Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2017-359
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Discussion started: 7 November 2017

Global assessment of land cover changes and rural-urban interface in Portugal

Marj Tonini[1], Joana Parente[2], Mario Pereira[2]

[1]Institute of Earth Surface Dynamics (IDYST), Faculty of Geosciences and Environment, University of Lausanne, Lausanne, 1000, Switzerland
[2]Centro de Investigação e de Tecnologias Agro-Ambientais e Biológicas (CITAB), Universidade de Trás-os-Montes e Alto Douro (UTAD), Vila Real, 5000-801, Portugal

Correspondence to: Marj Tonini (marj.tonini@unil.ch)

Abstract. The wildland-/rural-urban interface (WUI/RUI) is a particularly important aspect of the fire regime. In Mediterranean basin most of the fires in this pyro region are caused by humans and the risk and consequences are particularly high due to the close proximity to population, human infrastructures and urban areas. Population increase, urban growth and the rapid changes in land use incurred in Europe over the last 30 years has been unprecedented, especially nearby the metropolitan areas, and some of these trends are expected to continue. Associated to high socioeconomic development, Portugal experienced in the last decades significant land cover/land use changes (LCLUC), population dynamics and demographic trends in response to migration, rural abandonment, and ageing of rural population. This study aims to assess the evolution of RUI in Portugal, from 1990 to 2012, based on LCLUC providing also a quantitative characterization of forest fires dynamics in relation to the burnt area. Obtained results disclose important LCLUC which spatial distribution is far from uniform within the territory. A significant increase in artificial surfaces is registered nearby the main metropolitan communities of the northwest and littoral-central and southern regions, whilst the abandonment of agricultural land nearby the inland urban areas leads to an increase of uncultivated semi-natural and forest areas. Within agricultural areas, heterogeneous patches suffered the greatest changes and are the main contributors to the increase of urban areas. Moreover these are among the LCLU classes with higher burnt area, reasons why heterogeneous agricultural areas have been included in the definition of RUI. Finally, the mapped RUI's area, burnt area and burnt area within RUI allow to conclude that, form 1990 to 2012 in Portugal, RUI increased more than two thirds and total burnt area decreased one third. Nevertheless, burnt area within RUI doubled, which emphasize the significance of RUI for land and fire managers. This research provides a first quantitative global assessment of RUI in Portugal and presents an innovative analysis on the impact of land use changes on burnt areas.

1 Introduction

Fires can be considered a dynamical ecological factor and an efficient agricultural and landscape management tool but, more recently, they are increasingly considered an hazard (Bond and Keeley, 2005; Fernandes and Botelho, 2003; Hardy, 2005; Moreno and Oechel, 2012; Pyke et al., 2010; Van Wagtendonk, 2007). Mediterranean area is particularly affected by forest fires, mainly a consequence of its type of climate and vegetation cover fire proneness (Amraoui et al., 2015; Pellizzaro et al., 2012). In the European countries included in the Mediterranean Basin – Spain, Portugal, Italy and Greece – fire incidence had dramatically increased in the last decades and the average total burnt area has quadrupled since the 60's (San-Miguel-Ayanz et al., 2012). Portugal stands out from this group of countries for presenting the highest number of forest fires and for being the third most affected country in terms of burnt area in the last three decades (Pereira et al., 2014; San-Miguel-Ayanz et al., 2016). The main sources of ignition in the Mediterranean Europe is associated to human activities (>95%) while only a small percentage of fires (e.g., 1% in Portugal to 5% in Spain) are naturally caused by lightings (Ganteaume et al., 2013; Mateus and Fernandes, 2014; Vilar et al., 2016). In Portugal the primary cause of human-related fires is due to negligent or intentional ignition (Parente et al., 2017). A spatial-temporal analysis of these hazardous events discovered here a clustered pattern with hot spots concentrated in the north-west and center and lower densities of fires in the southern area (Pereira et al., 2015; Tonini et al., 2017): this finding indicates the need for a deeper characterization of fire distribution with the surrounding socio-economic and environmental factors.

Forest fires are assuming an increasing importance especially in relation to urban sprawl, which makes it difficult to outline a border between human infrastructures and forest, in order to protect better this vulnerable interface. The modern urban landscape in Europe has a typical star-shaped spatial pattern (Antrop, 2000) where wedge of unchanged countryside can persist between lobes of urban development (Antrop, 2004). The diffuse urban expansion along radiating access roads through industrial zones and dispersed housing, as well as the growth of peri-urban centers in previously rural areas, leaves gaps in suburban/exurban space of urban agglomerations (Trigal, 2010). In this context, rural areas nearby and interconnected to large cities and urban areas remain almost unchanged, so that populations and activities, described either as "rural" or "urban", are closely linked and their distinction is often arbitrary (Tacoli, 1998).

The increase of fire incidence has been considered mainly a consequence of climate and lands use changes (Ferreira-Leite et al., 2016; Moreira et al., 2011). Land use changes are at the origin of landscape patterns and dynamics which have a strong influence on forest fires and vice-versa (Silva et al., 2011). On the one hand, each vegetated land cover type, such as agricultural, natural and semi-natural vegetation cover, has a specific fire proneness depending on the differences in vegetation structure, moisture content and fuel load composition (Barros and Pereira, 2014; Oliveira et al., 2014; Pereira et al., 2014). Further, fire occurrence affects landscape dynamics by changing the vegetation structure and soil processes according to the fire adaptations of each ecosystem (Pausas et al., 2009; Viedma, 2008).

In Europe, population and urban growth significantly increase during the late XX century, which helps to understand the rapid land cover and land use change (LCLUC) (Noronha Vaz et al., 2012). In European Mediterranean countries LCLUC are mainly characterized by the increasing migration to urban centers at cost of the abandonment of rural areas, and by the expansion of costal tourism (Alodos et al., 2004; Tedim et al., 2016). The abandonment of low-intensity agricultural lands and grazing practices also caused the increase of forest cover and scrubland vegetation (Millington et al., 2007; Poyatos et al., 2003). Urbanization is defined as the process involving the inhomogeneous transformation of rural and natural landscape into urban and industrial areas, driven by physical conditions and accessibility to the area (Antrop, 2000). The recent urbanization process is characterized by the urban sprawl land use zoning plans, founded on new peri-urban settlements, usually promoted by neighboring municipalities of the central metropolitan city, which is occurring at an unprecedented rate, far beyond the rate of growth of the urban population (Trigal, 2010). The dynamic conversion between rural and urban spaces can become extremely complex (Strubelt and Deutschland, 2001). Urbanization generates the centralization of certain area by changing the land use, population density, economical activities and transportation network. Expansion and reconfiguration of urban and metropolitan areas comprise the processes of suburbanisation and periurbanisation, mainly of coastal regions and, in the interior, of agricultural areas (Trigal, 2010). This complex process causes also the abandonment of remote rural areas with poor accessibility, population ageing and death, allowing the expansion of natural vegetation and forest (Antrop, 2004).

Significant land use changes were observed in Portugal. Pereira et al. (2014) showed that Portugal presents the highest relative changes of land use among the southern European countries between 2000 and 2006, namely a significant increase in artificial surfaces and sclerophyllous vegetation and a decrease in forest area and natural grasslands, due to rural abandonment, urbanization and fires. According to Diogo and Koomen, (2012) and Van Doorn and Bakker, (2007), the urbanization of coastal areas is in concomitance with the abandonment of agricultural land in marginal areas and seems to prevails between 1990 and 2000 while, in the more recent investigated period (2000 – 2006), the intensification of agriculture in areas where irrigation was available is a predominant process.

