Authors thanks the reviewer for her/his time and constructive comments and suggestions, which we believe have improved the manuscript by making it more clearly and consistent. Our answers to the more general Reviewer' suggestions were uploaded in the form of a supplement.

Comment from Referee1

First of all, the manuscript requires a substantial grammatical revision. The authors should hire an English-proofreading expert in order to substantially improve the current text. Besides, many sentences are too vague, even confusing, and should be rewritten.

Author's response

Authors changed/rewrote all sentences highlighted by the reviewer to make them more comprehensible. An English-proofreading expert has revised the entire manuscript.

Comment from Referee1

All sections need to be substantially improved. (See detailed comments in the revised PDF file.)

Author's response

Authors carefully improved all sections, as can be seen in the annexed document.

In particular: (i) we propose to change the **title** as "Global assessment of rural-urban interface in Portugal related to land cover changes "; (i) in the **abstract** we introduced first the RUI and its relation with LULCC, and then the burnt area (in fact, forest first are not directly investigated in the present study); (iii) we reorganized a little bit the **Introduction** to better explain the objectives of the present paper; (iv) we moved some explanation from **Results** to **Data and Methodology** (see below); (v) we removed some long sentences from **Discussion**, expressing them in a more synthetic way, but we added information to link the broad CORINE classes to real habitats or vegetation types (see below); (vi) we reformulated the **Conclusions** (see below).

Comment from Referee1

The "Data and Methodology" section has to be completed. Several explanations appearing in the "Results" section have to be moved to the Methodology section. Many aspects need to be further explained and some methodological approaches have to be further justified.

Author's response

We implemented the "**Data and Methodology**" section and we moved some explanations from "**Results**" to this section.

More in detail: (i) we provided in "Data and Metgodology" section a new and more complete version of Table 1, showing the CORINE Land Cover nomenclature for the three level; (ii) the concept of "Area gained and lost" and "Net Chenges" was detailed and the computation of these values was well described; (iii) The choice of the buffer width used to compute the RUI has been discussed and justified; (iv) the CLC hierarchical levels considered for each analyses was deeper explained and justified based on the objectives.

Comment from Referee1

The characteristics and limitations of the various databases are not always well explained. In the case of the CORINE inventory, in particular, some of its limitations should have been commented (and slightly discussed in the discussion).

Author's response

Authors addressed to this issue in the section "**Discussion**"

Comment from Referee1

The "Discussion" is quite interesting, although some parts should be reduced and several relevant aspects are missing. The authors do not explain, for instance, which major habitats or plant communities correspond in Portugal to the CORINE classes that they cite throughout the manuscript. We miss this specific information (linking the broad CORINE classes to real habitats or vegetation types), which would have probably allowed to discuss other relevant issues that the paper is omitting (e.g. biodiversity, only briefly mentioned in the conclusions).

Author's response

We reduced this session, namely we removed details from literature on urban growth of MAP and MAL. As regards the request of including specific information linking CLC classes to real habitat, author decided to include in the analyses a more accurate and detailed Portuguese land use map, namely the Soil Use and Occupancy Chart (*Carta de Uso e Ocupação do Solo*, COS). The description of this map was added in the section "Data and Methodology". We compared CLC2006 and COS2007v2.0 because these are the closest inventories (in time) between them and within the study period. We introduced a table showing the result of the overlapping between the two land use maps, allowing to identify the vegetation types/major habitats/plant communities in each of the CLC for Portugal. This paragraph was added in the section "Discussion".

Comment from Referee1

The Portuguese legislation in relation to RUIs is not commented and this is a critical issue. The authors do not explain either which are the treatments usually implemented by Portuguese forest managers in RUIs and if these practices have changed in the last years due to RUI expansion and fire regime dynamics. Moreover, the discussion does not sufficiently connect the results of this research with Portuguese forest managers' needs and priorities. The authors could maybe propose some broad landscape management guidelines in relation to the objective of minimizing the risk of large intense fires under climate change.

Author's response

As far as we know, there is no specific or general Portuguese legislation about WUI or RUI. In Portugal, there is only one general mention about WUI/RUI in the National Plan to Protect the Forests against Wildfires (CM, 2009). In this Plan it is suggest that to protect urban-forest interface it will be necessary to create and maintain an external buffer strips around population clusters, especially in those with the highest fire vulnerability, as well as around parks, industrial polygons, landfills, housing, shipyards, warehouses, and other buildings. Usually, it is suggest a buffer of 100 meters around population clusters, 10 meters for each side of a road, and 50 meters around houses. For private and communal property there are the Municipal Plan for Territorial Planning, which include the municipal master plan, that regulates all land uses, the urbanization plan, and others specifics (Feliciano et al., 2015). Private properties within protect areas are restrict by SPFP. At local level, there is the Municipal director plan for landscape plan, and which incorporates the new municipal plan for forests against fire since 2006.

Authors introduced all these aspects in the new version on the present manuscript, in the section "**Discussions**".

Finally, better quality figures have been produced and will be uploaded separately.

Authors thanks the reviewer for her/his time and constructive comments and suggestions, which we believe have improved the manuscript by making it more clearly and consistent. Our answers to the more general Reviewer' suggestions were uploaded in the form of a supplement.

Comment from Referee2

The MS would benefit from an English language revision, some sentence are not clear and should be rephrased.

Authors changed/rewrote all the sentences highlighted by the reviewers to make them more comprehensible. An English-proofreading expert has revised the entire manuscript.

Comment from Referee2

The authors should select and better clarify objectives. In fact, it is not clear if the main aim of this study was to assess the impact of land use changes on burned areas, to provide a global assessment of land cover changes, or to assess the evolution of RUI.

We reorganized the **Abstract** and the **Introduction** to better explain the objectives of the present paper, and we specified at the end of Introduction: "In the present study, authors investigate the RUI in Portugal: the main objective is to analyze changes in land use/land cover occurred in this country in the period 1990-2012 and to assess their impact on RUI's evolution. Moreover, a qualitative and quantitative characterization of burnt areas within the RUI in relation to the LULCC is provided. Finally, this research provides a first attempt to map the RUI's extension at national level for continental Portugal."

Comment from Referee2

Page 1, lines 28-30: Three important points of view are condensed in a single short sentence. The authors should either give some details on different aspects of fire problem or to delete the whole sentence, it does not seem essential for introducing paper topics.

We moved this sentence later where it make more sense.

Comment from Referee2

Page 3, lines 6-9: I was not able to find coherence in this sentence, i.e. why is "spatial extension of the WUI" determined by the factors above-mentioned?
We reformulated this sentence

We changes in "these factors are broadly considered to elaborate WUI maps."
This is also clear from the cited literature.

Comment from Referee2

Page 3, lines 21-23: Authors should explain if WUI and RUI terms have different meanings and, in this case, why they chose RUI.

We added: "In this respect, recent studies defined the Rural-Urban Interface (RUI) as an alternative to the WUI, to highlight the importance of including the rural area,… In the present study, authors investigate the RUI in Portugal"

Comment from Referee2

Please check citation style. Done

Comment from Referee2

On the whole the authors should give some more details on methodology.

We implemented the "**Data and Methodology**" section and we moved some explanations from "**Results**" to this section.
More in detail: (i) we provided in "**Data and Metgodology**" section a new and more complete version of Table 1, showing the CORINE Land Cover nomenclature for the three level; (ii) the concept of "Area gained and lost" and "Net Chenges" was detailed and the computation of these values was well described; (iii) The choice of the buffer width used to computed the RUI has been discussed and justified; (iv) the CLC hierarchical level considered for each analyses was deeper explained and justified based on the objectives.

Table 1: Authors showed in table 1 first and second level classes of CLC but in the 4.2 section they discussed results relative to Corine Land Cover third level. I suggest adding CLC 3rd level in table 1. Done

Page 5, line 24: I suggest adding a figure where an example of RUI map at local scale is shown. This could help reader to better understand which land cover classes were included in RUI and how RUI was mapped.

We better explain the procedure to map the RUI in the section "**Data and Methodology**": "RUI was then mapped for each period using a geospatial approach designed to extract the area of intersection between a buffer 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). Different buffer width from 100 m to 2000 m were tested, but finally we adopted a buffer width of 1 km, corresponding to two times the spatial resolution of the CORINE Land Cover inventory (that is 500 by 500 m): this value is in line with values applied in other countries for WUI mapping (Vilar 2016, Radeloff et al., 2005) and, in the same time, is enough large to avoid bias in the results. The others agricultural areas (i.e. arable lands, permanents crops and pastures) were not included in the RUI definition since these vegetated land covers are usually well managed, mostly irrigated and frequently constitute an obstruction to fire spread. Similarly, San-Miguel-Ayanz et al., (2012) suggested that HAA have to be considered in the definition and quantification of the rural-urban interface in Portugal, together with forest and semi-natural areas. The geocomputation which allowed producing the RUI's maps was performed under ArcGIS™ software environment. Namely, the geoprocessing workflows was implemented into a Model Builder (Fig.3), a specific application used to create, edit, and manage models, meant as workflows that string together sequences of geoprocessing tools (e.g. selection, buffer, intersect), feeding the output of one tool into another tool as input (i.e. the raster or vector spatial data). "

Page 6, line 4: explain in the text what AA means. Done

Page 6, line 8-9: "predominating in the inner northern region and especially in the southern half of the country" the meaning of this sentence is not clear, please rephrase. Done

Page 6 line 10, and page 7 figure 5 and 6: in order to avoid confusion in reading the results reported in figures 5 and 6, I suggest adding in "Data and methodology" section a description of approach authors followed for calculating area gained or lost and net percentage changes. Done

Page 6, Figure 4: could authors improve resolution of this figure? Done: all the figures were uploaded in high resolution as single files

Page 9, lines 7-8: what total do authors refer?
We specified that it refers to the total burnt area

Page 9 lines 10: authors should give some further details in the text. Reader has to look for CLC classes and codes in table 1, to calculate the sum and to compare it with the other burned areas.
We changed as : ". It also emerges that the three over four sub-level of heterogeneous agricultural areas (code 243, 241, 242) are highly affected by wildfires"

Page 9 lines 11-12: I was not able to find a logical connection between this sentence and the previous one. Please explain better your thought.
We changed as "thus confirming the need of including HAA in the definition of the RUI".
Moreover, since in methodology we better explained the CLC classes we used to map the RUI, we hope that this sentence is now clearer.

