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Technical note

Geospatial analysis of woodland fire occurrence and recurrence in Italy

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Abstract - This technical note aims to exemplify the potential of annual time series of wildfire geodatasets to quantify fire occurrence and recurrence amongst different woodland types at large scale, under an international forestry perspective. The study covers a time series of areas affected by wildfire between 2007 and 2014 in Italy. A GIS operation of geometric intersection was carried out between time-series, geo-referred data of burned areas and synchronic Corine Land Cover maps. Mediterranean pine forest, high maquis, transitional woodland-shrub and high oro-Mediterranean pine forest are the woodland types most preferred in terms of fire occurrence and recurrence. Large fires and megafires hold a significant share of total burned area. An unexpected finding is the huge impact of fires in wildland-urban-interface areas. The proposed analysis provides spatial information that is central to any approach to fire management at large scale. Research findings provide support that can be used e.g. for positive and normative advancements, basically prioritization of fire prevention, suppression measures, economic incentive allocation, and sustainable land management in peri-urban districts.

Keywords - Wildfire, woodland type, geodataset, large fires, wildland-urban interface

Introduction

Wildfires are major disturbances in Mediterranean ecosystems worldwide. Wildfires affect natural resources and ecosystem services (e.g. tourism, local development, soil protection, biomass production, carbon sequestration, habitat provision), but also strategic policies and governance concerning the protection and enhancement of forest landscapes (Carmo et al. 2011, Kolström et al. 2011, Corona et al. 2015). Over the last few decades, the massive abandonment of, and the reduced land-use pressure on, rural lands have determined extensive woodland and shrubland re-colonization and fuel accumulation in many areas of Mediterranean Europe (Moreira et al. 2009, Moreira et al. 2011).

In regions such as the Mediterranean basin, almost all wildland fires are human-caused (Ganteaume et al. 2013). The number and size of wildfires is significantly influenced by the type, patterns and conditions of vegetation and fuels. For instance, the fuels produced by the main tree species that build up the forest physiognomy primarily drive its "baseline" flammability level (Xanthopulos et al. 2012, Corona et al. 2014), i.e. the relative ease by which a fuel will ignite and burn with a flame (Stacey at al. 2012, Fares at al. 2017). Xanthopoulos et al. (2012) proposed an assessment framework to assign a baseline flammability index to vegetation classes of the European Forest Types classification (Barbati et al. 2007, Barbati et al. 2014). Certain woodland types (e.g. shrublands or conifers) are at much greater risk of being affected by fire than other types (i.e. greater fire proneness or fire incidence), because of differences in forest management, vegetation structure, fuel load composition and proximity to human activities, all intended as causes of fires ignition (Moreira et al. 2011, Ganteaume et al. 2013, Barros and Pereira 2014, Oliveira et al. 2014, Pereira et al. 2014). In addition, the growing Wildland Urban Interface (WUI, e.g. Lampin-Maillet et al. 2010) poses new challenges to fire management, in terms of increase of fire ignition by human activities (*risk*), and of threats to local communities and properties (*vulnerability*).

A proper quantification of fire occurrence and recurrence amongst different woodland types is therefore essential to quantify need and priorities in fire management (Vazquez et al. 2015). The fire proneness of land cover types in Mediterranean Europe has been investigated in several studies (e.g. Nunes et al. 2005, Bajocco and Ricotta 2008, Moreira et al. 2009, Carmo et al. 2011, Marques et al. 2011, Barros and Pereira 2014; Oliveira et al. 2014, Pereira et al. 2014, Salvati et al. 2015). Earlier studies have highlighted the need to connect burned

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areas' perimeters to fire affected land cover types, in order to gain an understanding of differences in fire proneness amongst woodland types (e.g. Gonzalez et al. 2006, Silva et al. 2009, Corona et al. 2014, Oliveira et al. 2014). However, at least to our knowledge, no published study has addressed fire recurrence at country or regional scales in Mediterranean woodlands using annual time series of the wildfires perimeters, despite the most critical effects on ecosystem resilience are produced by recurrent fire events with short return periods (Moreira et al. 2011, Ricotta and Di Vito 2014, Barbati et al. 2015).