The area of interface between the wildland and the urban space, known as Wildland-Urban Interface (WUI), was deeply investigated by researchers and fire managers in the last decades. According with United States Department of Agriculture (USDA), WUI was defined as the area "where humans and their development meet or intermix with wildland fuels" (Stewart et al., 2007). Within the WUI fire can spread readily among vegetation fuels and urban structures. It is well known that anthropogenic features, such as the distance to roads and houses, negatively influence the probability of forest fire occurrence, while the population density positively affects it (Conedera et al., 2015; Haight et al., 2004; Hammer et al., 2009; Lampin-Maillet et al., 2010; Radeloff et al., 2005; Stewart et al., 2007), so that the spatial extension of the WUI is determined by these factors. Urbanization and the consequent abandonment of rural areas caused the expansion of this interface, increasing the probability that forest fires affect houses and infrastructures (Theobald and Romme, 2007; Zhang et al., 2008). Researchers developed several geospatial methods for defining and mapping WUI. In Europe, Lampin-Maillet et al. (2010) proposed an approach and based on the combination of four types of building configuration and three classes of vegetation structure, tested in the south of France. Following this model, Bouillon et al. (2012) developed WUImap, a software tool for mapping WUI in the Mediterranean region successfully applied in south-eastern France, eastern Spain and Sardinia in Italy. In the Alpine context, geospatial approach to map the WUI were developed in Switzerland by Conedera et al. (2015) and in France by Fox et al. (2015). Pellizzaro et al., (2012) characterized and mapped WUI in Sardinia, Italy, using temporal steps of about 10 years from 1954 and 2008. Other studies focus on additional aspects related to the WUI, namely hazard/risk, vulnerability and fire risk management in Spain (Badia et al., 2011; Galiana-Martin et al., 2011; Herrero-Corral et al., 2012), fuel and fire modelling in France (Cohen et al., 2003; Pugnet et al., 2013). Most of these studies are local, performed at house-spatial-scale or for small regions within each country.

The WUI concept has to be redefined especially in the European context, taking into account the rural-urban process and associated landscape changes. Recent studies identified the Rural-Urban Interface (RUI) as the most fire prone areas in Mediterranean countries (Badia-Perpinyà and Pallares-Barbera, 2006; Catry et al., 2010; Moreira et al., 2009). In the present study, RUI is considered and defined for Portugal: the main objective is to investigate RUI's spatio-temporal evolution at large scale from 1990 up to 2012. Secondly, it provides a quantitative characterization of forest fires occurred here in relation to the burnt areas and land covers' evolution. This research provides a first quantitative global assessment of RUI in Portugal and presents an innovative analysis on the impact of LCLUC on burnt areas.

2 Study area

Continental Portugal (c.a. of 90,000 km^2) is located in the southwest of Iberian Peninsula, bathed by the Atlantic Ocean on the south and west coast and bounded by Spain at north and east. The spatial distribution of the population (about 10,6 million habitants) presents higher density in the north-western and southern coastal areas as well around the major cities (Fig. 1). Tagus River divides the country into two regions with approximately similar area but very different in terms of several biophysical and human drivers (Fig. 2) (Parente et al., 2016; Pereira et al., 2015). The north region is characterized by a temperate climate ,with dry and warm summer (Kottek et al., 2006; Peel et al., 2007), altitude ranging from sea level to about 2000 m and mean water course density of about 0.65 km/km^2. According with CORINE Land Cover (hereafter, CLC) inventory 2012 (EEA, 2016), 54% of north's area is covered by forests and scrublands, 40% is used for agriculture and about 5% is occupied by artificial surfaces (Fig. 2). The region south of Tagus River is characterized by temperate climate with dry and hot summer (Kottek et al., 2006; Peel et al., 2007), altitude between sea level and about 1000 m, mean water course density of about 0.58 km/km^2. According with CLC

2012 inventory, 56% of this area is occupied by agricultural areas, 40% by forest and semi-natural areas, and only 2% by artificial surfaces (Fig. 2).

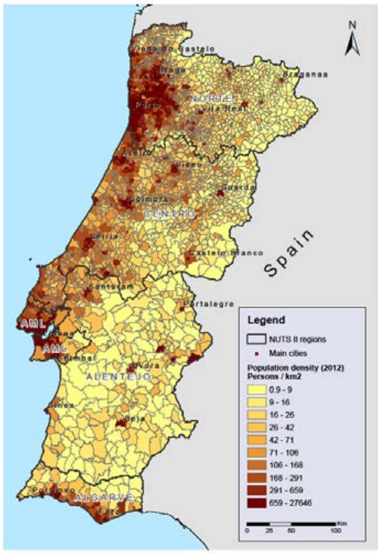

Figure 1 - Population density at parish level (INE, 2012) in the mainland Portugal, with the location of the of the major cities. NUTS refers to regions according with Nomenclature of Territorial Units for Statistics level II (Eurostat, 2017; Santos, 2014).

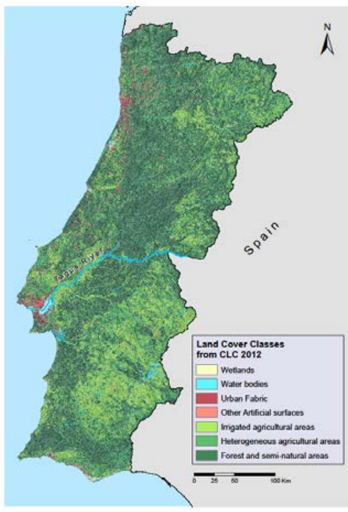

Figure 2 –Land cover of mainland Portugal based on the second level of CORINE land cover inventory 2012 (EEA, 2016)

3 Data and methodology

Forest fires digital data came from the National Mapped Burned Area dataset (NMBA), provided by the Portuguese Institute of Conservation of Nature and Forests (ICNF) for the period 1990-2015. The official NMBA was complemented with data from 1975 to 1989, provided by the research team from the Institute of Agronomy (*Instituto Superior de Agronomia*, ISA) which produced the official database (Barros and Pereira, 2014; Oliveira et al., 2012). The final fire database cover the 1975-2015 period and comprise about 49,000 fire events for a total of burnt area (BA) of 4,430,000 ha. The annual fire perimeter maps result from semiautomatic supervised image classification (Gorte, 1999) performed with the classification and regression trees algorithm of Breiman et al., (1984) on late summer-autumn Thematic Mapper/Enhanced Landsat satellite imagery. To ensure the accuracy of the data, the resulting fire perimeters map was compared against field statistics gathered on the ground by the National Forest Authority, and by the National Civil Protection Authority (Barros and Pereira, 2014; Oliveira et al., 2012). For each fire record, the dataset comprises the burnt area (BA) and the year of occurrence. Thanks to technological improvements, higher resolution original images were acquired and processed over time allowing to increase the accuracy to 5 hectares after 1984 and even higher after 2005. For homogeneity reasons, the present study was performed using forest fires with the minimum areal resolution fixed for consistency at 5 ha.

Land use/land cover's information comes from the CORINE Land Cover inventory (CLC) provided by European Environment Agency). CLC is delivered as cartographic product, both in raster and shapefile format. The minimum cartographic unit is of 25 ha with a geometric accuracy of 100 m minimum and a thematic accuracy over 85 percent (EEA, 1994). CLC nomenclature comprises 44 land cover classes grouped in a three-level hierarchy where the five more general classes are: artificial surfaces, agricultural areas, forest and semi-natural areas, wetlands, water bodies. CLC inventories are currently available for four periods (1990, 2000, 2006, 2012) with a minimum time consistency of plus/minus one year. CLC has already been used for land-use change and urban dynamics studies, namely in Portugal (Noronha Vaz et al., 2012). This study used the four CLC inventories according with the methodology describe below.

The first analyses consist in investigating the LCLUC between either ends of the study period (i.e. 1990-2012) which allowed to elaborate the map of changes showing the transitions among all the classes. A detailed analysis was carried out on LCLUC to explore gains and losses within different land cover classes, with particular regard to the classes most representative of RUI. Then, spatial and temporal distribution of BA on each land cover was computed and analysed to highlight which class is most affected by forest fires in each investigated period. To this end, we considered the cumulative burnt surface within the three-years' time consistency for CLC (i.e. CLC_year ± 1 year). Finally, RUI was mapped using a geospatial approach (Fig. 3) designed to extract the area of intersection between a buffer of 1 km around the Artificial Surfaces (AS) and the area resulting from the sum of the Forest and Semi-Natural Area (FSNA) plus the Heterogeneous Agricultural Areas (HAA). Other agricultural areas were not included in the RUI since arable lands and permanents crops are usually well managed, mostly irrigated and frequently constitute an obstruction to fire spread which, for these reasons, present much lower fire incidence in comparison to HAA and other vegetated CLC classes. The geocomputation was implemented into a Model Builder in ArcGIS™ environment and performed over the four periods, corresponding the available versions of CLC.