Figure 8: it is not clear what percentage authors refer to.
We refer to the percentage over the total BA for each frame period. We better explained this both in the image caption and in the text.

Page 13, lines 1-3: authors should explain how the factors listed in this paragraph have affected RUI changes.

We removed this sentence and we and the following : "These changes could be associated with the relative decrease of BA in the last investigated period, as a consequence of recent plans for territorial spatial planning and protection of forest against forest fires (Mateus and Fernandes, 2014; Parente et al., 2016)."

Page 13, lines 34-39: conclusions reported in this paragraph are not arising from results of this study. It would be better to move this paragraph to introduction or discussion section.

We deleted the second part of this paragraph (line 37-39) and we moved the first sentence on to "**Introduction**".

Page 13, line 43: "identify which regions need to be prioritized in term of : : :: : :: : :" I do not think that this issue was addressed in this study.

We changed as : "and identify which areas need to be prioritized in term of RUI monitoring". These are in fact the mapped RUI area.

Finally, better quality figures have been produced and will be uploaded separately

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

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Abstract. The wildland-/rural-urban interface (WUI/RUI) is a particularly important aspect of), known as the fire regime. In Mediterranean basin most of the fires in this pyro region area were structures and other human development meet or intermingle with wildland and rural area, is at present a central focus of wild fire policy and its mapping is crucial for wildfire management and impact. In the Mediterranean basin, the majority of fires are caused by humans and thefire risk and consequences are is particularly high due toin the close proximity to population, human of infrastructures and urbanof rural/wildland areas. Population increase,RUI's extension changes under the pressure of environmental and anthropogenic factors, such as urban growth and the rapid changes in , fragmentation of rural areas, deforestation and, more in general, 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/land cover changes (LULCC). As other Mediterranean countries, Portugal experienced significant LULCC 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. Thispopulation, and trends associated to the high socioeconomic development. In the present study aims to assess , we analysed LULCC occurred in this country in the evolution of RUI in Portugal, from 1990 to - 2012, based on LCLUC providing also a period with the main objective of investigating how these changes affected RUI's evolution. Moreover, a qualitative and quantitative characterization of forest fires dynamics in relation to the burnt area.areas within the RUI in relation the LULCC was performed. Obtained results disclose important LCLUCLULCC which spatial distribution is far from uniform within the territory. A significant increase in artificial surfaces iswas 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 leadsled to an increase of uncultivated semi-natural and forest areas. Within agricultural areas, heterogeneous patches suffered the greatest changes and are were the main contributors to the increase of urban areas. Moreover these are among the LCLU classes with higher ; moreover, this land cover class, together with forests, resulted to be highly affected by wildfires in terms of 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 concludefrom this analyses it appears that, form 1990 to 2012 in Portugal, during the investigated period RUI increased in Portugal more than two thirds and, while the total burnt area decreased one third.; nevertheless, burnt area within RUI doubled, which emphasizeemphasizes the significance of RUI monitoring 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.

Mediterranean area is particularly affected by wildfires, mainly as consequence of its type of climate and vegetation cover fire proneness (Pellizzaro et al., 2012; Amraoui et al., 2015). In the European Mediterranean countries, fire incidence has dramatically increased in the last decades and the average total burnt area (hereafter, BA) has quadrupled since the 60's (San-Miguel-Ayanz et al., 2012), mainly due to changes in climate and land use (Moreira et al., 2011; Ferreira-Leite et al., 2016). Portugal stands out from this group of countries since it counts the highest number of wildfires and has been the third most affected country in terms of BA in the last three decades (Pereira et al., 2014; San-Miguel-Ayanz et al., 2016). On average, about 95% of wildfires with known causes in Europe during the period 1995 to 2010 (corresponding to about 70% of the total number of recorded events) were associated to human activities (Ganteaume et al., 2013), while only a small percentage of fires (e.g. 1% in Portugal, 5% in Spain) were naturally caused by lightings (Mateus and Fernandes, 2014; Vilar et al., 2016). Wildfires have long been considered a dynamic ecological factor and an efficient agricultural and landscape management tool, but more recently they are increasingly considered a hazard (Fernandes and Botelho, 2003; Bond and Keeley, 2005; Hardy, 2005;

Van Wagtendonk, 2007; Pyke et al., 2010; Moreno and Oechel, 2012), which has motivated governments to implement measures for fires prevention, monitoring and mapping.

A key factor in this regards is to study the spatial and temporal distribution of wildfires into a given area, which, being influenced by the surrounding socio-economic and environmental factors, is far to be homogeneously distributed. For example a clustered pattern was discovered for Portugal, with fires' hot spots concentrated in the north-west and center regions, while the southern area presented lower densities of wildfires (Pereira et al., 2015; Tonini et al., 2017). Urban sprawl also affect the spatio-temporal pattern of these hazardous events and makes it difficult to define a boundary between human developments and rural areas, in order to better protect this interface where wildfires are more likely to occur. The modern urban landscape in Europe has a typical star-shaped spatial pattern (Antrop, 2000) with wedge of unchanged countryside persisting between lobes of urban development (Antrop, 2004). In this context populations and activities described either as "rural" or "urban" are closely linked and their distinction is often arbitrary (Tacoli, 1998). In the Iberian Peninsula, the diffuse urban expansion along radiating access roads connecting the center to commercial/industrial zones and isolated 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). Here the expansion and reconfiguration of urban and metropolitan areas comprise the processes of sub-urbanisation and peri-urbanisation, mainly of coastal regions and, in the interior, of agricultural areas (Trigal, 2010). Land use changes are at the origin of landscape patterns and dynamics and have a strong influence on forest fires (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 the soil processes according to the fire adaptation of each ecosystem (Viedma, 2008; Pausas et al., 2009).

Population and urban areas significantly increased in Europe during the late XX century, which helps to understand the rapid land cover and land use changes (LULCC) (Noronha Vaz et al., 2012). In the European Mediterranean countries, LULCC are mainly caused 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). One consequence is the urbanization, defined as the process involving the transformation of rural and natural landscape into urban and industrial areas, caused by the interaction of very different factors and largely influenced by communication, accessibility and mobility (Antrop, 2000). The dynamic conversion among 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. This complex process is at the origin of the abandonment of remote rural areas with poor accessibility, which allows the expansion of wild low vegetation and forest (Antrop, 2004). Specifically, the abandonment of low-intensity agricultural lands and grazing practices caused the increase of forest cover and scrubland vegetation (Poyatos et al., 2003; Millington et al., 2007).

Significant LULCC occurred in Portugal in the recent period. The urbanization of coastal areas in the country occurred in concomitance with the abandonment of agricultural land in marginal areas and seemed to prevail between 1990 and 2000 while, in the later period (2000-2006), the intensification of agriculture in areas where irrigation was available was a predominant process (Van Doorn and Bakker, 2007; Diogo and Koomen, 2012). Pereira et al. (2014) observed that among the southern European countries, in the period 2000-2006 Portugal registered the highest rates of land use change marked by a significant increase in artificial surfaces and sclerophyllous vegetation and a decrease in forest area and natural grasslands, because of rural abandonment, urbanization and wildfires.

The interface between the wildland and the urban space, called Wildland-Urban Interface (WUI), has been deeply investigated by researchers and fire managers in the last decades. The United States Department of Agriculture (USDA), defined the WUI as the area "where humans and their development meet or intermix with wildland fuels" (Stewart et al., 2007); here fires can spread readily among vegetation fuels and urban structures. 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 (Haight et al., 2004; Radeloff et al., 2005; Stewart et al., 2007; Hammer et al., 2009; Lampin-Maillet et al., 2010; Conedera et al., 2015), and these factors are broadly considered to elaborate WUI maps.

