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Addressing wildfire risk in forest management with a wildfire resistance indicator

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ABSTRACT

As a Mediterranean country, in Portugal forest fires are considered an issue. In addition, the main tendency is that the number of fires and burned area will increase, as well as large and catastrophic fires. Thus, the increase of the social, ecological and economic damages. Through forest prevention it is possible to control the only controllable factor, vegetation. The objective was to find and test the most suitable available indicator to address wildfire risk in forest management. The selected indicator is based on biometric and location variables. Besides, it considers the spatial context since stand susceptibility to fire is influenced by the surroundings. The wildfire resistance indicator was tested in Chamusca and Vale do Sousa, considering forest treatments randomly selected for each stand for 2014, 2015 and 2020. This allowed to identify where the most susceptible areas are located, with lower wildfire resistance. The indicator can be integrated as another ecosystem service by a management planning approach to evaluate the trade-offs between a set of criteria that includes wildfire resistance. In sum, this study showed one possible way to address wildfire risk in forest management.

Keywords: Indicator, Wildfire resistance, Spatial context, Forest treatments, Prevention.

TÍTULO DA DISSERTAÇÃO: Abordagem do risco do fogo na gestão florestal com o indicador de resistência do fogo

RESUMO

Em Portugal, como nos países mediterrâneos, os fogos florestais são uma preocupação. Além disso, a tendência é que o número de fogos e áreas ardidas aumentem, como também os grandes e catastróficos fogos. De modo que, aumentará ainda mais os impactos sociais, ecológicos e económicos. Através da prevenção florestal será possível controlar o único fator controlável que influência o fogo, a vegetação. O objetivo foi selecionar e testar o indicador que seria mais indicado para integrar o risco do fogo na gestão florestal. O indicador selecionado é baseado principalmente em variáveis biométricas e de localização. Para além disso, também considera o contexto espacial em que povoamento está inserido, cuja suscetibilidade ao fogo depende igualmente do que lhe rodeia. O indicador de resistência ao fogo foi testado na Chamusca e no Vale do Sousa, considerando tratamentos florestais para cada povoamento em 2014, 2015 e 2020. Com efeito, este permitiu identificar as áreas onde apresentam menor resistência ao fogo. No futuro, o indicador pode ser integrado num modelo já desenvolvido, que avalia *trade-offs* entre os diversos serviços de ecossistema, sendo este mais um a considerar. Em conclusão, o estudo mostrou um possível procedimento em integrar o risco do fogo na gestão florestal.

Palavras-chave: Indicador, Resistência ao fogo, Contexto espacial, Tratamentos florestais, Prevenção.

RESUMO ALARGADO

Portugal é o país na Europa com a maior frequência de ignições e área ardida. Definitivamente, é uma preocupação, tanto para a sociedade em geral como para os proprietários florestais. Sensivelmente, 93.4% da floresta pertence a proprietários privados e é na zona norte e centro do país que se encontra a maioria das propriedades com menor dimensão. As Zonas de Intervenção Florestal (ZIF's) surgiram para apoiar estes mesmos, de maneira a proteger os seus próprios interesses e alcançar benefícios semelhantes aos dos proprietários florestais que possuem maior área. Bem como, implementar proteção integrada da defesa florestal contra agentes abióticos e bióticos.

A tese tem como objetivo selecionar e testar o indicador que seria mais indicado para integrar o risco do fogo na gestão florestal. Com este permitir apoiar e guiar as decisões dos proprietários florestais face aos possíveis danos causados pelo fogo, fazendo prevenção florestal.

O indicador selecionado foi baseado nas necessidades dos proprietários, em termos de gestão florestal face ao risco do fogo. Sabendo que o nível de dano nos povoamentos florestais está relacionado com o comportamento do fogo, dimensão das árvores e estrutura dos povoamentos, as variáveis usadas têm de respeitar isso mesmo. Igualmente, que a fonte de informação possa ser facilmente obtida. Desta forma, o indicador de resistência ao fogo foi selecionado, sendo baseado principalmente em variáveis biométricas e também de localização correlacionadas com o comportamento do fogo. Mais do que isso, tem também em consideração o contexto espacial, já que a suscetibilidade do povoamento ao fogo depende do que está em redor. Todas as variáveis podem ser obtidas por inventário florestal, exceto os dados meteorológicos.