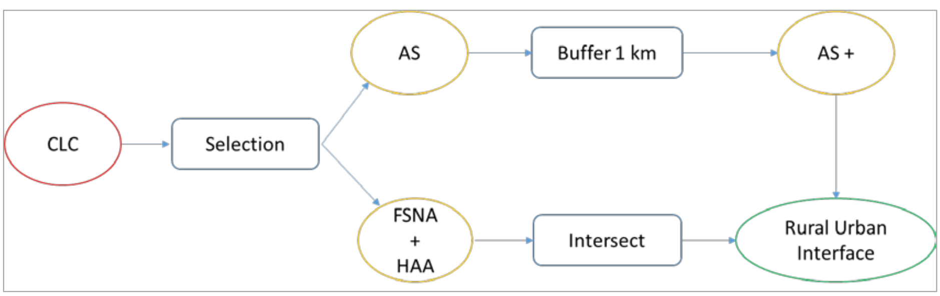

Figure 3 - Framework implemented in the Model Builder (ArcGIS™) to map the rural-urban interface. CLC=CORINE land cover; AS = artificial surfaces; FSNA = forest and semi natural areas; HAA = Heterogeneous agricultural areas.

4 Results

4.1 LULC change analysis

The LCLUC transition map (Fig. 4) was elaborated considering changes in the area occupied by the first level hierarchy classes between CLC1990 and CLC2012. The resulting main transitions concern vegetated areas (AA and/or FSNA) to AS and the transition between FSNA and AA in both directions. AS increased mainly nearby the main metropolitan communities of the northwest and littoral central and southern regions. An intensification of the main road network is also visible in centre-north, which takes the place of agricultural and semi-natural areas probably to connect the emergent inhabited rural-area. The conversion from FSNA to AA and vice-versa is an active and dynamic process predominating in the inner northern region and especially in the southern half of the country. Changes in surface were estimated for each class in absolute (as area gained and lost) and relative values (relatively to the total area of each class in the later land cover and express as percentage) (Fig. 5). The main changes in terms of surface are registered by AS, which increase 165×10^3 ha, and AA, which decrease 184×10^3 ha. These values have a completely different impact in terms of net percentage of change: the net increase of AS is of about 50%, while the net decrease of AA is only of 4.4%. The two classes which manly contributed to the increase in AS are AA, with 110×10^3 ha, and FSNA, with 50×10^3 ha.

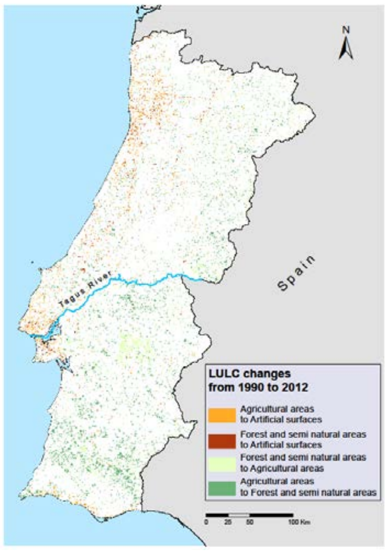

Figure 4 – Map of land cover/land use transition from 1990 and 2012, evaluated considering the first level hierarchy of CLC 1990 and CLC 2012

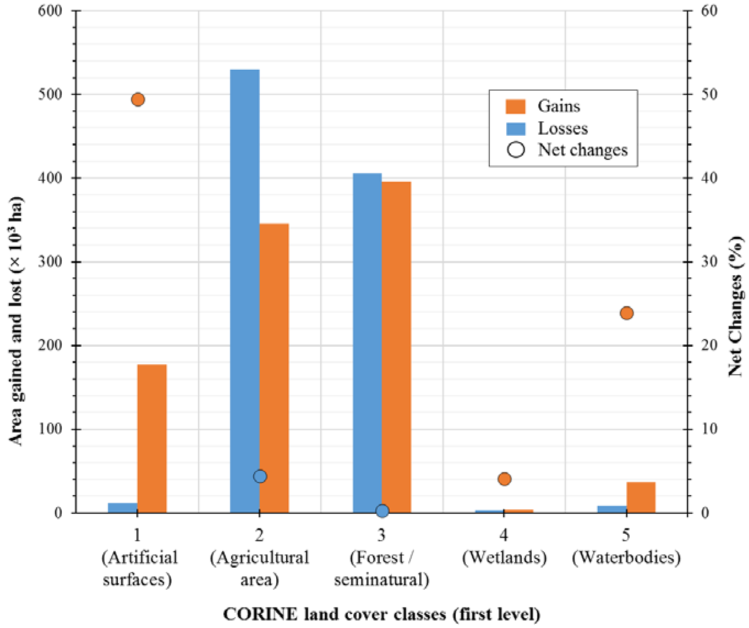

Figure 5 – Area gained and lost from 1990 to 2012 for each CORINE land cover classes, considering the first level hierarchy. Net percentage changes are computed relatively to the total area of each class in the later land cover.

A more detailed analyses was carried out to investigate changes from 1990 to 2012 occurred within classes considering the second level hierarchy (Table 1). Figure 6 shows that the majority of the CLC sub-classes display important net changes in terms of relative gains and losses compared with values for the same classes in the later period. Scrub and/or herbaceous vegetation associations registered a net gain of about 520 $\times 10^3$ ha (+24%) while the forest area decrease about 460 $\times 10^3$ ha (-23%). Arable land is the only agricultural areas registering an important negative net change of -225 $\times 10^3$ ha (-20%). Among artificial surfaces, urban fabric significantly increase of 110 $\times 10^3$ ha (45%), and, in terms of net percentage of change by class, all the other three AS sub-classes, including industrial/commercial and transport unit, mine/dump and construction sites, artificial/non-agricultural vegetated areas, increased more than half.

CLC level 1		**CLC level 2**	
1	Artificial surfaces	1.1	Urban fabric
		1.2	Industrial, commercial and transport units
		1.3	Mine, dump and construction sites
		1.4	Artificial, non-agricultural vegetated areas
2	Agricultural areas	2.1	Arable land
		2.2	Permanent crops
		2.3	Pastures
		2.4	Heterogeneous agricultural areas
3	Forest and semi natural areas	3.1	Forests
		3.2	Scrub and/or herbaceous vegetation associations
		3.3	Open spaces with little or no vegetation
4	Wetlands	4.1	Inland wetlands
		4.2	Maritime wetlands
5	Water bodies	5.1	Inland waters
		5.2	Marine waters

Table 1 - CORINE land cover (CLC) first and second level hierarchy

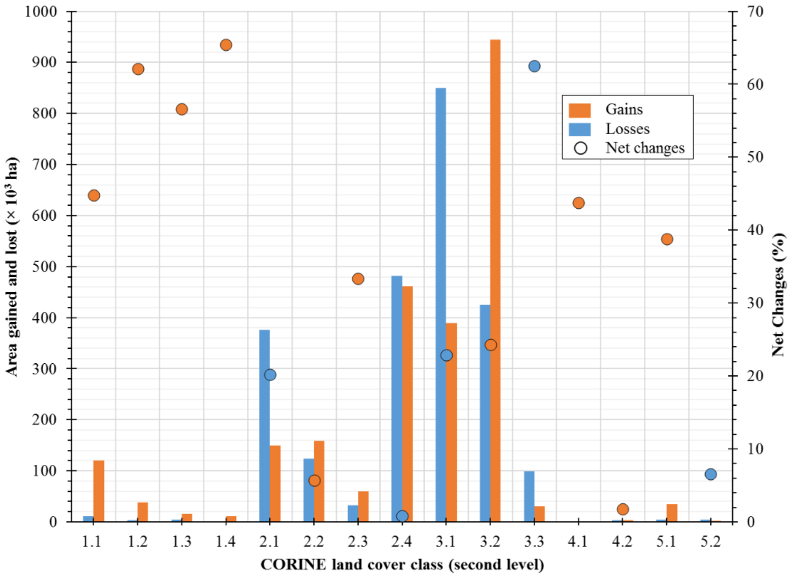

Figure 6 – Area gained and lost from 1990 to 2012 for each CORINE land cover classes, considering the second level hierarchy. Net percentage changes are computed relatively to the total area of each class in the later land cover.