Urbanization and the consequent abandonment of rural areas caused the expansion of this interface, increasing the probability that wildfires affect houses and infrastructures (Theobald and Romme, 2007; Zhang et al., 2008). There are strong evidences that the expansion of the urban and WUI area increased the fire density and related risk (Lampin-Maillet et al., 2011; Fox et al., 2015; Gallardo et al., 2015; Viedma et al., 2015), the cost of houses protection from fire (Pellizzaro et al., 2012) and have an impact on biodiversity and ecosystems (Radeloff et al., 2005). Researchers developed several geospatial models for defining and mapping the WUI, taking into account all the above-mentioned factors. In Europe, Lampin-Maillet et al. (2010) proposed an approach tested in southern France and based on the combination of four types of buildings configuration and three classes of vegetation structure. Following this model, Bouillon et al. (2012) developed WUImap, a software tool for mapping WUI in the Mediterranean region successfully applied in southeastern France, eastern Spain and Sardinia in Italy. In the Alpine context, geospatial approaches 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 the WUI in Sardinia, Italy, using temporal steps of about 10 years from 1954 and 2008, and found an increase of the WUI's extension. Other studies focused 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). The majority of these researches were developed locally and performed at house-spatial-scale or for small regions within each country.

The active rural-urban conversion processes and the associated landscape changes, largely documented in the European context, induced to reconsider the WUI concept. In this respect, recent studies defined the Rural-Urban Interface (RUI) as an alternative to the WUI, to highlight the importance of including the rural areas, and identified the 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, authors investigated the RUI in Portugal: the main objective was to analyze changes in land use/land cover occurred in this country in the period 1990-2012 and to assess their impact on RUI's evolution. Moreover, a qualitative and quantitative characterization of the burnt areas within the RUI in relation to the LULCC was performed. Finally, this research provides a first attempt to map the RUI's extension and evolution at national level for the entire continental Portugal.

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~~According to the census data, the population ~~(~~was about 10~~,~~.6 million ~~habitants) presents~~in 2011 and decreased to 10.3 million in 2017; its distribution displays a much higher density in the ~~north-western~~northwestern and southern coastal areas as well around the major cities (Fig. 1). Tagus river divides the country into two regions ~~with~~of approximately ~~similar~~the same 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~~watercourse density of about 0.65 km/km^2. According ~~with~~to CORINE Land Cover (hereafter, CLC) inventory 2012 ~~(EEA, 2016),~~(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),~~, low altitude range (between sea level and about 1000 m~~,~~), and mean ~~water course~~watercourse density of about 0.58 km/km^2. According ~~with~~to CLC 2012 inventory, 56% of this ~~area~~territory is occupied by agricultural areas, 40% by forest and semi-natural areas, and only 2% by artificial surfaces (Fig. 2).

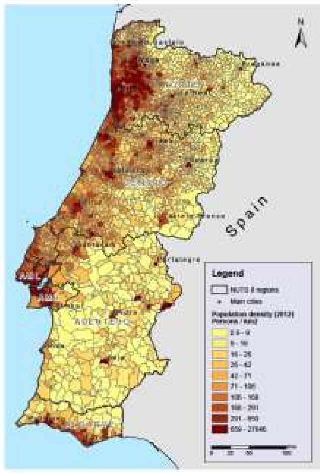

Figure 1 - Population density at parish level (INE, 2012) in the mainland Portugal, with the location of the of the major cities. NUTS refers to regions according with Nomenclature of Territorial Units for Statistics level II (Eurostat, 2017; Santos, 2014).

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

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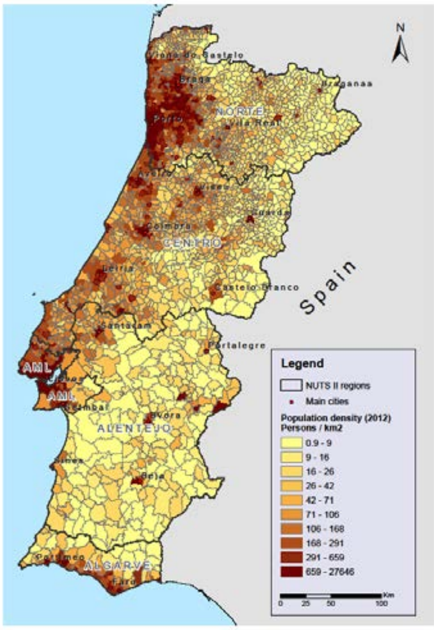

Figure 1 - Population density at parish level (INE, 2012) in the mainland Portugal, with the location of the of the major cities. NUTS refers to regions according to Nomenclature of Territorial Units for Statistics level II (Eurostat, 2017; Santos, 2014).

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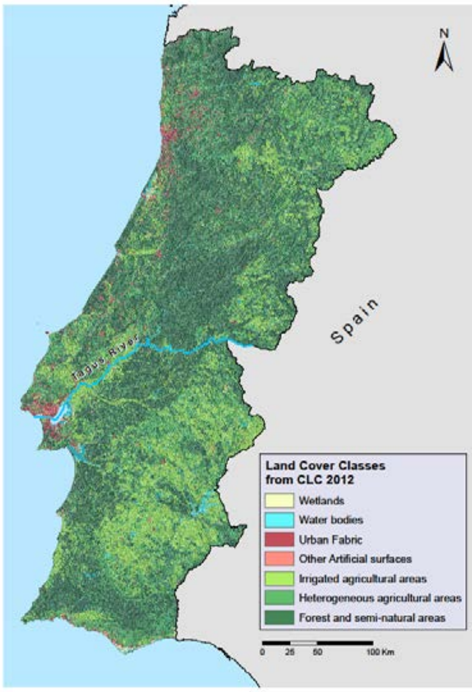


Figure 2 –Land cover of mainland Portugal based on the second level of CORINE land cover inventory 2012 (EEA, 2016)

3 Data and methodology

Forest firesWildfires 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 The Institute of Agronomy (*Instituto Superior de Agronomia*, ISA) which produced the official database ~~(Barros and Pereira, 2014; Oliveira et al., 2012). The final~~ in the earlier years (1975 to 1989) and finally the official National fire database ~~cover~~covers the 1975-2015 period and ~~comprise~~comprises about 49,000 fire events for a total ~~of burnt area (~~BA~~)~~ of 4,430,000 ha~~.~~ (Oliveira et al., 2012; Barros and Pereira, 2014). The annual fire perimeter maps ~~result~~resulted from semi-automatic supervised image classification ~~(Gorte, 1999)~~(Gorte, 1999) performed with ~~the~~ classification and regression trees algorithm of ~~Breiman et al., (1984)~~Breiman et al., (1984) on late summer-autumn Thematic Mapper/Enhanced Landsat satellite imagery. Technological improvements of satellite sensors allowed acquiring and processing over time higher-resolution images with an increasing accuracy from the initial 30 hectares to 5 hectares after 1984, and even higher after 2005. To ensure the accuracy of ~~the data,~~ the ~~resulting fire perimeters map was~~data, results were 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 (perimeter map) 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.~~

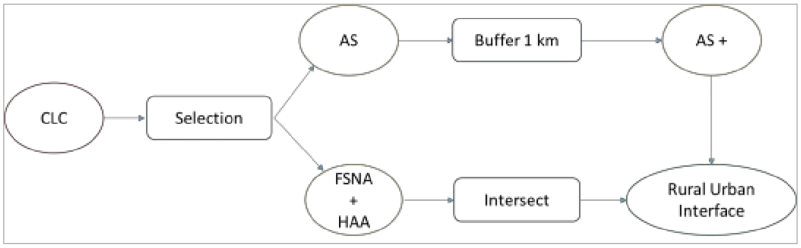
Land use/land cover's information ~~comes~~came from the ~~CORINE Land Cover~~CLC inventory ~~(CLC)~~ provided by European Environment Agency (EEA). CLC is delivered as cartographic product, both in raster ~~and~~ (i.e. a regular grid of cells) and in vector-shapefile (as point, line and polygons) format. The minimum cartographic unit is of 25 ha (500 by 500 m) with a geometric accuracy of 100 m minimum and a thematic accuracy over 85 ~~percent (EEA, 1994).~~% (EEA, 1994). CLC nomenclature ~~comprises 44 land cover classes grouped in~~ is a three-level ~~hierarchy where~~hierarchical classification system with 44 classes at the third and most detailed level (Table 1). The five more general classes for the first level are~~: artificial surfaces, agricultural areas,~~ the following: Artificial Surfaces (AS), Agricultural Areas (AA), Forest and Semi-Natural ~~areas,~~Area (FSNA), 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~~was already ~~been~~ used for land-use change and urban dynamics studies~~, namely~~ in Portugal ~~(Noronha Vaz et al., 2012). This study used~~ (Noronha Vaz et al., 2012; Pereira et al., 2014). To identify and detail the major habitats/plant communities/vegetation types corresponding to each CLC class in Portugal, we employed the Soil Use and Occupancy Chart (*Carta de Uso e Ocupação do Solo*, COS) provided by the Portuguese Directorate-General of the Territory (*Direção-Geral do Território*, DGT). DGT is the national public body responsible for pursuing public policies for land use and town planning. We compared CLC2006 with COS2007v2.0 because these are the closest inventories (in time) within the study period. In addition, COS2007v2.0 presents improvement from the thematic and geometric point of view (DGT, 2016; Sarmento et al., 2016): it includes 225 classes (32 more than the initial version) at the most detailed level, distributed over 5 hierarchical levels.

