Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/forestsystems
doi: http://dx.doi.org/10.5424/fs/2013223-03899

Forest Systems 2013 22(3): 526-534
ISSN: 2171-5068
eISSN: 2171-9845

Large wildland fires in three diverse regions in Spain from 1978 to 2010

A. Cardil* and D. Molina

ETSEA. Universidad de Lleida. Avda. Rovira Roure, 191. 25198 Lleida, Spain

Abstract

Aim of study: Large wildland fires (LWF) are major disturbance processes affecting many ecosystems each year. In last decades, socio-economic changes have contributed to major changes in land uses. This study assess trends in number, burned area and average size of large wildfires (> 100 ha) from 1978 to 2010 in Spain.

Area of study: This work analyzes three clearly different regions of Spain (Mediterranean coast, MC, Mediterranean Interior, MI, Northwestern Spain, NW).

Material and methods: We studied historical wildland fire data from Spain's EGIF database (General Statistics on Wildland Fires). We selected only wildland fires larger than 100 ha. All LWF were analyzed to test trends in number of fires, burned area and mean fire size.

Main results: The number of LWF decreased in all regions but the burned area only decreased in MC and NW regions. However, both the number of LWF and the burned area did not decrease after 1995 in any region. The average size of LWF did not change in any of the three regions. Fires larger than 500 ha were very significant due to the high percentage of area burned in relation to the total area burned by fires larger than 100 ha (79.3% in MC, 63.9% in MI, and 35.7% in NW).

Research highlights: After 1995, the number of LWF and burned area did not decrease. Additional actions are required including learned lessons from past LWF spread, and better trained fire suppression workers and more fuel management.

Key words: large wildland fires; trends; forest management; Spain.

Introduction

Wildland fires are a growing hazard to human and environmental values worldwide, mainly in the fire-prone areas as the Mediterranean Basin (Salis *et al.,* 2012). Many biomes of this region have endured an increasing incidence of severe fire seasons (Mouillot and Field, 2005; Trigo *et al.,* 2006). In a analogous way, fire activity is expected to rise based on the predicted changes in climate and land use (Thonicke *et al.,* 2001; Moriondo *et al.,* 2006). In the period 2000-2009, Southern European countries (Italy, France, Spain, Portugal and Greece) experienced ~57 000 wildfires year^{-1}, which burned ~430 000 ha year^{-1} and 90% were human caused (JRC-IES, 2010).

Spain like other Southern European countries (including France, Italy, Greece or Portugal) has a fire regime with large wildland fires (LWF) that have an extreme fire behavior exceeding firefighting capabilities (Miralles *et al*., 2010; Molina *et al*., 2010). Undesirable fires affect the forest landscape every year. In addition, when weather conditions facilitates fire propagation, fires can burn large areas as in 1994 in Spain with wildland fires larger than 20.000 ha. Other similar cases occurred in other countries as Greece (2008), Portugal (2003), Russia (2010), United States (2000) or Australia (2009).

Large wildland fires threaten social, economic and ecological resources (Alvarado *et al*., 1998; Salis *et al*., 2012), public and private properties

* Corresponding author: adriancardil@gmail.com
Received: 12-01-13. Accepted: 01-06-13.

Abbreviations used: LWF: Large wildland fires (those larger than 100 ha); MC: Mediterranean coast region; MI: Mediterranean interior region; NW: Northwestern Spain region.

(houses, infrastructures, roads, power lines and others) and the life of firefighters and people (Maselli *et al*., 2000). LWF accounted for the majority of the total area burned despite their small percentage of the total number of fire (Stocks *et al*., 2003; Molina *et al*., 2010) and the most resulting damage is concentrated in them (Ganteaume and Jappiot, 2012; Alvarado *et al*., 1998). Much discussion is concentrated around if fire and forest policies and practices on fuel management are missing their original goal (Moreira *et al.,* 2011). New approaches for reducing fire damage and improving fire suppression in terms of costs and effectiveness are available (Moreira *et al.,* 2011; Miralles *et al.,* 2010; Molina *et al.,* 2010).

Fire suppression resources have to be designed to reduce fire damage caused by LWF. Consequently, a large amount of money has been invested for this cause. The expenditure in fire suppression has grown a great deal and the Spanish Government were forced to create both the Emergency Military Unit (UME in Spanish in 2005) and the Attorney's Office of Environmental Crimes (within the Department of Justice, in 2006).