The bar graph with the contribution to net changes in the artificial surfaces sub-classes (Fig. 7) shows that urban fabric, which include buildings, roads and artificially surfaced areas, growths at the expense almost exclusive of heterogeneous agricultural areas, while the increase of industrial commercial and transport is mainly due to the decrease of forest, heterogeneous agricultural area and scrub and/or herbaceous vegetation associations.

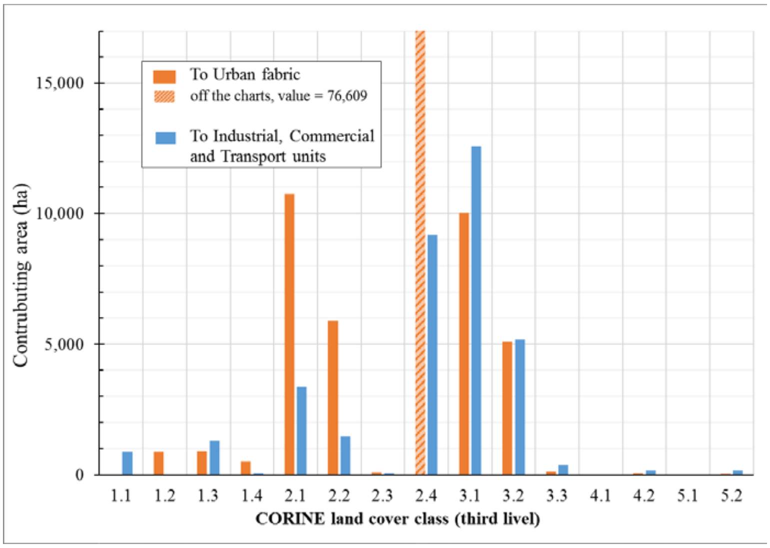

Figure 7 – Contribution to the net changes from 1990 to 2012 of "Industrial, commercial and transport" and "Urban fabric" from the other CLC sub-classes

Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2017-359
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Discussion started: 7 November 2017

Natural Hazards and Earth System Sciences
Open Access
Discussions

4.2 Spatial distribution and characterization of burned area

The overlapping between polygons identifying burnt area (BA) and the CORINE Land Cover maps was performed to investigate the land cover types most affected by forest fires. In this detailed analysis, the third level hierarchy of the CLC was considered and values computed for the four available periods (1990, 2000, 2006 and 2012). Therefore, burnt areas were aggregated over the three years around each period (i.e CLC_year ± 1). Fires affected almost all the sub-classes of the first level hierarchy forest and semi-natural area (Table 1), with the transitional woodland-shrub and mixed forest as the first and second more damaged classes in each period. This trend is similar in all the four investigated frame-periods, as highlighted in Fig. 8, which reveals that the sum of burnt areas within these two classes exceed the 50% of the total. The peak of BA in transitional woodland-shrub equal to about 43×10^3 ha in the period 2005-2007, compared with about 15×10^3 ha in 2011-2013, 14×10^3 ha in 1999-2001 and 6×10^3 ha in 1989-1991. It also emerges that the four sub-classes of heterogeneous agricultural areas are more affected by fires than other type wild scrub vegetation. Consequently, this agricultural land cover is more vulnerable to forest fires and has to be included in the definition of the interface zone between urban space and wildland-rural areas.

CLC code	CLC classes	BA within RUI (ha)			
		1989-1991	1999-2001	2005-2007	2011-2013
324	Transitional woodland-shrub	6086.31	8608.30	43274.65	14638.53
313	Mixed forest	4368.85	3282.67	4059.12	6763.27
312	Coniferous forest	3104.72	2055.41	1501.67	3572.43
322	Moors and heathland	1835.03	2329.69	3508.50	3492.56
243*	Land principally occupied by agriculture, with significant areas of natural vegetation	1535.36	1407.71	3252.81	3320.70
311	Broad-leaved forest	1144.72	1081.55	1299.13	4234.28
241*	Annual crops associated with permanent crops	698.75	253.85	996.29	930.20
242*	Complex cultivation patterns	677.27	688.53	1682.33	1123.00
321	Natural grasslands	638.39	1019.65	1180.63	1072.76
323	Sclerophyllous vegetation	562.68	477.15	1386.21	314.90
334	Burnt areas	396.87	640.29	4251.27	1691.23
333	Sparsely vegetated areas	321.85	761.01	1557.09	1403.56
332	Bare rocks	123.84	157.20	99.47	11.32
244*	Agro-forestry areas	17.25	32.19	93.43	185.92
331	Beaches, dunes, sands	5.22	2.65	2.65	0.99
(*) Heterogeneous agricultural areas					

Table 1 – Classes of land use, as defined by the third level hierarchy of the CORINE Land Cover (CLC), affected by forest fires in terms of Burned Area (BA) within the Rural Urban Area (RUI) during three investigated frame periods (1990, 2000, 2006, 2012).

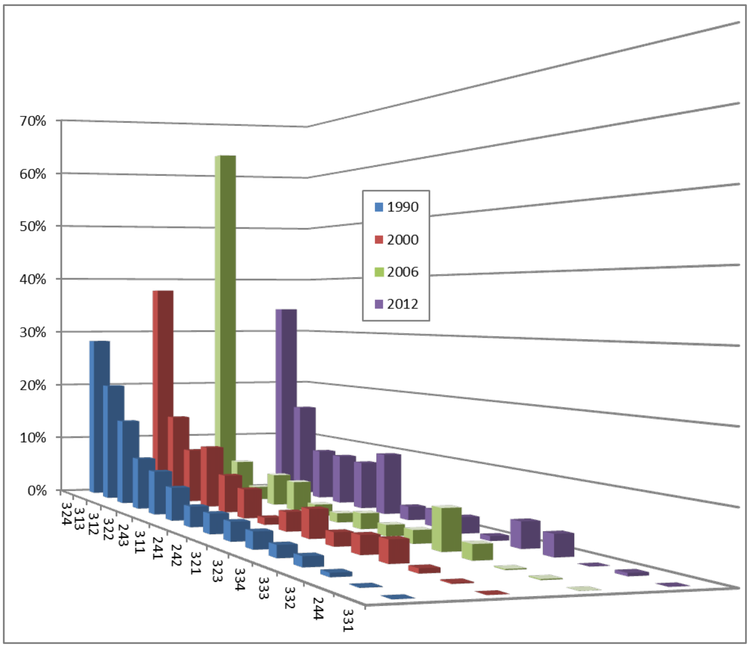

Figure 8 – Classes of land use, as defined by the third level hierarchy of the CORINE Land Cover, affected by forest fires in terms of Burned Area within the Rural Urban Interface during three investigated frame periods (1990, 2000, 2006, 2012), expressed as percentage.

4.3 RUI map

Evidence from the previous analyses indicates that heterogeneous agricultural areas (HAA) have to be included in the computation of the rural-urban interface: this land cover class contributes, with forest and semi-natural area (FSNA), to delimit the vegetated burnable area. RUI maps finally results from the zone of intersection between the sum of HAA plus FSNA and an enhanced area around artificial surfaces (AS). It results a dynamic zone of interface which evolve in space and in time following the LULC changes (Fig. 7). In the period 1990-2012, the increase of RUI is more active in the north-west and along the coast, where the transition from heterogeneous agricultural areas to urban fabric is particularly intense. This evolution is mainly due to the urban growth and to the intensification of the road network.

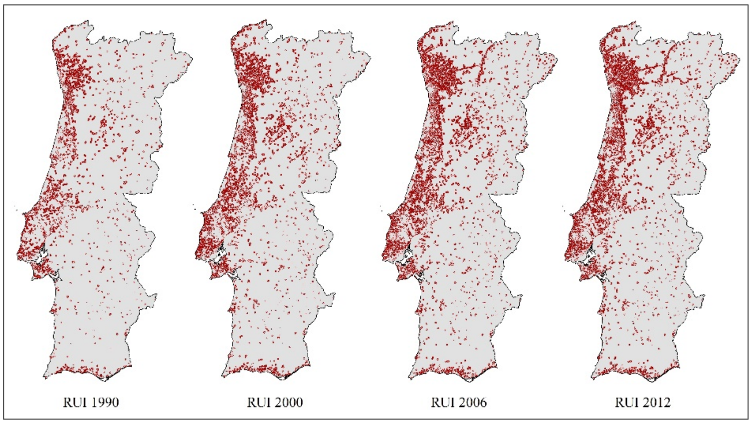

Figure 9 – Maps of the rural-urban interface (RUI) in Portugal estimated for the different periods of investigation, and corresponding to the available CORINE Land Cover inventories (1990, 2000, 2006, 2012)

Globally and in the investigated periods, some trends must be emphasized. Taking into account that the period between CLC inventories is not constant, RUI increased in time from about 780×10^3 ha in 1990 up to about 131×10^3 ha in 2012 following a power-law (RUI=776310.year0.1686, R^2=0.99). Total BA presents a slight decreasing trend (-6×10^3 ha/year) but, essentially, fluctuates between higher (BA > 450×10^3 ha), in 1990 and 2006, and lower values (BA ~ 310×10^3 ha), in 2000 and 2012. BA within the RUI slightly increase over time (1.5×10^3 ha/year), however doubled (7% to 15%) between 2000 and 2012 and tripled (4% to 15%) between 1990 and 2006.