Wildfire geo-databases (i.e. geometry and topology of burnt areas or ignition point data) have a high potential to qualify fire occurrence and recurrence amongst different woodland types over large areas, under an international forestry perspective. This kind of information is currently available in many Countries of Mediterranean Europe (Chiriacò et al. 2013). In Italy, the National Forest Service (Corpo Forestale dello Stato, CFS) and the Forest Services of autonomous Regions have provided aggregated data on wildfires since 1970. A vector geodataset of the areas affected by wildfires (forest and rural areas), recorded by ground-based GPS surveys, is currently available for the years 2007-2014. The dataset currently covers 17 of the 20 EU-NUTS2 level administrative units of Italy (i.e. Sardinia, Sicily and all the Regions with ordinary statute), totaling 95% of the area burned during this period.

This technical note examines Italy as a case study to exemplify the potential of very detailed time series analysis of wildfire geodatasets for addressing questions that are central to any approach to fire management at large scale: which woodland types are most prone to fire recurrence? Which woodland types are most affected by WUI fires, large fires and megafires? Detailed evidence-based answers to such questions have practical application for fire management prioritization at country and local levels, and even for stimulating legislative, planning and operational advances in fire protection.

Materials and methods

A Corine Land Cover (CLC) complete database has been chosen as a reference land cover map (CLC 2006; CLC 2012; EEA 2007). CLC is an European database in vector format available for the reference years 1990, 2000, 2006 and 2012; the minimum mapping unit is 25 ha and mapping technology is based on computer assisted visual interpretation of satellites images. CLC fourth hierarchical level, introduced in Italy since 2000, maps forest and semi-natural areas with a higher thematic detail compared to the standard CLC (ISPRA 2010), distinguishing, namely, the different physiognomies of woodland types reported in Table 1.

A GIS operation of geometric intersection was carried out between 2007-2011 wildfire perimeters and the CLC 2006 geodataset and between 2012-2014 wildfire perimeters and the CLC 2012 geodataset. The same method, using CLC 2006 only, was applied to identify repeatedly burned areas in the period 2007-2014.

Following San-Miguel-Ayanz et al. (2013), in this work we have considered large fires those larger than 100 hectares and megafires those larger than 500 hectares. Moreover, in order to locate WUI fires, a buffer zone of 200 meters from urban settlements has been delineated, according to the distance defined at national level for human settlements protection by the Italian Civil Protection Department (Presidenza Consiglio Ministri 2007). A similar definition of WUI has been adopted by other Mediterranean countries (e.g. Modugno et al. 2016).

Burned Area Selection Ratio (BASR) index has been chosen to measure wildfires incidence by woodland type. BASR is defined as the ratio between percentage of burned area of a given woodland type compared to the total burned woodland area and the percentage of the area of the woodland type compared to the total woodland area:

$$BASR = \frac{A_b/T_b}{A_r/T_r}$$

where A_b is the burned area of the considered woodland type, T_b is the total burned woodland area, A_r is the area of the considered woodland type and T_r is the total woodland area.

BASR is founded on the principle of resource selection function (for previous relevant applications to forest fires, see e.g. Bajocco and Ricotta 2008, and Pezzati et al. 2009). If BASR for a given woodland type equals 1, then that type burned in proportion to its wide spreadness on the territory. If BASR is higher than 1, the type burned more often than expected due to chance, thus indicating fire preference. Conversely, if BASR is lower than 1, the type burned less than expected (i.e. fire avoidance).

BASR has been also used here for characterizing large fires and megafires and for fire recurrence analysis. In the first two cases, numerator consists of the ratio between burned area of woodland type and total woodland burned area of a given kind of fires. In the case of fire recurrence, numerator consists of the ratio between area affected by repeated burning of a given woodland type and the total area affected by repeated burning in woodlands.