Numerous national authorities around the world gather datasets of wildland fire records. Examples of wildland fire databases are available from Spain (Bardaji and Molina, 1999; Spanish Environment Ministry, 2009) Switzerland (Conedera *et al.,* 1996), Austria (Eastaugh and Vacik, 2012), the USA (Brown *et al.,* 2002), Canada (Stocks *et al.,* 2003) and Europe (EC, 2008). Spain has compiled databases of forest and rangeland fire records since 1968, in a struggle to understand patterns, calculate risks and identify possible changes in wildland fire regimes. Such databases datasets, if valid and comprehensive, could be used for model validation, detection of trends and quantitative risk analyses (Eastaugh and Vacik, 2012). A growth in fire danger has been derived from historic wildland fire datasets (EC, 2008). However, others studies indicate that data quality issues can obstruct these findings (Podur *et al*., 2002).

Few studies on large fires (*i.e.*, that focus only in large fires) are available for Southern Europe (Ganteaume and Jappiot, 2012) and the assessment of suppression means and other policies in them. In this paper, we research LWF from 1978 to 2010 in three different regions of Spain in terms of number of fires, burned area and fire size.

Data and methods

We studied historical wildland fire data from Spain's EGIF database (General Statistics on Wildland Fires) which includes the Wildland Fire Reports sent to the Ministry of the Environment by both Fire-Fighting Services and Forest Services of the regions. This database has an entry from each fire, regardless of size, and contains the same fields of information for each fire. We selected only wildland fires larger than 100 ha (100 ha+ or LWF thereafter) for the period of 1978-2010. This is similar in other studies (De Zea Bermudez *et al*., 2009; Moreno *et al*., 2011). We did not use the first years of this database (1968-1977) because area burned in private properties were usually underreported in those years. We did not include burned agriculture lands or urban areas in this study.

All LWF from 1978 to 2010 were analyzed to test trends in number of fires, burned area and mean fire size. In the study, we set up three different regions using summer extent, intensity of sea influence in weather, intensity and frequency of extreme weather patterns, population density, amount of fire suppression resources and number of fires. This classification is an updated from Bardaji and Molina (1999) study. The Spanish Environment Ministry changed to this classification after Bardaji and Molina (1999) for their annual reports (Spanish Environment Ministry, 2009). These three regions are the following (Fig. 1):

— Northwestern Spain (NW). There are more fires than in the other regions in Spain (Pereira *et al*., 2005). The dry summer season is shorter than the other two regions. There is a more frequent traditional use of fire (traditional use of fire in range and agriculture). In this region, we included La Coruña, Lugo, Ourense, Pontevedra, León, Zamora, Asturias and Cantabria provinces.

— Mediterranean Coast (MC). There is an important sea influence and a long dry summer season. In general, population density is high. In MC, we included Girona, Barcelona, Tarragona, Castellón, Valencia, Alicante, Murcia, Almería, Málaga, Cádiz, Huelva provinces.

— Mediterranean Interior (MI): The dry summer season in the longest. Sea influence is minimal and air relative humidity is low during the summer without much day to day variability. Population density is the lowest. Land abandonment is very important. This region includes the following provinces: Guadalajara, Cuenca, Toledo, Ciudad Real, Albacete, Huesca,

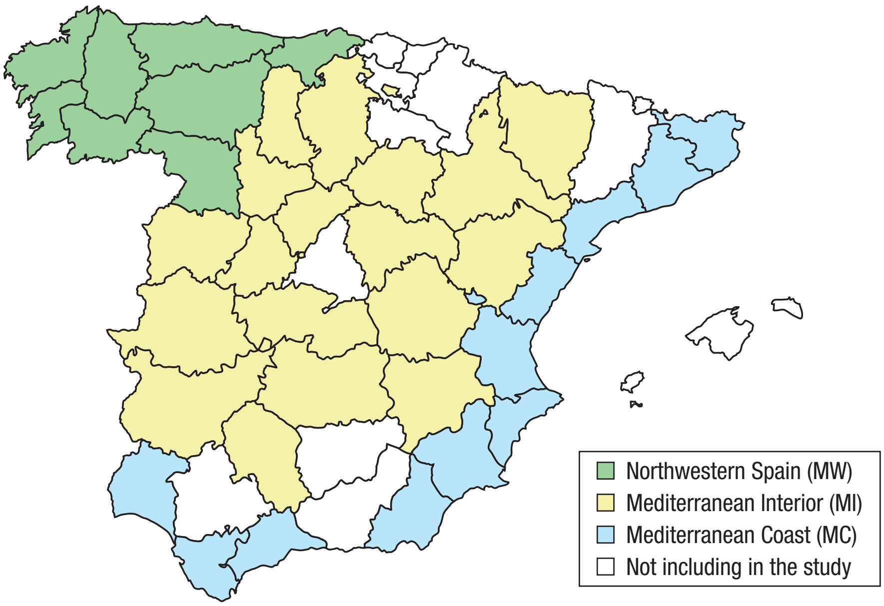

Figure 1. Regions in Spain to characterize large wildland fires. Canary Islands are neither displayed in this figure nor included in this study.