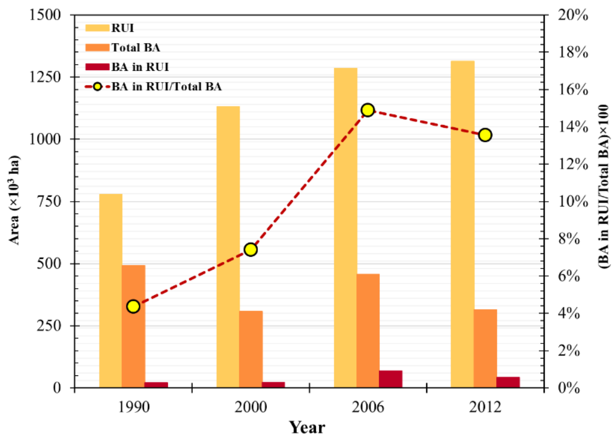

Figure 10 – Evolution of the absolute area of the rural-urban interface (RUI), total burnt area (Total BA), burnt area in the RUI (BA in RUI) and relative burnt area in the RUI (BA in RUI), from 1990 to 2012.

5 Discussion

The LCLUC analysis performed in the present study indicates that from 1990 to 2012 artificial surfaces globally increase in Portugal of about 50% (Fig. 5). The urban growth is mainly due to land cover changes of areas previously principally occupied by heterogeneous agriculture and secondly by forest and semi-natural land covers (Fig. 4 and Fig. 7). This growing process is evident in south coastal regions, mostly between Portimão and Faro, but is strongest nearby to the main metropolitan communities of the northwest and littoral centre, around Porto and Lisbon (Fig. 4 and Fig. 1). These patterns of changes are in very good agreement with previous findings of other authors. According to Marques et al. (2014), housing stock statistics reveal a significant increase in the last decades, namely: 30% of the buildings existing in 2011 were built in the previous two decades (1991-2011); buildings intended for housing and dwellings increased 12.2 % and 16.3% respectively from 2001 to 2011; the highest increase in number of buildings in Continental Portugal were in *Algarve* (24%), due to tourism (construction of hotels and second residence houses), *Centro* (12%) and the lowest in *Norte* and *Alentejo* (10%).

It is also important to understand the major features and drivers of urban development in these areas as well as main differences between regions, namely the metropolitan areas of Porto and Lisbon (MAP and MAL, respectively). Silva and Clarke (2002) described the characteristics and recent intense urban growth of MAP and MAL associated to the economic growth in the end of the XX century (Fernandez-Villaverde et al., 2013). MAL urban pattern is characterized by: (i) a mixture of urban surfaces and large farmlands (olive, cork, and fruit orchards); (ii) fast urban sprawl from main cities (Lisbon, Oeiras, Cascais, Setúbal, Almada and Barreiro); (iii) intense urbanization along with train lines and main roads diffusing from those major urban centres; and, (iv) emergence of tertiary centres and spread of low-density residential areas based on private car transport. On the other hand, MAP is described by: (i) scattered urbanization with high density in major cities (Porto, Matosinhos and Vila Nova de Gaia); (ii) dispersed settlements, towns and rural villages, surrounded by mountains, within small patches of intensive agriculture and pine forests, in a steep slope topography; and (iii) intense, unorganized and irregular urbanization growth from these scattered urbanization patches. Main drivers of the fast urbanization growth in XX century helps to better understand the LCLUC patterns, and comprises: (i) urban rent control (Malpezzi and Rydell, 1986; Marques et al., 2014); (ii) municipal autonomy law, which

Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2017-359
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Discussion started: 7 November 2017

allowed municipalities to issue licenses to build new houses and provide urban infrastructure services (Da Cruz and Marques, 2011; Delgado, 2014); (iii) easy access to credit market with low interest and mortgage rates for housing, construction and road infrastructures (Barradas et al., 2011; Fernandez-Villaverde et al., 2013; Marques et al., 2014; Ribeiro, 2007); (iv) liberalization of the real estate market and laws that protect tenants; (v) the return of the Portuguese habitants mainly from the former African colonies after the revolution of April 25, 1974 (Marques et al., 2014). The consequent decline of the rental market lead to the degradation of old urban areas and the increased construction in the immediate periphery in the case of Lisbon, while in the North, new houses were built by the owners in their small plots of land, promoting a more dispersed urban pattern and irregular spatial growth, jeopardizing the viability plan new settlements (Silva and Clarke, 2002). The dispersion of the population and its activities in MAP is also explained and reinforced by the absence of a regional territory planning and the adoption of polycentric models of urban growth by the national authorities (Cardoso, 1996; Silva and Clarke, 2002).

Another active process identified by the performed change analysis is the abandonment of agricultural land nearby the inland urban areas, which leads to an increase of uncultivated semi-natural and forest areas (Fig. 4). The rapid growth of metropolitan areas had been associated to intensive rural exodus by other authors (Marques et al., 2014). Between 1970 and 1990 an urbanized life style was adopted by the majority of population, which leads to a huge decrease of agricultural areas in towards to wooded areas (Oliveira et al., 2017). These changes cause an intensification of the urban/rural interface. During the entire study period, all the classes associated with forest and semi-natural areas plus heterogeneous agricultural areas represent the surfaces mainly affected by forest fires, in terms of burnt area (Fig. 8). These results are in very good accordance with the findings that San-Miguel-Ayanz et al., (2012) obtained for the shorter period 2000-2006, which suggests that heterogeneous agricultural areas have to be considered in the definition and quantification of the rural-urban interface in Portugal, together with forest and semi-natural areas. Heterogeneous agricultural areas were also considered to define the rural-/wildland-urban interface in Portugal, Spain, France and Italy in previous studies. Regarding the buffer width applied to delimitate this interface, Vilar et al. (2016) used 100 meters: this value corresponds to the median of the distances defined in each country's national legislation for protection against fires, which makes brush clearing obligatory within a certain radius around each house located close to forests or scrublands. In US, WUI was defined and mapped at a more global scale, considering census blocks above 6.17 housing units/km^2 within a distance of 2.4 km from wildland vegetation (Radeloff et al., 2005). In the present study, we applied a buffer width of 1 km, which is in between of the 100 m used in southern Europe and the 2.4 km used in US. Different buffer width were also tested, leading to different RUI size but, in essence, to approximately equivalent relative results.

RUI definition aims to map the area where wildland fires can cause deaths, injured, damage human structures, where vegetation is prone to fire and human-caused fires are more likely to occur. Nevertheless, since it is not based on fire incidence measures, RUI does not aim to assess fire risk or fire regimes, which depend on other factors such as topography, weather, vegetation characteristics and damages costs (Parente and Pereira, 2016; Radeloff et al., 2005). Most of RUI area detected in Portugal (Fig. 9) is located in regions of high population density and surrounding major cities, while RUI increase mainly occurs in the transition zones from agricultural areas and forest and semi-natural areas to artificial surfaces (Fig. 4). Urbanization and the consequent reconfiguration of Portuguese cities caused new urban problems and challenges associated to the increased fragmentation of the city and different rural-urban relationships, affecting small as well as medium and large cities, as also reported for Portugal and Spain (Trigal, 2010). It is important to underline that the impressive increase of the RUI and burnt area in RUI in just a little more than two decades is not exclusive of Portugal. In Continental US, WUI increased of 52% from 1970 to 2000 and 90% of this area include high and highly variable severity forest fire regimes (Theobald and Romme, 2007). In Europe, Fox et al. (2015) found a progressive increase in fire risk in French Maritime Alpes during approximately the same period (1960 – 2009). Badia et al. (2011) noticed that two representative Mediterranean WUI located in Catalonia were more prone to forest fires in the most recent decade of 2000 than in the 1990s. Pellizzaro et al. (2012) assess and analysed WUI dynamics and landscape changes in a tourist area of North-East Sardinia from 1954 to 2008. This region evolution resembles what happens in *Algarve* in last decades, reason why their findings are worth noting here and comprise: (i) large LCLUC associated to a transition from an agro-pastoral economy to one based on tourism; (ii) gradual increase in the number of houses and dwellers, which tripled during the study period, as well as sharp grow in summer population load which can be 10 times greater than in other seasons; (iii) rose of road network length; (iv) increase in WUI's presence, extension (particularly sharp in WUI's length) as well as intensification of the different types of WUI (isolated and scattered houses and clustered buildings).