Results

Since 1970, in Italy 46% of wildfires has occurred in the woodlands, with an annual mean surface of 48 700 ha. Annual mean number of fires has been 8700, with a decrease of about one third since the year 2000 compared to previous decades. The most critical situations were recorded in 1985 for the number of fires (18,664) and in 2007 for the wooded burned area (116,602 ha).

During the study period, the total burned area was 669 375 ha, corresponding to 2.4% of the land in Italy. The most fire-affected land cover class is scrub and/or herbaceous vegetation associations (35%), while forests represent 22% of the burned area (Fig.1).

Between 2007 and 2014 fires have affected all woodland types. According to Mann Kendall non-parametric test (Kendall 1975), statistically significant decreasing trends ($p<0.05$) have occurred in most woodland types as concern total burned area, number of fires and average area of fires. Exotic broad-leaved forest and Mediterranean pine forest do not show any trend for total burned area and number of fires.

The incidence of fires varies substantially across woodland types (Tab.1). In absolute terms, transitional woodland-shrub and deciduous oak forest have recorded the highest values both in terms of number of wildfires (5 685 and 6 843, respectively) and of total burned area (50 989 and 44 544 hectares, respectively). Larch and arolla pine forest and high oro-Mediterranean pine forest present the highest value of average burned area for fire (10.5 and 11.3 hectares, respectively).

BASR ranges from 0.04 to 3.46 (Fig.2). The rate of fire incidence in deciduous oak, hygrophilous and broad-leaved evergreen forest types is balanced with their land coverage, with a BASR value close to 1, while wildfire shows a strong preference for Mediterranean pine forest (BASR 3.46) and, to a lesser extent, high maquis, transitional woodland-shrub and high oro-Mediterranean pine forest (BASR around 2). Spruce/fir and larch and arolla pine forest are the least affected types, in both absolute and relative terms.

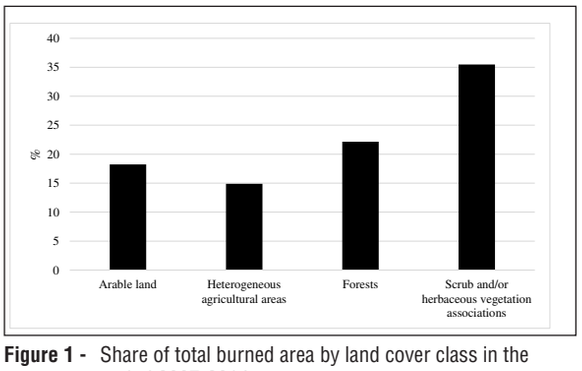

Figure 1 - Share of total burned area by land cover class in the period 2007-2014.

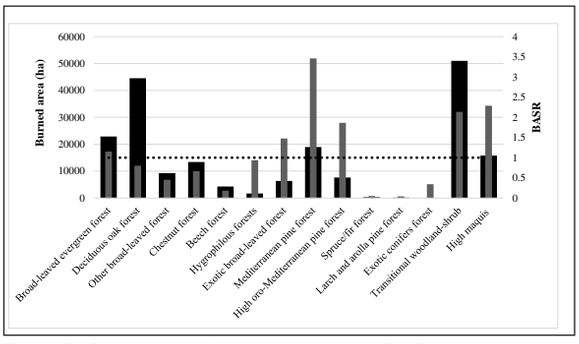

Figure 2 - Burned area (black histogram) and BASR values of burned area (grey histogram) by woodland type; the dashed line represents BASR=1.

Table 1 - Number of wildfires, total burned area, average burned area and contribution by large fires (>100 ha) and mega-fires (>500 ha) by woodland type in the period 2007-2014.