Zaragoza, Teruel, Cáceres, Badajoz, Salamanca, Valladolid, Palencia, Burgos, Soria, Segovia, Ávila, Jaén and Córdoba.

We excluded some provinces because of different causes:

— Madrid: It is an interior province; however, its population density is much higher than other interior provinces and its suppression resources are stronger.

— Lleida: In this province, suppression resources are much stronger than other interior provinces.

— Navarra, Guipúzcoa, and Alava: They are small size provinces with strong suppression resources and / or very few wildland fires larger than 100ha per year.

— Granada and Sevilla: These provinces have both an interior area and a coastal area. They do not fit to any of both conditions (Mediterranean Coast or Mediterranean Interior).

— Canary Island and Balear Islands: They are particular provinces because they suffer only few large wildland fires.

Statistical data treatment

LWF were classified into three wildland fire categories: fires larger than 100 ha (100 ha+), 250 ha (250 ha+) and 500 ha (500 ha+). Three normalized metrics were calculated and analyzed for three regions and fire categories: (1) annual ha burned for every 400.000 ha of forest and wildlands (relative burned area); (2) annual number of LWF for every 400.000 ha of forest and wildlands (relative total LWF); (3) average size of LWF. A base area of 400.000 ha was selected as in other studies (Stephens, 2005; Pyne, 1997). The wildland area was calculated using the Spanish National Forestry Inventory in all available editions, establishing linear interpolation to calculate the forest area in each year. The interpolation was performed only in the years between inventories. After the last available inventory for each province, the area was considered constant and before the first inventory, the forestry area also was considered constant for all previous years with the value of the first inventory.

The relative total LWF, relative burned area, and average size of LWF were analyzed in three regions and three wildland fire categories from 1978 to 2010 (27 time series). Analysis of these 27 time series showed that autocorrelations existed in some of them using Durbin-Watson Test. To reduce serial dependence, a 3-year average was calculated for each variable over 32 years (10 data points). This new condensed database was used in the analysis of variance (ANOVA) and linear regression analysis (Stephens, 2005).

We determined if there were significant changes (decrease, increase, no difference) in the three studied variables (relative burned area, relative total LWF and average size of LWF) from 1978 to 2010 in the three wildland fire categories with a linear regression analysis in a new condensed database (10 data points for each variable). The independent variable in the regression was the midpoint year of the average 3-year range and the dependent variable was the corresponding transformed 3-year averages of relative burned area, relative total LWF and average size of LWF.

An analysis of variance was performed using the series with 3-year average to determine significant differences ($p < 0.05$) by regions in the studied variables from 1978 to 2010. If significant differences were detected, a Tukey Multiple Comparion Test was performed to determine these differences among regions (MI, MC and NW).

The annual variability in fire occurrences is high, both in terms of large fire frequencies and their burned areas as reported in Stocks *et al*. (2003). This variability is caused by diverse environmental factors (*i.e.*, climate (Gillett *et al*., 2004)) and human influence (Mollicone *et al*., 2006). All series were shown using the moving average method for a better display of the evolution of the variables in time. This smoothing technique was applied to mitigate the effect due to year to year random variation. This practice, when properly applied, reveals more clearly the underlying trend (Legendre and Legendre, 1998). The method calculates successive arithmetic averages over $2\,m + 1$ contiguous data as one moves along the data series (Legendre and Legendre, 1998). The interval ($2\,m + 1$) is called window. In this study, we used simple moving average with five-year periods ($m = 1$).

Results

In relation to ANOVA analysis, there were significant differences among regions in several variables. The results of the Tukey Multiple Comparion Test and the values of each variable by region and wildland fire categories are in Table 1. The relative total LWF was significantly different from NW (14.97 in 100 ha+ category) to both MC and MI (3.76 and 2.14 respectively in 100 ha+ category) in 100 ha+ and 250 ha+ wildland fire categories. The relative total LWF was also significantly different from NW (1.47) to MI (0.43) in 500 ha+ category. The region with lowest value in relative total LWF in all wildland fire categories was MI but significant differences with MC were not detected.