De maneira a testar o indicador, foram usadas duas áreas de estudo. Uma no centro de Portugal na região da Chamusca, ZIF Chouto-Parreira e outra a norte, na região do Vale do Sousa, que incluí duas ZIF's (Paiva, e Entre Douro e Sousa). Para isso foi necessário usar quatro modelos, um com objetivo em simular a biomassa dos matos, e os outros três para os povoamentos florestais compostos por Eucalipto, Pinheiro bravo e outras espécies incluindo também povoamentos mistos. Estes três últimos modelos têm a mesma estrutura, calculam a probabilidade de ocorrência de fogo anual, preveem a probabilidade de ocorrência de mortalidade e estimam a proporção de árvores mortas. Posteriormente, calculou-se o indicador específico de resistência ao nível do povoamento e só depois ao nível da paisagem, visto que este último depende do anterior.

Os resultados foram apresentados em mapas, de maneira a tornar-se o mais visual possível. Apresentaram-se os mapas com os dados de inventário e os mapas com a ocupação florestal simulada para 2014, 2015 e 2020 que já incluem tratamentos florestais. Foram visualizadas e analisadas relações entre a composição florestal e a sua resistência ao fogo, como também relações com gestão florestal. O próximo passo será integrar este indicador num método multicritério, em que é possível confrontar os diversos serviços de ecossistema, e posteriormente analisar os *trade-offs* entre os diferentes objetivos.

Como anteriormente se referiu, o indicador de resistência depende sobretudo de variáveis que se obtêm em inventários florestais. Por um lado é vantajoso para os proprietários pois desta forma os dados tornam-se acessíveis, e por outro pode ser considerado um fator limitante, porque a qualidade do indicador depende diretamente da qualidade desses mesmos dados. Neste caso de estudo, a maior limitação foi a falta de dados relacionados com os matos.

No futuro, poderiam ser incluídos outros tipos de uso do solo, como por exemplo terrenos agrícolas, onde muitas as vezes se iniciam os fogos florestais. Para além disso, também seria interessante considerar uma área em volta da própria área de estudo, dado que os povoamentos na fronteira também terão de ser influenciados pelo que está em redor.

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1 INTRODUCTION

Forest fires are a common issue in all Mediterranean countries and Portugal is not an exception. Several damages are associated to forest fires, such as social, ecological and economic. In Europe, Portugal has the highest frequency of fire ignitions and burnt area (Catry et al., 2010b). In addition, the main tendencies are that the number of fires and burnt area will increase as well as large and catastrophic fires (Paton and Fantina, 2013).

A forest fire is influenced by weather, topography and vegetation, the last one being the only that can be altered, through preventive silviculture and fuel management. There are three types of possible forest interventions: reduction, isolation, modification (Fernandes, 2006). Reduction aims at decreasing the fire intensity, changing the forest vertical continuity and loading. Isolation refers to cut the fuel horizontal continuity in order to restrict the fire. Conversion aims to substitute the vegetation type, decreasing the fire behavior magnitude. So, in terms of avoiding the worst case scenario, if a surface fire passes to a canopy fire, it is advised to reduce surface fuels, increase the crown base height, decrease crown density and let in the forest large trees of fire-resistant species (Agee and Skinner, 2005).

In Portugal, approximately 93.4 % of the forest area belongs to private owners (Mendes et al., 2004), besides in the North and Central part of the country, the small-scale forest owners are in majority. Therefore, for them to make profit and pay for forest services is more challenging (Feliciano and Mendes, 2011). A solution came with the formation of Forest Owners Associations (FOA). These facilitate the cooperation between owners to protect their common interests and achieve similar benefits as larger-scale forest owners have, in terms of market opportunities, forest management and protection (Mendes et al., 2011). Consequently, the FOA or a collective person became the management entity of Forest Intervention Zone (ZIF). ZIF by definition is a continuous and delimited area, dominated by forest, which has to be under a forest management plan and a specific forest intervention plan, and it is managed only by one entity (Insituto da Conservação da Natureza e das Florestas (ICNF)). The aim is to implement an integrated forest defense against abiotic and biotic agents and manage the area in order to achieve a sustainable forest.