Woodland type	Number of fires (No.)	Total burned area (ha)	Average burned area (ha)	Large fires area (ha)	Megafires area (ha)
Broad-leaved evergreen forest	2 868	22 880	8.0	12 748	7 575
Deciduous oak forest	6 843	44 544	6.5	19 017	6 170
Other broad-leaved forest	1 405	9 254	6.6	3 761	1 287
Chestnut forest	2 189	13 412	6.1	4 118	758
Beech forest	542	4 284	7.9	2 199	418
Hygrophilous forests	307	1 667	5.4	419	5
Exotic broad-leaved forest	786	6 349	8.1	2 411	286
Mediterranean pine forest	1 892	18 975	10.0	11 589	5 855
High oro-Mediterranean pine forest	677	7 642	11.3	4 384	2 311
Spruce/fir forest	61	330	5.4	237	0
Larch and arolla pine forest	14	147	10.5	130	0
Exotic conifers forest	19	67	3.5	0	0
Transitional woodland-shrub	5 685	50 989	9.0	21 337	6 869
High maquis	1 534	15 765	10.3	9 598	5 899

During the study period, 1023 large fires (i.e. fire size >100 ha), corresponding to 317 996 hectares, have occurred in Italy and 115 of these are megafires (i.e. fire size >500 ha), corresponding to 142 946 hectares. Although large fires account for 2.3% of total fires, they represent the 47 % of total burned area. Similarly, megafires represent 0.25% of total fires, but 21 % of total burned area. Table 1 and Figure 3 highlight a breakdown by woodland types of the total area affected by large fires and mega-fires with respect to total burned area. Transitional woodland-shrub, deciduous oak forest and broad-leaved evergreen forest are the woodland types most affected by extensive fires. In Mediterranean pine

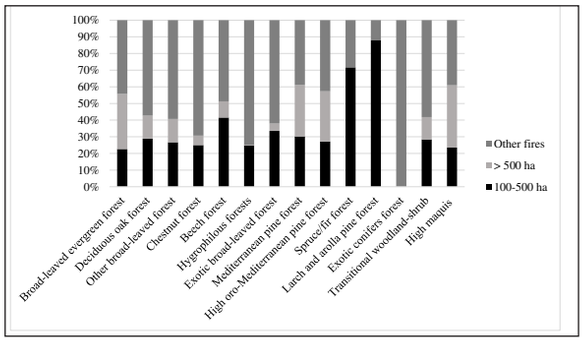

Figure 3 - Contribution of large fires and megafires to the total burned area by woodland type.

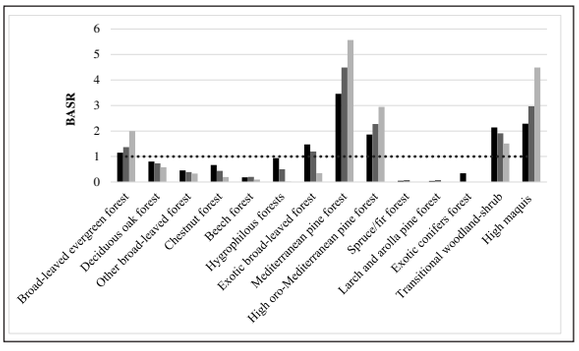

Figure 4 - BASR values of burned area (black histogram), BASR values of large fires (dark grey histogram) and BASR values of megafires (light grey histogram) by woodland type; the dashed line represents BASR=1.

forests, high maquis, spruce/fir forests and larch and arolla pine forests the contribution of large and megafires exceeds 60 % of total burned area (Fig. 3). A comparison amongst the BASR values referred to total fires, large fires and megafires is shown in Figure 4. In the case of Mediterranean pine forest, high oro-Mediterranean pine forest and high maquis and transitional woodland-shrub all such values are greater than 1, and even much higher in the case of megafires and large fires, except for transitional woodland-shrub.

Overall, 5 411 woodland fire events, for a total of 143 850 hectares, have affected WUI space. These events represent 21% of total burned area and 12% of fire events number. Broad-leaved evergreen forest, transitional woodland-shrub, deciduous oak forest and high maquis have the highest values in terms of burned area (Tab. 2). The contribution to the total burned area is higher than 20% in high maquis, spruce/fir forest, broad-leaved evergreen forest and Mediterranean pine forest types.