The relative burned area was not different significantly among regions in 250 ha+ wildland fire category. However, there were clear differences in 100 ha+ and 500 ha+ categories. In the first, the maximum value occurred in NW with 4030.63 ha burned for every 400.000 ha of forest and wildlands. This value was significantly different from MI (1014.28 ha) but not from MC (2909.21 ha). No difference was found between MC and MI. By contrast, in 500 ha+ category, the largest value was in MC (2307.51 ha) and it did differ from MI value (648.30 ha) significantly. No difference was found between MC and NW region (1441.51 ha).

The average size of LWF is less in NW than both MC and MI in 250 ha+ and 500 ha+ categories. In 100 ha+ category, the LWF average size is larger in MC (651.72 ha) than NW (261.44 ha). There was no difference between MC and MI in any wildland fire category.

Table 1. Average of ha burned for every 400.000 ha by large wildland fires (LWF) (relative burned area), number of LWF for every 400.000 ha (relative total fires) and LWF average size from 1978 to 2010 in each region

	Wildland fires categories	**Relative total LWF**	**Relative burned area (ha)**	**LWF Average size (ha)**
Mediterranean Coast (MC)	100 ha+	3.76[b]	2909.21[ab]	651.72[a]
	250 ha+	1.89[b]	2617.56[a]	1103.72[a]
	500 ha+	1.03[ab]	2307.51[a]	1877.96[a]
Mediterranean Interior (MI)	100 ha+	2.14[b]	1014.38[b]	493.45[ab]
	250 ha+	0.90[b]	820.28[a]	914.39[a]
	500 ha+	0.43[b]	648.30[b]	1472.81[a]
Northwestern Spain (NW)	100 ha+	14.97[a]	4030.63[a]	261.44[b]
	250 ha+	4.30[a]	2432.17[a]	534.38[b]
	500 ha+	1.47[a]	1441.51[ab]	913.54[b]

Mean values in a column in each wildland fires categories followed by the same letter are not significantly different ($p < 0.05$).

Table 2. Change of number of large wildland fires (LWF) for every 400.000 ha (relative total LWF), ha burned for every 400.000 ha by LWF (relative burned area) and average size of the LWF from 1978 to 2010 in each region. Coefficient of determination of linear regressions

	Wildland fire categories	Relative total LWF	Relative burned area (ha)	Average size (ha)
Mediterranean Coast (MC)	100 ha+	— (0.003)	— (0.014)	n.s. (0.756)
	250 ha+	— (0.007)	— (0.017)	n.s. (0.868)
	500 ha+	— (0.017)	— (0.040)	n.s. (0.518)
Mediterranean Interior (MI)	100 ha+	— (0.019)	n.s. (0.160)	n.s. (0.082)
	250 ha+	n.s. (0.062)	n.s. (0.285)	n.s. (0.211)
	500 ha+	n.s. (0.209)	n.s. (0.536)	n.s. (0.255)
Northwestern Spain (NW)	100 ha+	— (0.007)	— (0.049)	n.s. (0.094)
	250 ha+	— (0.036)	n.s. (0.179)	n.s. (0.223)
	500 ha+	n.s. (0.200)	n.s. (0.493)	n.s. (0.623)

+ significantly increased; – significantly decreased at $p < 0.05$; n.s. not significant. Values in parenthesis are the p statistic. In MC, we did not consider 1994 in relative burned area because it was an anomalous data in terms of burned area due to mega-fires that burned 279172 ha (100 ha+).

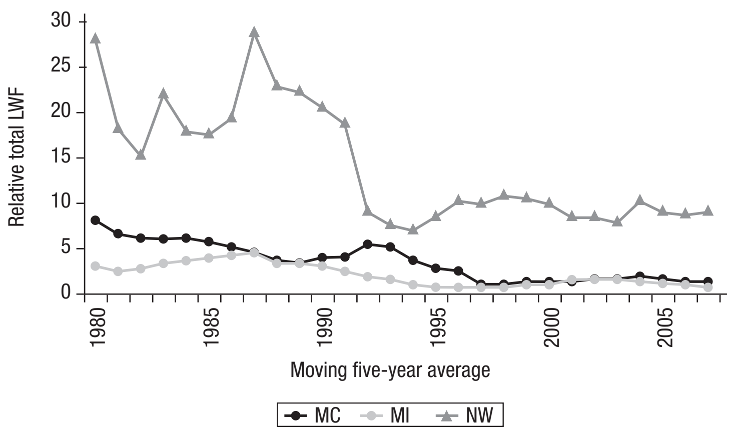

Figure 2. Relative total large wildland fires by regions. (MC: Meditarrenan Coast, MI: Mediterranean Interior, NW: Northwestern Spain).

