall fit	56%	Overall fit	53%	Overall fit	50%

Regarding deliberately caused fires, *goat* and *FAI* are the variables that in all periods enter the models with a negative sign, meaning that these variables are less likely to be linked to higher ratings of fire density. *Goat* enters in the models in 1990s and 2000s in the second and first position respectively, while in 2006s in the 5^{th} position. This fact may be related to the loss of the role goats played in the past helping to prevent fire thanks to grazing. *WUI* and *holders55* enter with a positive sign in all periods, meaning they are more likely to be linked to higher ratings of fire density. The overall fit of models was between 40% and 50% for accident-negligence models and above 50% for deliberate fire models. Results were improved when modelling was attempted by sub-country regions, reaching 74% for the best fitting of deliberate fires.

4. Conclusions

Models show temporal trends in time in the case of the variables *WUI* for both type of fire cause and *goats/FAI* in the deliberated caused fires. For the rest of predictors the models did not highlighted clear trends. This suggests the need to analyse data with larger time span, to include more important socio-economic and territorial changes. The depopulation of rural areas in Europe started after the II World War, being more intense from the 50s and 60s in southern Europe. Changes in regional development have happened since the 60s and 70s. To analyze this issue, homogeneous data would be required for the study area for these periods. The negative sign of some of the variables is non-intuitive. This issue might have a reason related to limitations of the data, lack of explanatory variables or the statistical analysis itself. Further investigation will be needed in these cases. The variables representing the socio-economic issues are an indirect way of measuring the role of socio-economic influence on forest fires. Human behaviour is very difficult to predict and to represent, in particular regarding deliberate actions. Consistent, complete and trustworthy data (both fire data and socioeconomic drivers) is essential to obtain reasonable models.

Generally speaking, the fit is slightly better in the case of the deliberately caused fires. It might be indicative of the influence of fire causality and the scale of the analysis.

Despite the relatively homogeneous socio-economic characteristics of Mediterranean Europe, differences are found at regional level and by fire cause category. The anthropogenic drivers of forest fires remain a challenging yet fundamental factor to understand and model the European Mediterranean fire environment.

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