In the present study, the four CLC inventories were employed to analyze LULCC at different levels and to map RUI at different periods, according ~~with~~to the methodology ~~describe~~described below.

The first ~~analyses consist~~analysis consisted in investigating LULCC within the ~~LCLUC between either ends of~~entire the study period (i.e. from 1990~~-~~ to 2012~~) which~~). This allowed ~~to~~ ~~elaborate~~elaborating the map of changes showing the transitions among ~~all the classes. A detailed analysis was carried out on LCLUC to explore~~ the five more general classes (CLC first level hierarchy) and, more in detail, to quantify gained and lost areas with reference to both the first and the second level hierarchy of CLC. Moreover, the difference between 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 covereach class divided by the total area covered by the specific class in the later period (i.e. the net change) 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)the result expressed in percentage.

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.



RUI was then mapped for each period (1990, 2000, 2006 ant 2012) using a geospatial approach designed to extract the area of intersection between a buffer around the AS and the area resulting from the sum of the FSNA plus the Heterogeneous Agricultural Areas (HAA, a sub-level of AA). Different buffer width from 100 m to 2 km were tested: finally, we adopted a buffer width of 1 km, corresponding to two times the spatial resolution of CLC inventories. This value is in line with values applied in other countries for WUI mapping (Radeloff et al., 2005; Vilar et al., 2016) and, in the same time, is enough large to avoid bias in the results. The others agricultural areas (i.e. arable lands, permanents crops and pastures) were not included in the RUI definition since these vegetated land covers are usually well managed, mostly irrigated and frequently constitute an obstruction to fire spread. Similarly, San-Miguel-Ayanz et al., (2012) suggested that HAA have to be considered in the definition and quantification of the RUI in Portugal, together with FSNA.

The geocomputation which allowed producing the RUI's maps was performed under ArcGIS™ software environment. Namely, the geoprocessing workflows was implemented into a Model Builder (Fig. 3), a specific application used to create, edit and manage models, meant as workflows that string together sequences of geoprocessing tools (e.g. selection, buffer, intersect), feeding the output of one tool into another tool as input (i.e. the raster or vector digital data). Finally, we analyzed how each land cover class (in respect of the third level hierarchy of CLC) was affected by wildfires in terms of BA for each investigated period within the RUI. To this end, polygons defining the BA registered at each CLC_year plus/minus one year (1989-1991, 1999-2001, 2005-2007, 2011-2013) were merged together and the resulting BA polygons were clipped over the corresponding RUI map. The resulting outputs, representing the BA within the RUI cumulated over three years around each investigated period, were finally overlapped with the CLC source map.

Level 1	**Level 2**	**Level 3**
1 Artificial surfaces	11 Urban fabric	111 Continuous urban fabric
		112 Discontinuous urban fabric
	12 Industrial, commercial and transport units	121 Industrial or commercial units
		122 Road and rail networks and associated land
		123 Port areas

		124 Airports
	13 Mine, dump and construction sites	131 Mineral extraction sites
		132 Dump sites
		133 Construction sites
	14 Artificial, non-agricultural vegetated areas	141 Green urban areas
		142 Sport and leisure facilities
2 Agricultural areas	21 Arable land	211 Non-irrigated arable land
		212 Permanently irrigated land
		213 Rice fields
	22 Permanent crops	221 Vineyards
		222 Fruit trees and berry plantations
		223 Olive groves
	23 Pastures	231 Pastures
	24 Heterogeneous agricultural areas	241 Annual crops associated with permanent crops
		242 Complex cultivation patterns
		243 Land principally occupied by agriculture, with significant areas of natural vegetation
		244 Agro-forestry areas
3 Forest and semi natural areas	31 Forests	311 Broad-leaved forest
		312 Coniferous forest
		313 Mixed forest
	32 Scrub and/or herbaceous vegetation associations	321 Natural grasslands
		322 Moors and heathland
		323 Sclerophyllous vegetation
		324 Transitional woodland-shrub
	33 Open spaces with little or no vegetation	331 Beaches, dunes, sands
		332 Bare rocks
		333 Sparsely vegetated areas
		334 Burnt areas
		335 Glaciers and perpetual snow
4 Wetlands	41 Inland wetlands	411 Inland marshes
		412 Peat bogs
	42 Maritime wetlands	421 Salt marshes
		422 Salines
		423 Intertidal flats
5 Water bodies	51 Inland waters	511 Water courses
		512 Water bodies
	52 Marine waters	521 Coastal lagoons
		522 Estuaries
		523 Sea and ocean

Table 1: CORINE Land Cover (CLC) nomenclature. Numbers on the left represent the CLC code. (Source: EEA, 2016)

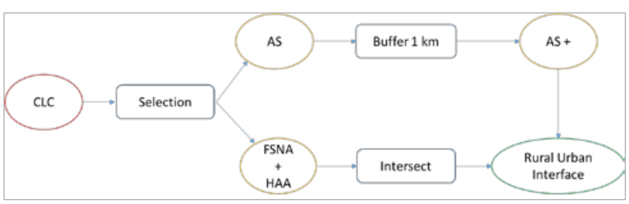


Figure 3 - Framework implemented in the Model Builder (ArcGIS™) to map the rural-urban interface. CLC=CORINE land cover; AS ~~=~~ = artificial surfaces; FSNA ~~=~~ = forest and semi natural areas; HAA ~~=~~ = Heterogeneous agricultural areas.

4 Results

4.1 LULC change analysis

The ~~LCLUC transition map (Fig. 4) was elaborated considering~~analysis of main changes in the area occupied by the first level hierarchy classes between CLC1990 and CLC2012~~. The resulting~~ allowed to visualize the main transitions ~~concern~~ occurred within the entire investigated period (Fig. 4) and thus to have an overview of the LULCC occurred in Portugal. It resulted that main transitions occurred between vegetated areas (i.e. AA and/or FSNA) to artificial surfaces (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 A transition from vegetated areas (AA and FSNA) to AS is also visible in centre-north and is probably due to the 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 isappeared to be an active and dynamic process predominating in the inner northern region and especiallyprevailing in the southern half of the country. Changes in surface were estimated, but it was revealed also in the inner northern region. Figure 5 shows the areas gained and lost for each CLC first-level class in absolute (as area gained and lost) and relative values (and the net percentage of changes, computed relatively to the total area of each class in the later land cover and express as percentage) (Fig. 5). The

. The main changes in terms of surface arewere registered by AS, which increaseincreased 165×10^3 ha, and AA, which decreasedecreased 184×10^3 ha. These values have a completely different impact, but in terms of net percentage of change: the net increase of AS is ofwas about 50%, while the net decrease of AA isdecreased only of 4.4%. The two classes which manly contributed to the increase in AS arewere AA, with 110×10^3 ha, and FSNA, with 50×10^3 ha.

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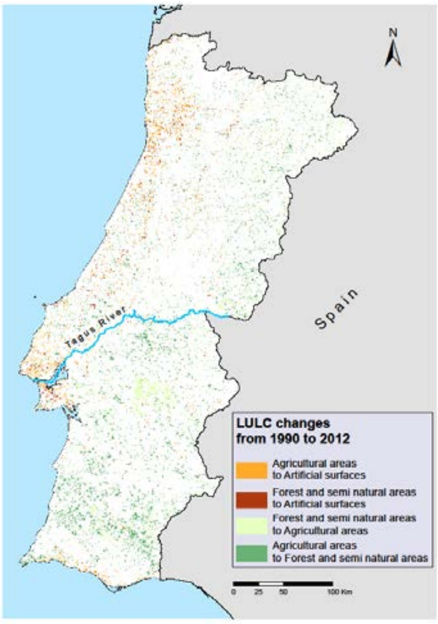
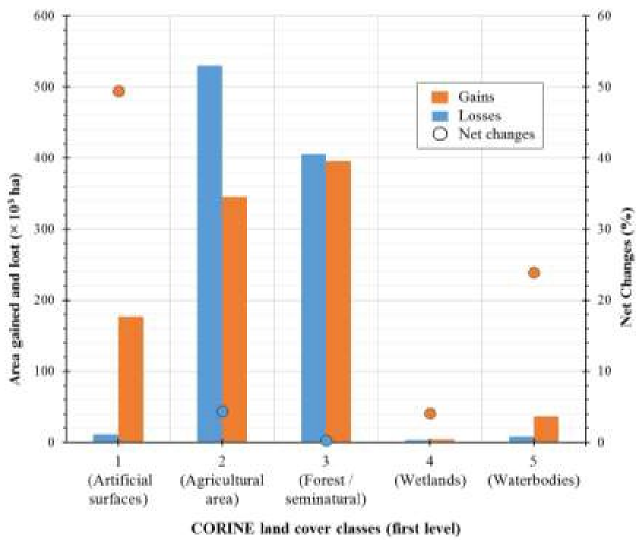


Figure 4 – Map of land cover/land use transition from 1990 and 2012, evaluated considering the first level hierarchy of CLC 1990 and CLC 2012