Table 2 shows the trends in relative total LWF, relative burned area and average size of LWF in relation to wildland fire categories and regions in the studied period (1978-2010). In MC, we observed a significant decrease in relative total number of fires and relative burned area in all wildland fire categories. In MI, we did not find any significant trend in relative burned area and we only found a significant decrease in relative total number of LWF in 100 ha+ category. In NW, the relative total number of LWF decreased in the studied period in 100 ha+ and 250 ha+ wildland fire categories and the relative burned area also decreased in 100 ha+ category. Additionally, we observed and assessed that the relative total number of LWF did not decrease and this number was nearly constant from 1995 to 2010 in all regions (1.3 fires/yr in MC, 1.1 fires/yr in MI and 9.2 fires/yr in NW) as shown in Fig. 2. We also observed that the burned area did not decrease in 1995-2010 period and remained almost constant (802 ha/yr in MC, 642 ha/yr in MI and 2755 ha/yr in NW) such as the number of LWF (Fig. 3). Note that in MC, there is a peak in years close to 1994 and it is caused by mega-fires (*i.e.*, 10,000 ha+) occurred in 1994 and the moving average method moves this disturbance to neighboring years (Fig. 3).

The average size of LWF did not change significantly in the studied period in three regions and three categories (651.72 ha in MC, 493.45 ha in MI and 261.44 ha in NW in 100 ha+ category).

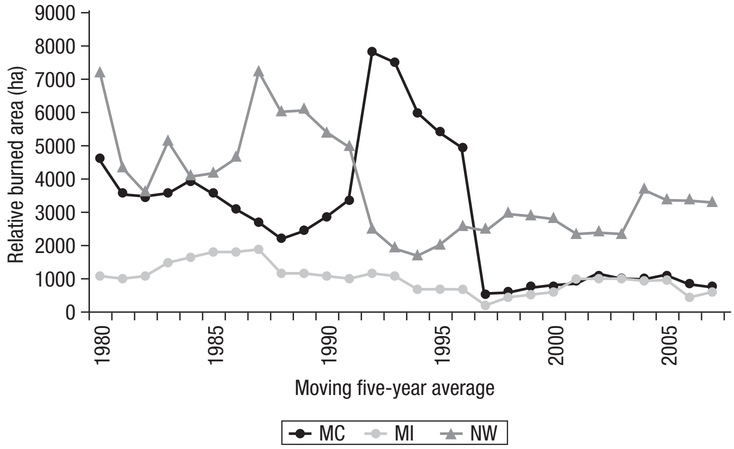

Figure 3. Relative burned area by regions (MC: Meditarrenan Coast, MI: Mediterranean Interior, NW: Northwestern Spain).

The importance of the largest forest fires is very high in terms of relative burned area and, particularly in MC region in which the burned area in 500ha+ wildland fire category account for 79.3% of the total area burned by LWF. In MI, this value decreased to 63.9% and in NW to 35.7%. In both MI and NW, we observed that these values do increase along the study period.

Discussion

After 1995, we observed that relative total LWF and the relative burned area did not decrease and was nearly constant from 1995 to 2010 in all regions. Therefore, it is clear from our results that we are unable to solve the wildland fire problem through allocating more resources to fire suppression.

For the whole time period studied, the relative number of LWF (100 ha+) decreased in all regions (MC, MI and NW). Zavala *et al.,* (2011) studied trends in all fires (small and large fires) in several regions in Spain in a similar time period. Note that we used provinces as independent units and Zavala *et al.*, (2011) employed 10 regions, taking into account regional administrative borders and bio-geographical characteristics. We excluded from our analysis those provinces that do not fit easily in either region as we have defined them (NW, MC and MI). Zavala *et al.,* (2011) found an increase in number of fires in MI provinces series. Spanish Environment Ministry (2006) also perceived this trend in MI from 1996 to 2005. This is mostly due to the small size fires; however, this did not happen in our study about LWF in MI provinces. In MC, we found a significant decrease in the number of LWF and burned area in all wildland fire categories. Zavala *et al.,* (2011) also found this decreasing trend in the number of all fires (small and large fires).