As shown in Figure 5, fire recurrence is a phenomenon that affects primarily scrub and/or herbaceous vegetation types (44%), but also a significant proportion of forests (18%). During the 8 years covered by the time series, 19 396 hectares of woodlands have been affected by at least two fire events (9% of the woodlands burned area), of which 2 038 hectares burned more than twice (0.95% of woodland burned area). Larch and arolla pine forest type, spruce/fir forest and exotic conifers forest types are negligibly affected by fire recurrence, while transitional woodland-shrub is the most affected type (6 137 hectares), followed by deciduous oak forests (4 169 hectares), in the case of forest areas burned twice, and by Mediterranean pine forests (393 hectares) in the case of areas with more than two fire events (Tab. 2). The contribution of repeatedly burned area to total burned area is greater than 10% in transitional woodland-shrub, Mediterranean pine forests and hygrophilous forests. Mediterranean pine forest presents the highest values of BASR (i.e. 3.4), in terms of repeatedly burned area (Fig. 6), followed by transitional woodland-shrub and

Table 2 - Burned areas in the Wildland-Urban Interface and fire recurrence by woodland type.

	WUI fires		Fire recurrence		
Woodland types	**Area**	**Share of total burned area**	**Repeatedly burned area**	**Share of total burned**	**More than 2 fire events**
	(ha)	**(%)**	**(ha)**	**(%)**	**(ha)**
Broad-leaved evergreen orest	6 476	28.3	1 344	5.9	120
Deciduous oak forest	5 413	12.2	4 169	9.4	300
Other broad-leaved forest	878	9.5	641	6.9	59
Chestnut forest	1 904	14.2	1 159	8.6	105
Beech forest	452	10.6	83	1.9	3
Hygrophilous forests	96	5.8	206	12.3	30
Exotic broad-leaved forest	306	4.8	754	11.9	54
Mediterranean pine forest	4 830	25.5	1 736	9.1	393
High oro-Mediterranean pine forest	815	10.7	575	7.5	45
Spruce/fir forest	111	33.5	9	2.9	1
Larch and arolla pine forest	6	4.3	0	0.0	0
Exotic conifers forest	0	0.0	6	9.1	0
Transitional woodland-shrub	9 619	18.9	6 137	12.0	766
High maquis	5 059	32.1	1 105	7.0	78

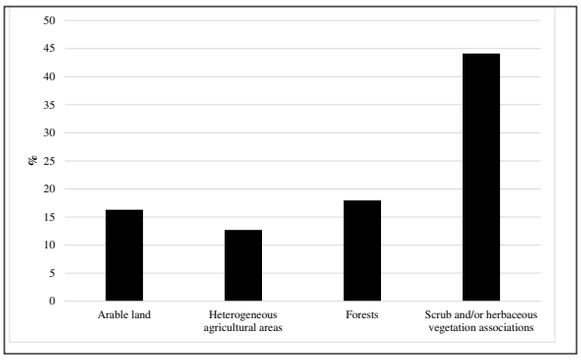

Figure 5 - Share of total repeatedly burned area by land cover class in the period 2007-2014.

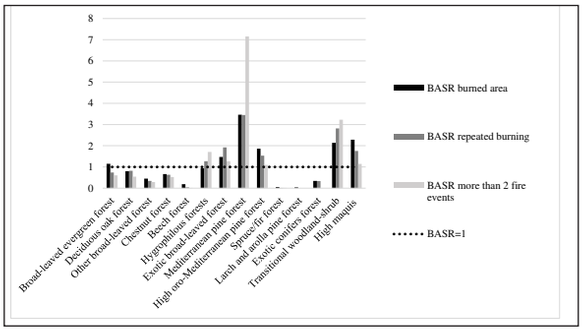

Figure 6 - BASR values of total burned area (black histogram), BASR values of total repeatedly burned area (dark grey histogram) and of repeatedly burned area with more than 2 fire events (light grey histogram) by woodland type; the dashed line represents BASR=1.

exotic broad-leaved forest (respectively, BASR = 2.8 and BASR = 1.9). In the case of area with more than two fire events Mediterranean pine forests are by far the most affected (BASR = 7.2), followed by transitional woodland-shrub (BASR = 3.2). 75 % of large fires and 86% of megafires have been affected by fire recurrence. Repeated burning affects 12% and 9% of the areas burned by large fires and megafires, respectively.