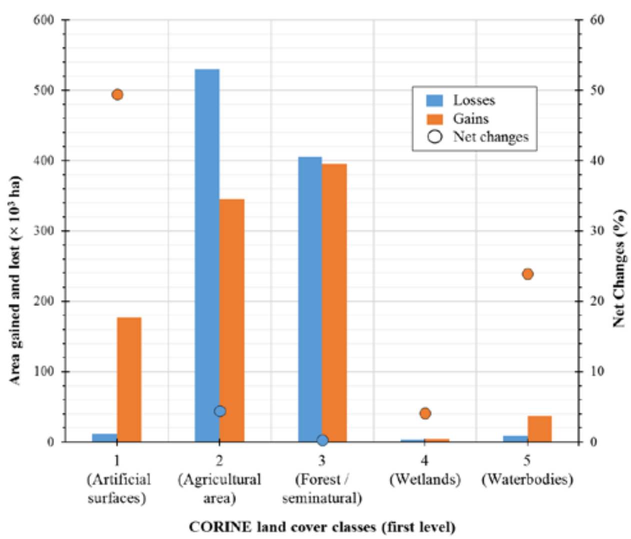


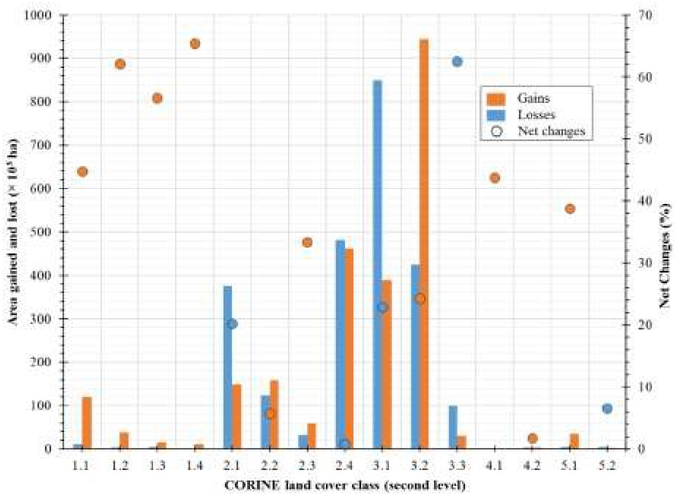
Figure 5 – Area ~~gained~~lost and ~~lost~~gained from 1990 to 2012 for each CORINE land cover classes, considering the first level hierarchy. Net percentage changes ~~are~~were computed relatively to the total area of each class in the later land cover.

A more detailed analyses was carried out to investigate changes from 1990 to 2012 occurred within classes considering the ~~5~~ second level hierarchy ~~(Table 1)~~.. Figure 6 shows that the majority of the CLC ~~sub-~~classes ~~display~~(level 2, Table 1) displayed 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 (code 32) registered a net gain of about 520 $\times 10^3$ ha (+24~~%)~~%), while the Forest area ~~decrease~~(code 31) decreased about 460 ×10³ ha (-23%). Arable land is(code 21) was the only agricultural areas AA registering an important negative net change of -225 ×10³ ha (-20%). Among artificial surfacesAS, Urban fabric (code 11) significantly increase ofincreased 110 ×10³ ha (45%), and, in terms of net percentage of change by class, all the other three AS sub-levels, including Industrial/commercial and transport unit (code 12), Mine/dump and construction sites (code 13), Artificial/non-agricultural vegetated areas (code 14), increased more than half.

10 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



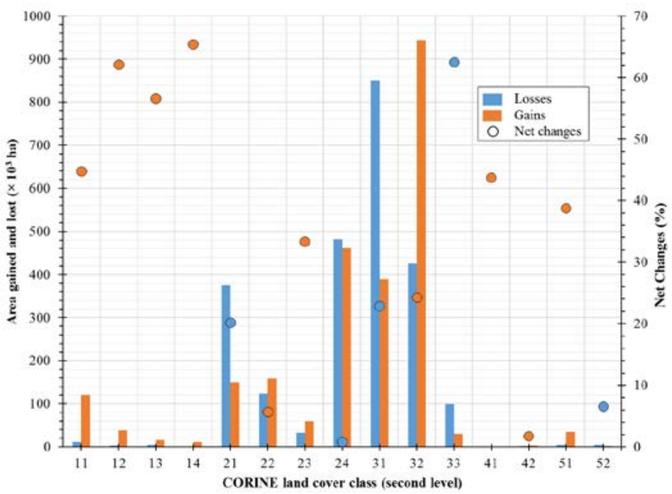
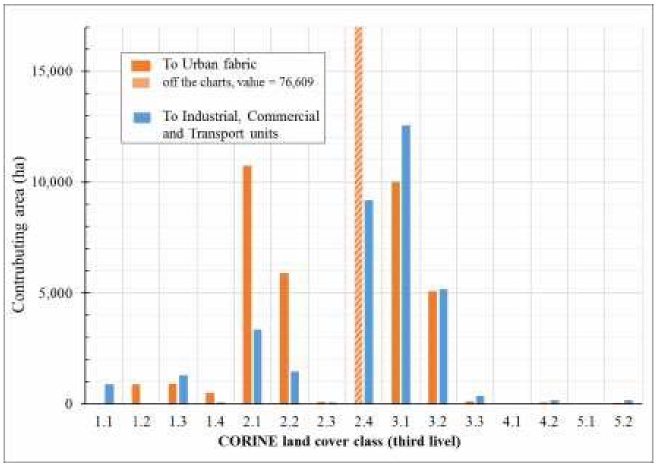


Figure 6 – Area lost and gained and lost from 1990 to 2012 for each CORINE land cover classes, considering the second level hierarchy. Net percentage changes arewere computed relatively to the total area of each class in the later land cover.

The bar graph withof the contributioncontributions to net changes in the artificial surfacesAS sub-classeslevels (Fig. 7) shows that Urban fabric, (orange bars), which 5 include includes buildings, roads and artificially surfaced areas, growthsgrew at the expense almost exclusive of heterogeneous agricultural areas, whileHAA (code 24). On the other hand, the increase of Industrial commercial and transport is (blues bars) was mainly due to the decrease of forest, heterogeneous agricultural areaForests (code31), HAA (code 24) and Scrub and/or herbaceous vegetation associations. (code 32).



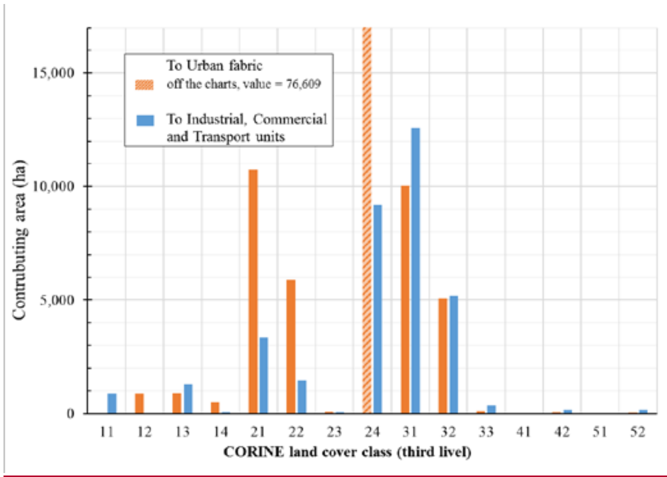


Figure 7 – Contribution to the net changes from 1990 to 2012 of "Urban fabric" (orange bars) and "Industrial, commercial and transport" and "Urban fabric" (blue bars) from the

10 **other CLC sub-classeslevels**

4.2 Spatial distribution and characterization of burned areaareas

The overlapping between polygons identifying burnt area (BA) and the CORINE Land Cover maps was performedAlmost all the CLC third-level classes belonging to investigate the land cover types most FSNA (code 3) were 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

4 the three years around each period (i.e CLC_year ± 1). Fires affected almost all the sub-classes wildfires in terms of the first level hierarchy forest

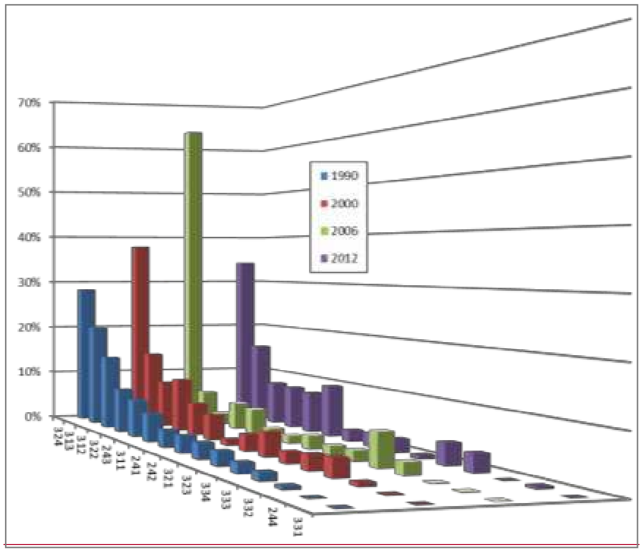
and semi-naturalburned area (Table 12), with the Transitional woodland-shrub (code 324) and Mixed forest (code 313) as the first and second more damaged classes in each period.. This trend iswas similar in all the four investigated frame-periods, as highlighted in Fig. 8, which reveals that the sum of burnt 8, where the same results are expressed in percentage for each CLC classes considering only the areas within these two classes exceed the 50%RUI, as the ratio of BA over the total. BA for the entire frame period. The peak of BA in Transitional woodland-shrub equal(code 324) equals to about 43 $\times 10^3$ 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 three over four sub-classeslevels of heterogeneous agricultural areasHAA (code 243, 241, 242) are morehighly 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 thewildfires, thus confirming the need of including HAA in the RUI's 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 12 – Classes of land use, as defined by the third level hierarchy of the CORINE Land Cover (CLC), affected by forest fires inexpressed in terms of Burned Area (BA) within the Rural Urban Area (RUI) during three investigated frame periods.

terms of Burned Area (BA) within the Rural Urban Area (RUI) during three investigated frame periods (1990, 2000, 2006,2012).