The relative burned area decreased in MC and NW regions in 100 ha+ wildland fire category and only in MC in 250 ha+ and 500 ha+ categories in the study period. However, observing the data in more detail and highlighting the underlying trends in MC and in the other two regions, we detected that after 1995, the decrease in both the number of LWF and the burned area did stop despite the additional investments in technology, roads, water reservoirs, material and human resources in the last 15 years. The mean size did not decrease in any region and the significance of LWF larger than 500 ha is higher in all regions in the recent years. Therefore, fire suppression effectiveness to reduce the effects from LWF is not improving in recent years and, for this reason, Castellnou *et al.* (2010), suggested needed actions to improve fire suppression. These actions may involve learned lessons from past LWF spread; in particular, identifying synoptic weather patterns and critical areas to fire spread. Molina *et al*. (2010), also suggested a need for much better trained fire suppression workers; i.e, improving fire management success through fire behaviour specialists.

Under the actual fire suppression policies and practices in Spain, our data shows that we are unable to further reduce the effects of LWF by spending more money in suppression means (in a reasonable figures) because in last 15 years, the area burned did not decrease in any region. Molina *et al*. (2010), explained that more suppression resources are needed when biomass depletion and the mosaic arrangement of the landscape have collapsed. This is due, in part, to agricultural abandonment and land cover changes that has increased fuel load (Millán *et al*., 1998) and the fuel homogeneity and continuity that are facilitators for both a faster fire propagation and a higher fireline intensity (Pausas *et al.,* 2012; Molina *et al*., 2010; Vega-García and Chuvieco, 2006). Climate change issues are also instrumental and they could be already playing a significant role (Moreira *et al.,* 2011) due to the increase in the number of years with adverse fire weather; *i.e.*, an increase in the length of the fire season and/or more frequent extreme events (Cardil *et al.,*2013; Moriondo *et al*., 2006). In a similar way, Pausas *et al.* (2012), tested the hypothesis that fire regime changed in western Mediterranean Basin during the last century. They compiled a 130-year fire history for the Valencia province (Spain) to assess the role of climate and human-driven fuel variations on the fire regime change. The outcome suggested that there was a major fire regime alteration about the early 1970s in such a way that fires augmented in annual frequency (doubled) and area burned (an order of magnitude). The key driver of this modification was the increment in fuel amount and continuity due to countryside abandonment.

NW is the region more affected in terms of relative total fires and relative burned area in our studied period. This agrees with De Zea Bermudez *et al*. (2009). In MI, these indexes had lower values than in NW. In MC, suppression means reduced the relative total LWF and burned area in our studied period because of strong resources in suppression tasks. However, the decrease in the number of fires and burned area did stop and, therefore, a further decrease in the last years was not able to be produced by the suppression resources.

Suppression expenditure increases with fire size (Liang *et al*., 2012). In SW USA, large fires are 2 percent of the total number of fires but 84 percent of suppression expenses (Gebert and Schuster, 2008). Therefore, limiting fire potential (in terms of area to burn), we can reduce the costs of the fire suppression (Miralles *et al*., 2010). Fire potential can be limited using fire prevention measures, including strategic fuel management actions and resource management plans and limiting human-caused fire occurrences. In Spain, the majority of the fires are human-caused (Padilla and Vega-García, 2011; Ministry of Enviorment, 2009). In Spain, we need more resources allocated to vegetation and fuel management, and should not focus only on increasing wildland fire suppression means. A revisited approach to vegetation and fuel management should include dealing with agriculture field abandonment (limiting shrub encroachment), and addressing the needed thinning in our forest stands (Costafreda-Aumedes *et al*., 2013). Moreover, surface fuel treatments including broadcast prescribed burning are desirable (Moreira *et al.,* 2011; Stephens *et al*., 2009). Lastly, we need to understand that bio-energy (fire wood, wood chips, and pellets) is an opportunity for our forests in Spain, particularly those less profitable as timber sites.

Within Europe, an inter-agency approach must be implemented towards harmonizing the international efforts in reducing the negative consequences of wildfires (Goldammer, 2008, Miralles *et al*., 2010). A better cooperation among regions and countries would be an enormous improvement in the firefighting system. By intensifying material and human resource sharing among all fire agencies (and therefore distributing the suppression means adequately depending on fire risk map or other specific necessities of each moment), we could significantly reduce the suppression expenditure. Additionally, this could improve the training of both professional firefighters and volunteer. In this way, while decreasing the suppression spending, we will be able to allocate more funds for prevention measures to diminish the vulnerability of the forests and wildlands against LWF. This would be a pro-active approach (reducing fire potential by fuel management) instead of trusting only re-active actions (fire suppression).

Conclusions

In all regions (MC, MI and NW), the relative number of LWF (100 ha+) decreased in the study period but the relative burned area only lessened in MC and NW regions. However, after 1995, the number of LWF and burned area remained constant despite the added investments in roads, water reservoirs, technology, material and human resources in all regions. The mean fire size did not decline in any region and the importance of LWF larger than 500 ha was higher in all regions in the recent years. Therefore, fire suppression effectiveness to reduce the effects from

LWF is not improving in recent years. Additional actions are required including learned lessons from past LWF spread, and better trained fire suppression workers.