Discussion

Our study demonstrates how time series analysis of wildfires perimeters can help to figure out differences in fire occurrence and recurrence across different woodland types, over relatively large areas. Sinergy between administrative data (wildfire cadastre) and land cover maps (Corine Land Cover initiative) is particularly relevant in this case for identification of vulnerable areas to forest fires. In Italy, Mediterranean pine forest is the most preferred by fire, followed by high maquis, transitional woodland-shrub and high oro-Mediterranean pine forest. Fire selectivity is in line with previous research findings indicating that Mediterranean coniferous forests show the highest fire incidence compared with other woodland types (e.g. Gonzalez et al. 2006, Silva et al. 2009, Barros and Pereira 2014). The same types, with the addition of broad-leaved evergreen forest, have also the highest fire incidence for large fires. Thus, for these woodland type fire incidence does not change with fire size.

Fire recurrence affects Mediterranean pine forest too, followed by transitional woodland-shrub, high maquis, and high oro-Mediterranean pine forest. The high incidence of recurrent fire events in Mediterranean pine forest can lead to severe effects in terms of soil and vegetation degradation processes. Despite the high post-fire resilience, regeneration of Mediterranean pines may fail when time lag between fires is so short (Pausas et al. 2009, De las Heras et al. 2012). Even the high fire recurrence in transitional shrub-woodland requires a careful land management, especially where such woodland type represents a stage of forest succession, as most often happens in Italy. Repeated fire disturbance may hamper or even reverse vegetation dynamics, and ultimately leads to land degradation.

In the considered period, there is an overall decreasing trend of total burned area, number of fires and average burned area. Our findings agree with the results by Turco et al. (2016) in the case of burned area. As concerns the trend of fire number, findings from previous studies are relatively controversial: Turco et al. (2016) ascribe these differences to the different methods, datasets and studied periods. The significant declining trend here observed can be mainly explained by improvements of fire prevention and suppression measures, even under a fire management governance perspective (Corona et al. 2015), as well as by progresses in public awareness and education occurred in the last decade.

Not surprisingly, large fires and megafires hold a significant share of total burned area, as observed over all the Mediterranean Europe (San-Miguel-Ayanz et al. 2013). On the other hand fire recurrence does not seem to affect such areas with an incidence higher than that of other burned areas.

A perhaps unexpected finding is the huge impact of fires in WUI areas, as concern both their with respect to total burned area (21%) and their average size, that is 1.7-fold larger than the average size of all fires. Our outcome is in accordance with Modugno et al. (2016) that showed a higher frequency of large fires in WUI areas in Italy as in other Mediterranean countries (e.g. Spain, France). This calls upon more and more fire management to come to terms with fire prevention in order to more effectively tackle such complex issue in the WUI, e.g. prioritally allocating there fire suppression resources, planning fuel modification treatments and educational programs.

Conclusions

The analytical approach here applied can be easily replicated under an international forestry perspective, e.g. in other countries where forest type maps and annual time series of wildfire perimeters are available on large scales. This technical note has shown examples on how to unlock the power of such tools whose information potential becomes even more higher as the time window of available data becomes longer.

The spatial analyses allow quantitative assessment of the phenomenon, providing information (e.g. BASR) that can be used e.g. for advancements in research (e.g. risk models), prioritization of fire

prevention, suppression measures, economic incentive allocation, and landscape and peri-urban planning, as shown for WUI which has proven to have an unexpectedly huge impact in Italy. Ultimately, such analyses support basic knowledge for evidence-based understanding and management of fires, with special reference to those with short return period which are one of the main socio-ecological factors influencing the state and dynamics of Mediterranean woodlands (Filotas et al. 2014, Moreira et al. 2011).

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