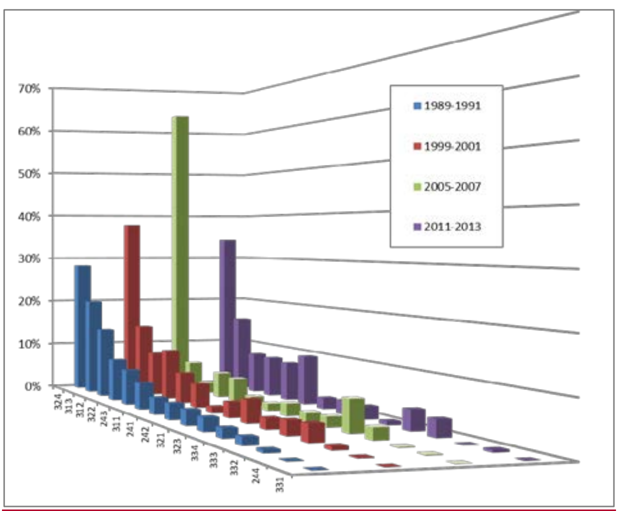
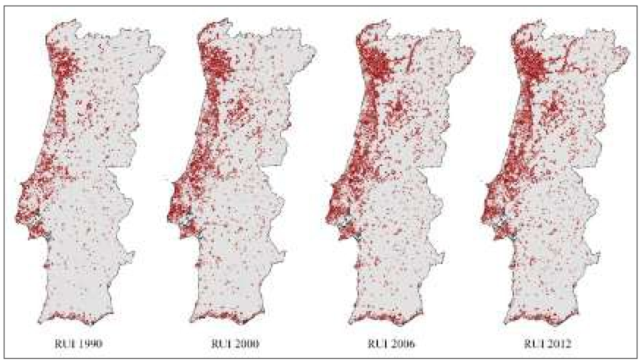


Figure 8 – Classes of land use, as defined by the third level hierarchy of the CORINE Land Cover, affected by ~~forest fires in terms of Burned Area within the Rural Urban Interface during three investigated frame periods (1990, 2000, 2006, 2012), expressed as percentage~~wildfires expressed in percentage as the ratio of BA affecting each CLC classes over the total BA for each frame period.

~~5~~ 4.3 RUI map

~~Evidence from the previous analyses indicates that heterogeneous agricultural areas (~~The classes FSNA and HAA~~) have to be~~

~~included~~ were considered in the ~~computation of the~~ present study to describe the flammable rural- area which, intermingling with the urban ~~interface: this land cover class contributes, with forest and semi-natural area (FSNA), to delimit~~area, defines the ~~vegetated burnable area.~~RUI. Thus, RUI maps ~~finally results~~arose from the zone of intersection between the sum of HAA plus FSNA and an enhanced area around ~~artificial surfaces (~~AS~~). It results~~ (Fig.3). The result was a ~~dynamic~~ zone of interface ~~which evolve~~evolving in space and in time ~~following~~ ~~the LULC changes~~due to LULCC (Fig.~~7). In~~ 9). Analyzing the period 1990-2012, the increase of RUI ~~is~~was more active in the north-west and along the coast, where the transition from ~~heterogeneous agricultural areas~~HAA to Urban fabric ~~is~~was particularly intense. This evolution ~~is~~was mainly due to the urban growth and to the intensification of the road network.



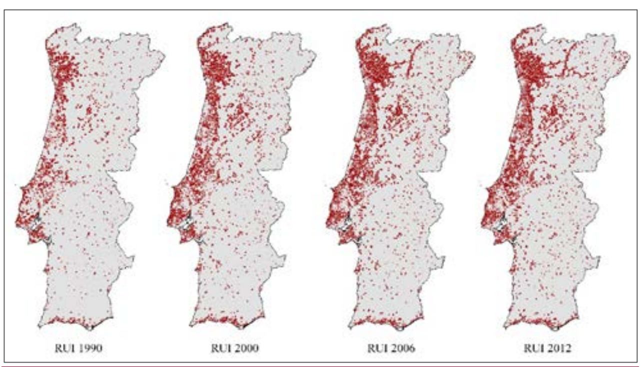
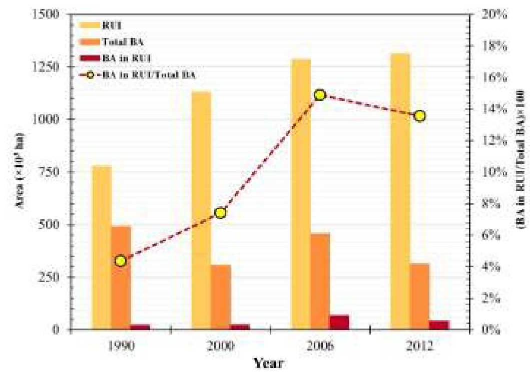


Figure 9 – Maps of the rural-urban interface (RUI) in Portugal estimated for the different periods of investigation, and corresponding to the available CORINE Land Cover inventories (1990, 2000, 2006, 2012)

~~**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.



The total size of the RUI, the fraction of BA within the RUI (BAR) and the total BA (TBA) were computed (Fig. 10). It resulted that RUI increased from about 780×10^3 ha in 1990 up to about 1310×10^3 ha in 2012 following a power-law (RUI=776310.year0.1686, R^2=0.99). Moreover, we computed the contribution both to the RUI and to the BA within the RUI (BAR) of each CLC class that make up the RUI, namely HAA (code 24), Forests (code 31), Scrub and/or herbaceous vegetation associations (code 32), and Open spaces with little or no vegetation (code 33). Results can be summarized as follows (Fig. 10): (a) the relative contribution of the those four CLC classes to the RUI increases in time at approximately the same rate; (b) HAA (code 24) is the CLC class with the largest area within the RUI (~50%); (c) in terms of relative BA within the RUI (BAR), the most affected class is the Scrub and/or herbaceous vegetation associations (code 32), followed by Forest (code 31), HAA (code 24) and then Open spaces with little or no vegetation (code 33). The total extent of the BA (TBA) fluctuated, with a maximum in 1990 (about 500×10^3 ha) followed by 2006 (~ 460×10^3 ha), while in in 2000 and 2012 its value was lower and equal to about 310×10^3 ha. The portion of BA included within the RUI (RBA), expressed as percentage over the total BA, tends to increase in time, passing from 4% and 7% in 1990 and 2000 to 15% and 14% in 2006 and 2012, respectively.

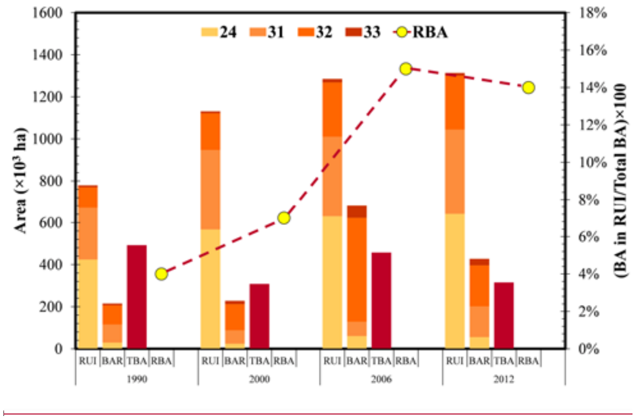


Figure 10 – Evolution of the absolute area of the rural-urban interface (RUI), ~~total~~ burnt area ~~(Total BA),~~within the RUI (BAR), total burnt area ~~in the RUI (BA in RUI)~~(TBA), and relative burnt area in the RUI (~~BA in RUI), from~~ RBA, as %), for each investigated period (1990 ~~to~~, 2000, 2006, 2012~~.~~).