In recent years, land abandonment have provided fuel load and fuel continuity that enable a more dramatic fire propagation and, similarly climate change have made available some more heat waves and longer fire risk seasons. We have to change our fire management programs and strategies if we want less area burned in the future. We suggest that a change is required in both forest policies and practices to accomplish a more powerfully fuel management. An enhanced implementation of suppression capabilities is also needed. Better inter-agency cooperation agreements are essential to distribute the resources efficiently in the territory to improve the fire suppression systems in three regions in this study.

Acknowledgements

We are grateful to the University of Lleida for supporting this paper through a partial grant to Adrian Cardil to enroll in the PhD program. We also thank Antonio Muñoz from the Ministry of Environment for his help with the EGIF Database.

References

Alvarado E, Sandberg DV, Pickford SG, 1998. Modeling large forest fires as extreme events. Northwest Science 72: 66-75.

Bardaji M, Molina D, 1999. Interregional comparative analysis of wildland fires in Spain. Analisis comparativo interregional de los incendios forestales en la España Peninsular. Investigacion Agraria, Sistemas y Recursos Forestales 8: 151-170.

Brown TJ, Hall BL, Mohrle CR, Reinbold HJ, 2002. Coarse Assessment of Federal Wildland Fire Occurrence Data. Reno, Desert Research Institute. 31 pp.

Cardil A, Molina DM, Ramírez J, Vega-García C, 2013. Trends in adverse weather patterns and large wildland fires in Aragón (NE Spain) from 1978 to 2010, Nat. Hazards Earth Syst. Sci 13, 1393-1399. doi: 10.5194/nhess-13-1393-2013.

Castellnou M, Larrañaga A, Miralles M, Molina DM, 2010. Improving wildfire scenarios: Learning from experience. EFI Research Report, European commission 23: 121-133.

Conedera M, Marcozzi M, Jud B, Mandallaz D, Chatelain F, 1996. Incendi boschivi al Sud delle Alpi: passato, presente e possibili sviluppi futuri. NRP 31 report. Zurich, vdf Hochschulerverlag and ETH. 143 pp.

Costafreda-Aumedes S, Garcia-Martin A, Vega-García C, 2013. The relationship between landscape patterns and human-caused fire occurrence in Spain. Forest System 22(1): 71-81.

De Zea Bermúdez P, Mendes J, Pereira JMC, Turkman KF, Vasconcelos MJP, 2009. Spatial and temporal extremes of wildfire sizes in Portugal (1984-2004). Int J Wildland Fire 18: 983-991.

Eastaugh CS, Vacik H, 2012. Fire size/frequency modelling as a means of assessing wildfire database reliability. Austrian journal of forest science 129: 228-247.

EC, 2008. Forest fires in Europe 2007. Report No 8. European Commission, Joint Research Centre, Institute for Environment and Sustainability. Ispra, Italy. 80 pp.

Ganteaume A, Jappiot M, 2012. What causes large fires in Southern France. For Ecol Manag 294: 76-85.

Gebert KM, Schuster EG, 2008. Forest service fire suppression expenditures in the Southwest. General Technical Report – Pacific Southwest Research Station, USDA Forest Service, 227-236.

Gillett NP, Weaver AJ, Zwiers FW, Flannigan MD, 2004. Detecting the effect of climate change on Canadian forest fires. Geophys Res Lett 31: L18211 1-4.

Goldammer JG, 2008. Towards developing a global wildland fire strategy. General Technical Report – Pacific Southwest Research Station, USDA Forest Service. pp: 683-695.

JRC-IES, 2010. Forest Fires in Europe. European Union, Office for Official Publications of the European Communities, Scientific and Technical Research series, Report Number 11. Luxembourg.

Legendre P, Legendre L, 1998. Numerical ecology. Elsevier. 854 pp.

Liang J, Calkin DE, Gebert KM, Venn TJ, Silverstein RP, 2012. Factors influencing large wildland fire suppression expenditures. Int J Wildland Fire 21: 650-659.

Maselli F, Rodolfi A, Bottai L, Romanelli S, Conese C, 2000. Classification of Mediterranean vegetation by TM and ancillary data for the evaluation of fire risk. Int J Remote Sens 21: 3303-3313.

Millán MM, Estrela MJ, Badenas C, 1998. Meteorological processes relevant to forest fire dynamics on the Spanish mediterranean coast. J Appl Meteorol 37: 83-100.