Results from our analyses shows that total RUI area increase of about 40% from 1990 to 2012, but in the second half of the investigated period (2000-2006 and 2006-2012) the growth rate is lower than in the first decade (1990-2000), probably due to a lower growth rate in the process of urbanization of rural areas. It is also important to underline the decrease of relative BA in RUI

Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2017-359
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Discussion started: 7 November 2017

Natural Hazards and Earth System Sciences
Discussions

from 2006 to 2012. These changes could be associated to the consequences of the recent economic and financial crisis, such as immigration and emigration trends (Cairns, 2011; Ganga et al., 2016; Fonseca and McGarrigle, 2014) and recent plans for territorial spatial planning and protection of forest against forest fires (Mateus and Fernandes, 2014; Parente et al., 2016). Urban sprawl's complexity and magnitude motivated the European Commission to recommend actions to ameliorate their impacts and coordinate land use policies, within the European Cohesion Policy 2007–2013 period (CEC, 2006; EEA, 2006). In Portugal these efforts are complemented with national programs and regional plans such as the National Policy and Territorial Management (*Programa Nacional da Política de Ordenamento do Território*, PNPOT) and Regional Plan for Territorial Planning (*Plano Regional de Ordenamento de Território*, PROT) supporting the sustainable development and the environmental landscape quality of NUTS-III areas (Noronha Vaz et al., 2012).

6 Conclusions

Continental Portugal registered important land cover changes (about 9% of total land area) and rural-urban interface increase in the period 1990-2012. Most significant changes are associated to transitions from: agricultural areas (35.1%) and aorest and semi-natural areas (15.2%) to artificial surfaces (including urban areas); agricultural areas to aorest and semi-natural areas (7.3%) and vice-versa (6.3%). However, relative net changes in the areas of these main land cover types are only significantly positive for artificial surfaces, representing a substantial increase (50%) in these areas, while forest and semi-natural areas remains almost constant (0.3%) and agricultural areas slightly decreased (-4.4%). The spatial distribution of these changes are far from uniform within the territory. Urban sprawl is concentrated in the metropolitan areas of Lisbon and Porto, as well as in central-north and south coastal areas (region of *Algarve*). Main drivers for the expansion and reconfiguration of urban areas are the prosperity and promoted socioeconomic development, intense rural abandonment and, in the particular case of *Algarve*, the development of mass tourist industry. On the other hand, transitions to vegetated land use/land cover types occurred mainly in the south and interior north regions.

LULC subclasses with higher changes in the study period were scrub and/or herbaceous vegetation associations, forests and heterogeneous agricultural areas. The increase in artificial surfaces' areas is due precisely to transitions from these classes of land cover/land use. These findings suggest the needs of extending the notion of wildland-urban interface for Portugal to rural-urban interface, defined as the forest semi-natural plus heterogeneous agricultural areas adjacent to artificial surfaces. Vegetated classes with higher burnt area within RUI in the study period were precisely transitional woodland-shrub, the three types of forests considered in CORINE inventories and the subclasses of heterogeneous agricultural areas.

Results of the evolution analysis of RUI's size, burnt area and burnt area within RUI allow to conclude that, from 1990 to 2012, RUI increased about 70%, burnt area decreased 35% but, nonetheless, burnt area within RUI increased 100%. These findings underline the need of frequent monitoring and assessment of land use changes and RUI evolution in Portugal, and reinforce the need to focus the attention of forest and fire managers on this highly fire prone region. As indicated by the Portuguese National Fire Plan 2006 (Oliveira, 2005) the increase of the urban/rural interface, as a consequence of the above-mentioned LULC dynamics, causes this area to be under the use of people "not educated" for fire and unware of the origin of ignition.

There are strong evidences that urban and RUI's expansion increase fire density and risk (Lampin-Maillet et al., 2011; Fox et al., 2015; Gallardo et al., 2015; Viedma et al., 2015), cost of houses protection from fire (Pellizzaro et al., 2012) and other impacts beyond fire, such as on biodiversity and ecosystems. Areas with higher density of housing, human population and roads tend to exhibit lower population of migrant birds, wolves and other carnivorous as well as species richness of mammals and butterflies, while urban development lead to habitat loss and fragmentation which, in turn, lead to smaller habitat patches and remnant populations (Radeloff et al., 2005).

The conclusions of this study do not prevent but, instead, suggest and encourage more accurate analyses at large scale for characterizing and mapping RUI using high resolution and precise data (e.g. true houses footprints, road network, census data) to provide practical indications in term of land and fire management. Nevertheless, our study provide precious suggestions as for what is the global distribution of RUI in Portugal and identify which regions need to be prioritized in term of RUI monitoring and forest fire protection.

Acknowledgements

This work was prepared in the frame of project FIREXTR - Prevent and prepare society for extreme fire events: the challenge of seeing the "forest" and not just the "trees", co-financed by the European Regional Development Fund (ERDF) through the COMPETE 2020 - Operational Program Competitiveness and Internationalization (POCI Ref: 16702) and national funds by FCT-Portuguese Foundation for Science and Technology (FCT Ref: PTDC/ATPGEO/0462/2014. The study was also supported by: i) Project Interact - Integrative Research in Environment, Agro-Chain and Technology, NORTE-01-0145-FEDER-000017, research line BEST, co-funded by FEDER/NORTE 2020; and, ii) European Investment Funds by FEDER/COMPETE/POCI– Operacional Competitiveness and Internationalization Programme, under Project POCI-01-0145-FEDER-006958 and National Funds by FCT - Portuguese Foundation for Science and Technology, under the project UID/AGR/04033/2013. We are especially grateful to ICNF for providing the fire data and to João Pereira for the final spelling and grammar review of the manuscript.

References

Alodos, C. L., Pueyo, Y., Barrantes, O., Escós, J., Giner, L. and Robles, A. B.: Variations in landscape patterns and vegetation cover between 1957 and 1994 in a semiarid Mediterranean ecosystem, Landsc. Ecol., 19(5), 543–559, 2004.

Amraoui, M., Pereira, M. G., DaCamara, C. C. and Calado, T. J.: Atmospheric conditions associated with extreme fire activity in the Western Mediterranean region, Sci. Total Environ., 524, 32–39, 2015.

Antrop, M.: Changing patterns in the urbanized countryside of Western Europe, Landsc. Ecol., 15(3), 257–270, doi:10.1023/A:1008151109252, 2000.

Antrop, M.: Landscape change and the urbanization process in Europe, Landsc. Urban Plan., 67(1–4), 9–26, doi:10.1016/S0169-2046(03)00026-4, 2004.

APA: SNIRH :: Sistema Nacional de Informação de Recursos Hídricos, [online] Available from: http://snirh.pt/ (Accessed 26 July 2017), 2017.

Badia, A., Serra, P. and Modugno, S.: Identifying dynamics of fire ignition probabilities in two representative Mediterranean wildland-urban interface areas, Appl. Geogr., 31(3), 930–940, doi:10.1016/j.apgeog.2011.01.016, 2011.

Badia-Perpinyà, A. and Pallares-Barbera, M.: Spatial distribution of ignitions in Mediterranean periurban and rural areas: the case of Catalonia, Int. J. Wildland Fire, 15(2), 187–196, 2006.