5 Discussion

The ~~LCLUC~~LULCC analysis performed in the present study indicates that from 1990 to 2012 ~~artificial surfaces~~AS (code 1) globally ~~increase~~increased in Portugal ~~of~~ about 50% (Fig. 5). This growing process is in good agreement with previous findings of other authors (Tavares et al., 2012; Marques et al.,2014; Meneses et al., 2014; Oliveira et al., 2017). Moreover, the present study confirms that the urban growth ~~is mainly due to land cover~~ process in Portugal (quantified as changes ~~of areas previously~~in AS) was principally ~~occupied~~ caused by ~~heterogeneous agriculture~~the transition from HAA (code 24) and secondly ~~by forest and semi-natural land covers~~from FSNA (code 3) (Fig. 4 and Fig. ~~7). This growing process is evident in~~ 7). The urban development mainly affected the south coastal regions, mostly in the area between Portimão and Faro, ~~but is strongest~~and was particularly strong nearby to the main metropolitan communities of the northwest and littoral centre, ~~around~~namely 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)~~

1). Silva and Clarke (2002) described the characteristics and the recent intense urban growth of the metropolitan area of Porto (MAP) and Lisbon (MAL) associated ~~to~~with the economic growth in the end of the XX century ~~(Fernandez-Villaverde et al., 2013).~~(Fernandez-Villaverde et al., 2013). More in details, 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)~~, an intense urbanization along with train lines and main roads ~~diffusing from those major urban centres; and, (iv)~~ , and the 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)~~and 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 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 . The decline of the rental market in the country lead to the degradation of old urban areas and the increased constructionincrease of constructions 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 an irregular spatial growth, jeopardizing the viability plan new settlements (Silva and Clarke, 2002). (Silva and Clarke, 2002). The dispersion of the population and of 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).(Cardoso, 1996; Silva and Clarke, 2002).

Another active process identified by the performed change analysis is the abandonment of agricultural landlands nearby the inland urban areas, which leads to an increase of uncultivated semi-natural and forest areas (Fig. 4). The rapid growth of metropolitan 4) causing an increase of the urban/rural interface.

areas had been associated to intensive rural exodus by other authors (Marques et al., 2014). Between 1970 and 1990 anurbanized 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.

As regards the RUI definition and mapping model developed in the present study, we tested different buffer width from 100 m to 2 km, which led to different RUI's size but, in essence, to approximately equivalent results relatively to the RUI's dynamic. In literature, Vilar et al. (2016) applied a buffer width of 100 m, corresponding to the median of the distances defined in each country's national legislation (Portugal, Spain, South-France and Italy) for protection against wildfires, which makes brush clearing obligatory within a certain radius around each house located close to forests or scrublands. In US, interface WUI was defined as developed areas in the vicinity of wildland vegetation and mapped considering census blocks above 6.17 housing units/km^2 that are within a distance of 2.4 km from wildland vegetation (Radeloff et al., 2005). Finally, we decided to show results obtained applying a buffer width of 1 km because smaller values, even if more in line with the Portuguese national indications, could bias the results, given that the spatial resolution of the CLC inventory was of 500 by 500 meters.

RUI definition aimsaimed to map the area developed area located in close proximity of wild vegetation, where wildland fireswildfires can cause deaths, injured, damagedamages to human structures, and finally where vegetation is prone to fire and human-caused fireswildfires are more likely to occur. Nevertheless, since it is RUI map was not based on fire incidence measures, RUI doesthus it not aimaimed 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).(Radeloff et al., 2005; Parente and Pereira, 2016). Most of ~~RUI~~ RUI's area detected in Portugal (Fig. 9) ~~is~~was located in regions of high population density and surrounding major cities, while ~~RUI increase~~RUI's growths mainly ~~occurs~~occurred in the transition zones from ~~agricultural areas~~vegetated lands (AA and ~~forest and semi-natural areas~~FSNA) to ~~artificial surfaces~~AS (Fig. 4). Urbanization and the consequent reconfiguration of Portuguese cities caused new urban problems and challenges associated to the increased fragmentation of the ~~city~~cities and different rural-urban relationships, ~~affecting small as well as medium and large cities,~~ as also reported for Portugal and Spain ~~(Trigal, 2010).~~(Trigal, 2010). It is important to underline that the impressive increase of the RUI and ~~burnt area in~~of BA within the RUI, detected 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~~included high and highly variable severity ~~forest~~ fire regimes ~~(Theobald and Romme, 2007).~~(Theobald and Romme, 2007). In Europe, ~~Fox et al. (2015)~~ Fox et al. (2015) found a progressive increase in fire risk in French Maritime ~~Alpes during approximately~~Alps in the ~~same~~ period ~~(~~1960–2009~~). Badia et al. (2011)~~. Badia et al. (2011) noticed that two representative Mediterranean WUI ~~located~~areas in Catalonia were more prone to ~~forest fires~~wildfires in the most recent decade of 2000 than in the 1990s. ~~Pellizzaro et al. (2012) assess and analysed WUI~~Pellizzaro et al. (2012) analyzed WUI's dynamics and landscape changes in a tourist area of North-East Sardinia (Italy) 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~~ and discovered that LULCC was largely associated to a transition from an agro-pastoral economy to one based on tourism~~; (ii) gradual~~. Moreover they showed: an increase in the number of houses and dwellers, which tripled during the study period, as well as a sharp grow in summer population ~~load which can be 10 times greater than in other seasons; (iii)~~; rose of road network length~~; (iv)~~ and; finally, increase ~~in~~of the 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).~~.

The inspection of the accurate Soil Use and Occupancy Chart national map (COS2007 v2.0) allowed us to identify the vegetation types and major habitats/plant communities corresponding to each one of the CLC classes for Portugal. Table 3 of the annex/supplementary material, shows the composition of the CLC classes in terms of COS classes. For simplicity, results are only presented for COS classes with more than 1% of total CLC area. Nevertheless, it is important to underline that these 19 COS classes account for 98.3% of total CLC area. Despite some expected differences between classifications, essentially noted in CLC classes less affected by wildfires, results for all the other classes can be summarized as follows: (i) Temporary dryland crops is the larger COS class (22% of total CLC area) and accounts for higher area fraction in CLC Agricultural area (code 2) and Scrub and/or herbaceous vegetation associations (code 32); this is particularly consistent with the agricultural practices, especially in southern Portugal; (ii) COS class of Temporary irrigated crops is well distributed by CLC classes of Rice fields, Permanently irrigated land, Pastures, as well as Beaches, dunes, sands; (iii) COS Shrub classes are particularly present in CLC classes of Shrubs, Pastures as well as in Open spaces with little or no vegetation; (iv) Tree vegetation in COS is also well related to the correspondent CLC classes and allows us to better understand the composition of Forests and Agricultural areas; for example, pure or mixt forests of Cork and Holm oak trees are particularly evident in the CLC classes of Agro-forestry areas, Broad-leaved forests, and Non-irrigated arable lands; on the other hand, Eucalyptus (pure or mixed forests) in COS are important components of the CLC classes of Mixed forests, Complex cultivation patterns, Annual crops associated with permanent crops, and Broad-leaved forests; finally, pure *pinus pinaster* forests in COS are comprised in the CLC classes of Coniferous forests, Transitional woodland-shrub, and are especially important in Beaches, dunes, sands, where account for 30% of total area; this finding is in good agreement with the presence of *pinus* forests in the entire central western coast.

It is important to underline that, from 1990 to 2012, the increase in the BA within the RUI is higher (100%) than the increase in the RUI area (70%). This result suggest that other factors, besides the increase of the RUI area, are responsible of the increase of the burnable area within the RUI. In this regard, it is important to take into account some of the specific characteristics of the country, well described in terms of demographic, territory and forest statistics compiled in Feliciano et al. (2015), which can help to understand the most important factors affecting the forest management in Portugal. Forest is nowadays the dominant land use in the country (with more than 35% of total area), followed by bushes and grasslands (>29%), and agricultural areas (>24%) (Feliciano et al., 2015; FAO, 2018). According to the National Forest Inventory (IFN, 2010), in the 1995-2010 period, four tree species occupied about 85% of total forest area: Eucalyptus (22%-27%), Cork oak (23%-24%), Maritime pine (30%-23%) and, Holm oak (10%-11%). The first three species have the ability to generate land and business income exceeding 50 euros/ha/year (CM, 2015). Most of the forests and wooded lands (>93% in 1995) have non-industrial private owners and there is a high fragmentation of the forest property, particularly evident in the private sector (Mendes et al., 2004). Management practices are also very different and changed significantly in the last years, especially in non-industrial private forest (Novais and Canadas, 2014). According to Feliciano et al. (2015), 1/3 of Eucalyptus area is well managed by the industrial pulp and paper companies, with their own forest management and wildfire prevention/fighting resources, while the remaining area is managed by non-industrial private owners, characterized by different objectives and economic logics. In addition, there is a significant heterogeneity in the spatial distribution of all these characteristics/factors (Baptista and Santos, 2005). Small forest holdings (<10 ha), mainly composed by pine and eucalyptus with low profitability, are much more frequent in the northern and central Portugal, while large properties (>100 ha), essentially of cork oak or a complex and unique agroforestry system of cork oak savanna ("*montado*"), are predominant in the southern regions of the country. Table 4 of the annex/supplementary material, provides a general description of the main characteristics of forest holdings and forest owners and summarizes the interrelationship between these factors.

Other aspects related to LULCC, such as climate change and biodiversity, are somewhat outside the scope of the present study. However, the abandonment of rural and forest areas, traditional agricultural practices, and the lack of forestry management practices lead to an increase of biomass and fire risk, which can be empowered in a warmer and drier future climate and may have profound impact on ecosystems and biodiversity. For example, the *montado*, which is composed by sparse cork oak trees and a diversity of understory vegetation (e.g., shrub formations, grasslands), supports higher levels of biodiversity. The decrease in demand and price of cork has led to a reduction in management practices and to the abandonment of these lends, leading to the invasion of shrubs, reducing the biodiversity and degrading the services provided by these ecosystems (Bugalho et al., 2011).