Miralles M, Kraus D, Molina D, Loureiro C, Delogu G, Ribet N, Vilalta O, 2010. Improving suppression fire capacity. Research Report – European Forest Institute (EFI). pp: 203-215.

Molina D, Castellnou M, García-Marco D, Salgueiro A, 2010. Improving fire management success through fire behaviour specialists. Research Report – European Forest Institute (EFI). pp: 105-119.

Mollicone D, Eva HD, Achard F, 2006. Ecology: human role in Russian wild fires. Nature 440: 436-437.

Moreno JM, Viedma O, Zavala G, Luna B, 2011. Landscape variables influencing forest fires in central Spain. Int J Wildland Fire 20: 678-689.

Moreira F, Viedma O, Arianoutsou M, Curt T, Koutsias N, Rigolot E, Barbati A, Corona P, Vaz P, Xanthopoulos G, Mouillot F, Bilgili E, 2011. Landscape-wildfire interactions in southern Europe: implications for landscape management. J environ manage 92, 2389-2402.

Moriondo M, Good P, Durao R, Bindi M, Giannakopoulos C, Corte-Real J, 2006. Potential impact of climate change on fire risk in the Mediterranean area. Climate Research 31, 85-95.

Mouillot F, Field CB, 2005. Fire history and the global carbon budget: a1° x 1° fire history reconstruction for the 20th century. Glob Change Biol 11, 398-420.

Padilla M, Vega-Garcia C, 2011. On the comparative importance of fire danger rating indices and their integration with spatial and temporal variables for predicting daily human-caused fire occurrences in Spain. Int J Wildland Fire 20, 46-58.

Pausas JG, Fernández-Muñoz S, 2012. Fire regime changes in the Western Mediterranean Basin: from fuel-limited to drought-driven fire regime. Climatic Change 110, 215-226.

Pereira MG, Trigo RM, Camara CCd, Pereira JMC, Leite SM, 2005. Synoptic patterns associated with large summer forest fires in Portugal. Agric For Meteorol 129, 11-25.

Podur JJ, Martell DL, Knight K, 2002. Statistical quality control analysis of forest fire activity in Canada. Can J Forest Res 32, 195-205.

Pyne, 1997. America's fires: management on wildlands and forests. Forest History Society: Durham, NC, 54 pp.

Salis M, Ager AA, Arca B, Finney MA, Bacciu V, Duce P, Spano D, 2012. Assessing exposure of human and ecological values to wildfire in Sardinia, Italy. Int J Wildland Fire.

Spanish Environment Ministry, 2006. Forest fires in Spain. www.magrama.gob.es.

Spanish Environment Ministry, 2009. Forest fires in Spain. www.magrama.gob.es.

Stephens SL, 2005. Forest fire causes and extent on United States Forest Service lands. Int J Wildland Fire 14, 213-222.

Stephens SL, Moghaddas JJ, Edminster C, Fiedler CE, Haase S, Harrington M, Keeley JE, Knapp EE, Mciver JD, Metlen K, Skinner CN, Youngblood A, 2009. Fire treatment effects on vegetation structure, fuels, and potential fire severity in western U.S. forests. Ecol Appl 19, 305-320.

Stocks BJ, Mason JA, Todd JB, Bosch EM, Wotton BM, Amiro BD, Flannigan MD, Hirsch KG, Logan KA, Martell DL, Skinner WR, 2003. Large forest fires in Canada, 1959-1997. J Geophys Res D Atmos 108, FFR 5-1 FFR 5-12.

Thonicke K, Venevsky S, Sitch S, Cramer W, 2001. The role of fire disturbance for global vegetation dynamics: coupling fire into a Dynamic Global Vegetation Model. Global Ecol Biogeogr 10, 661-677.

Trigo RM, Pereira JMC, Pereira MG, Mota B, Calado MT, DaCamara CC, Santo FE, 2006. Atmospheric conditions associated with the exceptional fire season of summer 2003 in Portugal. Int J of Climatol 26, 1741-1757.

Vega-García C, Chuvieco E, 2006. Applying local measures of spatial heterogeneity to Landsat-TM images for predicting wildfire occurrence in Mediterranean landscapes. Landsc Ecol 21, 595-605.

Zavala G, Urbieta IR, Rieiro I, Bedia J, Gutiérrez JM, Moreno JM, 2011. Trends in number of fires and burned area and their relationships with climatic variables across regions in Spain during 1974-2008. *In:* International Conference on Fire Behaviour and Risk, Alguero (Italy), October 4-6, 2011.