Barradas, R., Lagoa, S., Leão, E. and others: The non-for-profit banks in Portugal: specificities, social role and evolution, Rev. Econ. Solidária, 58–97, 2011.

Barros, A. M. and Pereira, J. M.: Wildfire selectivity for land cover type: does size matter?, PloS One, 9(1), e84760, 2014.

Bond, W. J. and Keeley, J. E.: Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems, Trends Ecol. Evol., 20(7), 387–394, 2005.

Bouillon, C., Ramiro, M. M., Costantino, S., Fierro Garcia, B., Long-Fournel, M. and Casula, F.: European software tools for mapping Wildland Urban Interfaces in the Mediterranean context., 2012.

Breiman, L., Friedman, J., Stone, C. J. and Olshen, R. A.: Classification and regression trees, CRC press., 1984.

Cairns, D.: Youth, precarity and the future: undergraduate housing transitions in Portugal during the economic crisis, Sociologia, (66), 2011.

Cardoso, A.: Do desenvolvimento do planeamento ao planeamento do desenvolvimento., 1996.

Catry, F. X., Rego, F. C., Bação, F. L. and Moreira, F.: Modeling and mapping wildfire ignition risk in Portugal, Int. J. Wildland Fire, 18(8), 921–931, 2010.

CEC: Cohesion policy and cities: The urban contribution to growth and jobs in the regions, Commun. Counc. Parliam., 2006.

Cohen, M., Rigolot, E. and Valette, J. C.: From the vegetation to the inputs of a fire model: fuel modelling for WUI management, in Proceedings of the international workshop "Forest fires in the Wildland–urban interface and rural areas in Europe: an integral planning and management challenge, pp. 113–120., 2003.

Conedera, M., Tonini, M., Oleggini, L., Orozco, C. V., Leuenberger, M. and Pezzatti, G. B.: Geospatial approach for defining the Wildland-Urban Interface in the Alpine environment, Comput. Environ. Urban Syst., 52, 10–20, 2015.

Da Cruz, N. F. and Marques, R. C.: Viability of municipal companies in the provision of urban infrastructure services, Local Gov. Stud., 37(1), 93–110, 2011.

Delgado, A. P. M.: A Configuração do Poder Local na Constituição Portuguesa de 1976: A Autonomia do Poder Local e o Poder Regulamentar Municipal., 2014.

Diogo, V. and Koomen, E.: Land-Use Change in Portugal, 1990–2006: Main Processes and Underlying Factors, Cartogr. Int. J. Geogr. Inf. Geovisualization, 47(4), 237–249, 2012.

EEA: CORINE Land cover - Part 1: Methodology, Eur. Environ. Agency [online] Available from: https://www.eea.europa.eu/publications/COR0-part1 (Accessed 5 August 2017), 1994.

EEA: Urban sprawl in Europe – The ignored challenge., Eur. Environ. Agency [online] Available from: www.eea.europa.eu/publications/ (Accessed 5 August 2017), 2006.

EEA: Corine Land Cover 2012 raster data, Eur. Environ. Agency [online] Available from: https://www.eea.europa.eu/data-and-maps/data/clc-2012-raster (Accessed 10 August 2017), 2016.

Eurostat: History of NUTS, [online] Available from: http://ec.europa.eu/eurostat/web/nuts/history, 2017.

Fernandes, P. M. and Botelho, H. S.: A review of prescribed burning effectiveness in fire hazard reduction, Int. J. Wildland Fire, 12(2), 117–128, 2003.

Fernandez-Villaverde, J., Garicano, L. and Santos, T.: Political credit cycles: the case of the Eurozone, J. Econ. Perspect., 27(3), 145–166, 2013.

Ferreira-Leite, F., Bento-Gonçalves, A., Vieira, A., Nunes, A. and Lourenço, L.: Incidence and recurrence of large forest fires in mainland Portugal, Nat. Hazards, 84(2), 1035–1053, 2016.

Fonseca, M. L. and McGarrigle, J.: Immigration and Policy: New Challenges after the Economic Crisis in Portugal, Impacts Recent Econ. Crisis 2008-2009 Int. Migr., 51–75, 2014.

Fox, D. M., Martin, N., Carrega, P., Andrieu, J., Adnès, C., Emsellem, K., Ganga, O., Moebius, F., Tortorollo, N. and Fox, E. A.: Increases in fire risk due to warmer summer temperatures and wildland urban interface changes do not necessarily lead to more fires, Appl. Geogr., 56, 1–12, 2015.

Galiana-Martin, L., Herrero, G. and Solana, J.: A Wildland–Urban Interface Typology for Forest Fire Risk Management in Mediterranean Areas, Landsc. Res., 36(2), 151–171, doi:10.1080/01426397.2010.549218, 2011.

Ganga, R., Silva, J. P., Gomes, R., Vaz, H., Lopes, J. T., Silva, S., Cerdeira, L., Cabrito, B., Magalhães, D., Lurdes Machado-Taylor, M. and others: Portuguese Scientists' Migration: a study on the 2008 crisis aftermath, Int. Migr., 54(6), 43–55, 2016.

Ganteaume, A., Camia, A., Jappiot, M., San-Miguel-Ayanz, J., Long-Fournel, M. and Lampin, C.: A review of the main driving factors of forest fire ignition over Europe, Environ. Manage., 51(3), 651–662, 2013.

Goncalves, J. A. and Morgado, A. M.: Use of the SRTM DEM as a geo-referencing tool by elevation matching, Int Arch Photogramm Remote Sens Spat Inf Sci, 37, 879–883, 2008.

Gorte, B.: Supervised image classification, in Spatial statistics for remote sensing, pp. 153–163, Springer., 1999.

Haight, R. G., Cleland, D. T., Hammer, R. B., Radeloff, V. C. and Rupp, T. S.: Assessing fire risk in the wildland-urban interface, J. For., 102(7), 41–48, 2004.

Hammer, R. B., Stewart, S. I. and Radeloff, V. C.: Demographic trends, the wildland–urban interface, and wildfire management, Soc. Nat. Resour., 22(8), 777–782, 2009.

Hardy, C. C.: Wildland fire hazard and risk: problems, definitions, and context, For. Ecol. Manag., 211(1), 73–82, 2005.

Herrero-Corral, G., Jappiot, M., Bouillon, C. and Long-Fournel, M.: Application of a geographical assessment method for the characterization of wildland–urban interfaces in the context of wildfire prevention: A case study in western Madrid, Appl. Geogr., 35(1–2), 60–70, 2012.

INE: Censos 2011. Resultados Definitivos—Portugal, Lisb. Stat. Port., 2012.

Kottek, M., Grieser, J., Beck, C., Rudolf, B. and Rubel, F.: World map of the Köppen-Geiger climate classification updated, Meteorol. Z., 15(3), 259–263, 2006.

Lampin-Maillet, C., Jappiot, M., Long, M., Bouillon, C., Morge, D. and Ferrier, J.-P.: Mapping wildland-urban interfaces at large scales integrating housing density and vegetation aggregation for fire prevention in the South of France, J. Environ. Manage., 91(3), 732–741, 2010.

Malpezzi, S. and Rydell, C. P.: Rent control in developing countries: a framework for analysis, Water Supply and Urban Development Department, Operations Policy Staff, the World Bank., 1986.

Marques, T. S., Matos, F. L. de, Guerra, P. and Ribeiro, D.: Housing problems in Portugal: a challenge to define a territorialised policy in times of crisis, in Procedings of the International Conference the Welfare State in Portugal in the Age of Austerity., 2014.

Mateus, P. and Fernandes, P. M.: Forest fires in Portugal: dynamics, causes and policies, in Forest Context and Policies in Portugal, pp. 97–115, Springer., 2014.

Millington, J. D., Perry, G. L. and Romero-Calcerrada, R.: Regression techniques for examining land use/cover change: a case study of a Mediterranean landscape, Ecosystems, 10(4), 562–578, 2007.

Moreira, F., Vaz, P., Catry, F. and Silva, J. S.: Regional variations in wildfire susceptibility of land-cover types in Portugal: implications for landscape management to minimize fire hazard, Int. J. Wildland Fire, 18(5), 563–574, 2009.

Moreira, F., Viedma, O., Arianoutsou, M., Curt, T., Koutsias, N., Rigolot, E., Barbati, A., Corona, P., Vaz, P., Xanthopoulos, G. and others: Landscape–wildfire interactions in southern Europe: implications for landscape management, J. Environ. Manage., 92(10), 2389–2402, 2011.