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~~of RUI was 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~~ Moreover, the decrease of relative BA ~~in~~within the RUI from 2006 to 2012~~. These changes~~ could be associated ~~to~~with the ~~consequences~~relative decrease of BA in the ~~recent economic and financial crisis, such~~ last investigated period, as ~~immigration and emigration trends (Cairns, 2011; Ganga et al., 2016; Fonseca and McGarrigle, 2014) and~~a consequence of recent plans for territorial spatial planning and protection of forest against forest fires ~~(Mateus and Fernandes, 2014; Parente et al., 2016).~~(Mateus and Fernandes, 2014; Parente et al., 2016). At European level, urban sprawl's complexity and magnitude motivated the European Commission to recommend actions ~~to ameliorate their impacts and~~and to coordinate land use policies, within the European Cohesion Policy 2007~~–~~-2013 period ~~(CEC, 2006; EEA, 2006).~~(CEC, 2006; EEA, 2006). In Portugal these efforts ~~are~~were 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 the 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).~~(Noronha Vaz et al., 2012). However, as far as we know, there is no a specific or general Portuguese legislation about WUI or RUI. It only exists one general mention about RUI in the National Plan to Protect the Forests against Wildfires (CM, 2009). In this Plan it is suggested that to protect urban-forest interface is necessary to create and maintain an external buffer strips (10-100 m) around population clusters, especially in those with the highest fire vulnerability, as well as around parks, industrial polygons, landfills, housing, shipyards, warehouses, and other buildings.

Finally, we firmly believe that the results of this study are sufficiently motivating to promote the development of specific policies and legislation, as well as changes in forest and fire management. The increase of the RUI area and particularly of the BA within the RUI clearly suggests the need of improving fire prevention measures and preparedness policies for this interface region. In fact, 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 LULCC, causes this area to be under the use of people not educated for fire and unware of possible source of ignition. In particular, portuguese forestry/forest managers must prioritize sustainable forest management practices and make brush clearing obligatory. These paradigm shifts make even more sense if one takes into account that the risk of fire is likely to increase in a future climate with a higher frequency of longer and more intense extreme events, such as drought and heat waves.

6 Conclusions

Continental Portugal registered important land cover changes (about 9% of total landthe whole area) and an increase of the rural-urban interface increase in the investigated period (1990-2012.). Most significant changes arewere associated to transitions from the following CORINE Land Cover classes: Agricultural areas (35.1%) and aorestForest and semi-natural areas (15.2%) to Artificial surfaces (including Urban areas); Agricultural areas to aorestForest 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 appreciable only significantly positive for Artificial surfaces, representingwhich registered a substantial increase (of about 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 arewas far from uniform within the territory. Urban sprawl iswas 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 andA promoted socioeconomic development, within the country, the intense rural abandonment and, in the particular case of *Algarve*, the development of mass tourist industry. could act as main drivers for the expansion and reconfiguration of urban areas. On the other hand, transitionsin the south and interior north regions we assisted to a transition to vegetated land use/land cover types occurred mainly in the south and interior north regions. LULC subclasses with higher , probably caused by deforestation/afforestation and rural abandonment. The CLC classes mainly affected by these changes in the study period werewhere Scrub and/or herbaceous vegetation associations, Forests and Heterogeneous agricultural areas.: the increase in Artificial surfaces' areas is due surfaces was precisely due to transitions from these classestype of land cover/land use. Vegetated classes with higher burnt area within the RUI in the study period were: Transitional woodland-shrub, the three types of Forests considered in the CLC inventories and, the three sub-levels of Heterogeneous agricultural areas. 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 analysisanalyses of RUI's size, burnt areaareas and burnt areaareas within the RUI in the fours investigated periods (1990, 2000, 2006, 2012) allow to conclude that, from 1990 to 2012, RUI increased about 70%, burnt area decreased 35% but, nonetheless, burnt area within the 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~~provides precious suggestions as for what is the global distribution and evolution of RUI in Portugal ~~and identify~~, identifying which regions need to be prioritized in term of RUI monitoring ~~and forest fire protection~~.

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Annexes/supplementary material

		Road network and associated spaces	Temporary dryland crops	Temporary irrigated crops	Vineyards	Olive groves	Permanent pastures	Agroforestry systems (AFS) of cork oak with pastur	AFS o holm oak with pastures	Forests of Cork oak	Eucalypt forests	Pinus pinaster forests	Eucalyptus forests with other coniferous/softwood	Pinus pinaster forest with broadleaved/hardwood	Dense shrubs	Less dense shrubs	Dense sclerophyllous vegetation	Open forests of pinus pinaster	Natural water courses	Dam reservoirs
211	Non-irrigated arable land	3%	19%	2%	1%	9%	10%	4%	15%	3%	2%	2%	0%	0%	4%	2%	1%	1%	1%	5%
212	Permanently irrigated land	4%	55%	8%	1%	4%	4%	2%	5%	2%	2%	2%	0%	1%	0%	0%	0%	0%	1%	1%
213	Rice fields	6%	16%	16%	0%	1%	7%	7%	8%	9%	1%	1%	0%	0%	0%	0%	0%	0%	3%	0%
221	Vineyards	5%	31%	4%	9%	8%	4%	1%	3%	1%	5%	3%	1%	2%	2%	2%	2%	1%	0%	2%
222	Fruit trees and berry plantations	7%	23%	2%	2%	8%	4%	0%	1%	0%	3%	1%	0%	1%	3%	2%	10%	0%	3%	3%
223	Olive groves	1%	48%	1%	3%	9%	6%	2%	6%	1%	2%	1%	0%	1%	1%	0%	2%	1%	1%	6%
231	Pastures	2%	18%	7%	0%	0%	6%	0%	7%	1%	2%	2%	0%	1%	20%	5%	1%	0%	2%	3%
241	Annual crops associated with permanent crops	5%	31%	3%	1%	4%	3%	0%	2%	1%	9%	5%	5%	2%	5%	1%	2%	3%	1%	1%
242	Complex cultivation patterns	7%	17%	4%	2%	5%	4%	1%	3%	2%	10%	7%	2%	2%	5%	2%	2%	3%	1%	2%
243	Land principally occupied by agriculture, with	6%	15%	3%	6%	3%	3%	1%	1%	2%	7%	7%	2%	2%	9%	3%	4%	4%	2%	3%
244	Agro-forestry areas	1%	37%	1%	0%	6%	13%	5%	9%	5%	1%	0%	0%	0%	0%	0%	0%	0%	1%	7%
311	Broad-leaved forest	3%	17%	1%	1%	3%	9%	3%	11%	4%	9%	2%	1%	1%	3%	1%	2%	1%	1%	8%
312	Coniferous forest	7%	2%	5%	4%	1%	1%	1%	0%	2%	6%	16%	2%	3%	14%	2%	1%	11%	1%	2%
313	Mixed forest	8%	4%	7%	4%	1%	1%	2%	0%	3%	20%	8%	5%	3%	7%	2%	1%	2%	0%	2%
321	Natural grasslands	5%	15%	2%	1%	3%	6%	0%	1%	0%	1%	2%	0%	0%	23%	11%	3%	1%	1%	5%
322	Moors and heathland	4%	6%	1%	5%	2%	1%	0%	0%	0%	3%	6%	0%	1%	35%	12%	0%	4%	0%	1%
323	Sclerophyllous vegetation	3%	12%	1%	0%	3%	8%	0%	4%	3%	3%	0%	0%	0%	0%	0%	17%	0%	10%	8%
324	Transitional woodland-shrub	4%	18%	2%	3%	2%	4%	1%	3%	3%	8%	9%	2%	1%	7%	3%	3%	2%	2%	3%
331	Beaches, dunes, sands	1%	3%	8%	0%	0%	0%	0%	0%	0%	0%	30%	0%	0%	1%	1%	2%	1%	11%	0%
332	Bare rocks	0%	1%	1%	0%	1%	0%	0%	0%	0%	1%	1%	0%	0%	41%	24%	2%	1%	0%	1%
333	Sparsely vegetated area	2%	1%	1%	0%	1%	0%	0%	0%	0%	1%	3%	0%	1%	35%	35%	1%	3%	0%	1%
	Sum	4%	22%	3%	2%	4%	6%	2%	5%	3%	6%	5%	1%	1%	6%	2%	2%	2%	1%	4%

Table 3 – Fraction of COS2007v2.0 classes' area within CORINE land cover classes.

Area	**< 1 ha**	**< 5 ha**	**5 – 20 ha**	**5 – 100 ha**	**>20 ha**
Forest owners (%)	31%	30%	14%	10%	15%
Area (%)	10%	16%	12%	7%	55%
Main tree species	Maritime pine	Maritime pine and chestnut	Eucalyptus		Holm oak and cork oak
Investment	No investment		With investment		
Management practices	No active management	Management depends on how economy goes		Active management	
Income	Property-reserve irregular income			Forest-enterprise	
Region	Northern and central				Southern

Table 4 - Main characteristics of a sample of forest holdings and forest owners studied by Baptista and Santos (2005). Adapted from Feliciano et al. (2015).