Moreno, J. M. and Oechel, W. C.: The role of fire in Mediterranean-type ecosystems, Springer Science & Business Media., 2012.

Noronha Vaz, E., Nijkamp, P., Painho, M. and Caetano, M.: A multi-scenario forecast of urban change: A study on urban growth in the Algarve, Landsc. Urban Plan., 104(2), 201–211, 2012.

Oliveira, S., Moreira, F., Boca, R., San-Miguel-Ayanz, J. and Pereira, J. M.: Assessment of fire selectivity in relation to land cover and topography: a comparison between Southern European countries, Int. J. Wildland Fire, 23(5), 620–630, 2014.

Oliveira, S. L., Pereira, J. M. and Carreiras, J. M.: Fire frequency analysis in Portugal (1975–2005), using Landsat-based burnt area maps, Int. J. Wildland Fire, 21(1), 48–60, 2012.

Oliveira, T.: The Portuguese National Plan for Prevention and Protection of Forest Against Fires: The First Step, Nternational For. Fire News, 30–34, 2005.

Oliveira, T. M., Guiomar, N., Baptista, F. O., Pereira, J. M. and Claro, J.: Is Portugal's forest transition going up in smoke?, Land Use Policy, 66, 214–226, 2017.

OpenStreetMap, F.: OpenStreetMap, OpenStreetMap [online] Available from: https://www.openstreetmap.org/ (Accessed 26 July 2017), 2016.

Parente, J. and Pereira, M. G.: Structural fire risk: the case of Portugal, Sci. Total Environ., 573, 883–893, 2016.

Parente, J., Pereira, M. G. and Tonini, M.: Space-time clustering analysis of wildfires: The influence of dataset characteristics, fire prevention policy decisions, weather and climate, Sci. Total Environ., 559, 151–165, 2016.

Parente, J., Pereira, M., Amraoui, M. and Tedim, F.: Negligent and intentional wildfires in Portugal: spatial distribution characterization, Submitted, 2017.

Pausas, J. G., Llovet, J., Rodrigo, A. and Vallejo, R.: Are wildfires a disaster in the Mediterranean basin?–A review, Int. J. Wildland Fire, 17(6), 713–723, 2009.

Peel, M. C., Finlayson, B. L. and McMahon, T. A.: Updated world map of the Köppen-Geiger climate classification, Hydrol. Earth Syst. Sci. Discuss., 4(2), 439–473, 2007.

Pellizzaro, G., Arca, B., Pintus, G. V., Ferrara, R. and Duce, P.: Wildland-urban interface dynamics during the last 50 years in North East Sardinia, Model. Fire Behav. Risk Nuova Stampa Color Publ. Muros, 249–254, 2012b.

Pereira, M. G., Aranha, J. and Amraoui, M.: Land cover fire proneness in Europe, For. Syst., 23(3), 598–610, 2014.

Pereira, M. G., Caramelo, L., Orozco, C. V., Costa, R. and Tonini, M.: Space-time clustering analysis performance of an aggregated dataset: The case of wildfires in Portugal, Environ. Model. Softw., 72, 239–249, 2015.

Poyatos, R., Latron, J. and Llorens, P.: Land use and land cover change after agricultural abandonment: the case of a Mediterranean mountain area (Catalan Pre-Pyrenees), Mt. Res. Dev., 23(4), 362–368, 2003.

Pugnet, L., Chong, D. M., Duff, T. J. and Tolhurst, K. G.: Wildland–urban interface (WUI) fire modelling using PHOENIX Rapidfire: A case study in Cavaillon, France, in Proceedings of the 20th International Congress on Modelling and Simulation, Adelaide, Australia, pp. 1–6., 2013.

Pyke, D. A., Brooks, M. L. and D'Antonio, C.: Fire as a restoration tool: a decision framework for predicting the control or enhancement of plants using fire, Restor. Ecol., 18(3), 274–284, 2010.

Radeloff, V. C., Hammer, R. B., Stewart, S. I., Fried, J. S., Holcomb, S. S. and McKeefry, J. F.: The wildland–urban interface in the United States, Ecol. Appl., 15(3), 799–805, 2005.

Ribeiro, N.: Debt growth: factors, institutional issues and implications—the Portuguese case, in Rapid Credit Growth in Central and Eastern Europe, pp. 296–311, Springer., 2007.

San-Miguel-Ayanz, J., Schulte, E., Schmuck, G., Camia, A., Strobl, P., Liberta, G., Giovando, C., Boca, R., Sedano, F., Kempeneers, P., McInerney, D., Withmore, C., de Oliveira, S. S., Rodrigues, M., Durrant, T., Corti, P., Oehler, F., Vilar, L. and Amatulli, G.: Comprehensive Monitoring of Wildfires in Europe: The European Forest Fire Information System (EFFIS), in Approaches to Managing Disaster - Assessing Hazards, Emergencies and Disaster Impacts, edited by J. Tiefenbacher, InTech., 2012.

San-Miguel-Ayanz, J., Durrant, T. H., Boca, R., Libertá, G., Boccacci, F., Di Leo, M., Pérez, J. L., Schulte, E., Benchikha, A., Abbas, M. and others: Forest fires in Europe, Middle East and North Africa 2015, 2016.

Santos, F. F. M.: PORDATA—Base de dados Portugal contemporâneo, O Que São NUTS [online] Available from: http://www.pordata.pt/O+que+sao+NUTS, 2014.

Silva, E. A. and Clarke, K. C.: Calibration of the SLEUTH urban growth model for Lisbon and Porto, Portugal, Comput. Environ. Urban Syst., 26(6), 525–552, 2002.

Silva, J. S., Vaz, P., Moreira, F., Catry, F. and Rego, F. C.: Wildfires as a major driver of landscape dynamics in three fire-prone areas of Portugal, Landsc. Urban Plan., 101(4), 349–358, doi:10.1016/j.landurbplan.2011.03.001, 2011.

Stewart, S. I., Radeloff, V. C., Hammer, R. B. and Hawbaker, T. J.: Defining the wildland–urban interface, J. For., 105(4), 201–207, 2007.

Strubelt, W. and Deutschland, Eds.: Study programme on European spatial planning: final report, Bundesamt für Bauwesen und Raumordnung, Bonn., 2001.

Tacoli, C.: Rural-urban interactions: a guide to the literature, Environ. Urban., 10(1), 147–166, doi:10.1177/095624789801000105, 1998.

Tedim, F., Leone, V. and Xanthopoulos, G.: A wildfire risk management concept based on a social-ecological approach in the European Union: Fire Smart Territory, Int. J. Disaster Risk Reduct., 18, 138–153, 2016.

Theobald, D. M. and Romme, W. H.: Expansion of the US wildland–urban interface, Landsc. Urban Plan., 83(4), 340–354, 2007.

Tonini, M., Pereira, M. G., Parente, J. and Orozco, C. V.: Evolution of forest fires in Portugal: from spatio-temporal point events to smoothed density maps, Nat. Hazards, 85(3), 1489–1510, 2017.

Trigal, L. L.: The Process of Urbanisation and Reconfiguration of Spanish and Portuguese Cities, Open Urban Stud. J., 3, 14–20, 2010.

Van Doorn, A. M. and Bakker, M. M.: The destination of arable land in a marginal agricultural landscape in South Portugal: an exploration of land use change determinants, Landsc. Ecol., 22(7), 1073–1087, 2007.

Van Wagtendonk, J. W.: The history and evolution of wildland fire use, Fire Ecol., 3(2), 3–17, 2007.

Viedma, O.: The influence of topography and fire in controlling landscape composition and structure in Sierra de Gredos (Central Spain), Landsc. Ecol., 23(6), 657–672, 2008.

Vilar, L., Camia, A., San-Miguel-Ayanz, J. and Martín, M. P.: Modeling temporal changes in human-caused wildfires in Mediterranean Europe based on Land Use-Land Cover interfaces, For. Ecol. Manag., 378, 68–78, 2016.

Zhang, Y., He, H. S. and Yang, J.: The wildland–urban interface dynamics in the southeastern US from 1990 to 2000, Landsc. Urban Plan., 85(3), 155–162, 2008.