Taking into account all this panorama, the forest owner as individual or as association will need help to deal with this issue. As, at least, it is unquestionable that in the case of a fire there is always a possibility of damage occurrence. Therefore, the improvement of fire prevention is vital and to achieve that, tools oriented to forest managers should be developed and tested.

The research objective is to find the most suitable available indicator to address wildfire risk in forest management planning, supporting the definition of forest treatments allocation in time and space. In this way provide technical assistance to forest managers.

1.1 Synopsis

The purpose of finding the most suitable forest wildfire indicator is mainly to guide the forest managers in the identification of critical areas. This allows to increase the stand resistance to fire and also to show how to change the spatial continuity considering the economic viability at landscape level (González-Olabarria et al., 2012). In this way, it will make cheaper and more efficient to apply the preventive measures by stablishing priorities (Kaloudis et al., 2005). Therefore, it should be expected that the indicator is able to provide the potential damage for pre and post-fire decisions (Catry et al., 2010a).

There is already some research related to the construction of indicators to support the fire risk assessment. It is possible to organize the indicators according to the objective and study area characteristics. For example, in a supporting operational firefighter plan it is needed to be more focused on variables that show the accessibility to the area, the firefighter resources availability (equipment, water tanks and fire stations) besides all the characteristics of the area such as topography, hydrography and land use (Sauvagnargues-Lesage et al., 2001). In a protected area the vulnerability to fire should be measured according to the present sensitivity (habitat relevance, patch fragmentation, vegetation susceptibility and recover) and stressors such as human in general, tourists and also caused by agriculture (Aretano et al., 2015). In a Wildland-Urban Interface, a new approach involves paying attention to the relationship between the dwellings spatial arrangement and fire behavior (Lampin-Maillet et al., 2011, 2009). So, within the forest should be applied an indicator which is adapted to the forest itself. In general, the indicator should include biometric variables.

Another aspect is that the study area can be all the country, region, or even a small property and there is not a specific manner to do it. For example, in Portugal, risk mapping is being done through the fire risk index, composed by a static index and a dynamic index. The static index is based on variables that don’t change fast, such as past wildfire history, topography, land use (Verde and Zêzere, 2010), the population density and human accessibility. The last two variables intend to represent the anthropogenic fires (Catry et al., 2009). The static index provides long-term predictions, supporting prevention plans (San-Miguel-Ayanz et al., 2003). The dynamic index is based on variables that continuously change and for that it is used the Fire Weather Index (FWI), which evaluates the weather influence on the forest fuels and fires (Groot, 1987). Since, it gives short-term predictions, it will support the firefighters operations, during the fire season (San-Miguel-Ayanz et al., 2003). However, this is done for all country and maybe can be applied for a region but for a specific property the field data become even more relevant (Mbow et al., 2004), since more detail is required. For example, in the work of Maeda et al. (2011) the authors assumed that their method based just on remote sensing data only can be used at regional scale.

In the case of a managed forest, the owner wants to ensure prevention against fire, and so, forest treatments should be applied in order to alter the forest structure. Moreira et al. (2011) argues that the structure of the forest might be more important for the fire behavior than the composition. Actually, there are studies which rank the different species according to their fire proneness and the results are explained trough their forest structure (Barros and Pereira, 2014; Silva et al., 2009). In this way, a meteorological indicator described, for example, in Mokhov & Chernokulsky (2010) work, is not enough in terms of providing information to the forest owner since vegetation variables are not included (Grishin and Filkov, 2011). Using computer simulations is another approach, for instance BehavePlus (Heinsch and Andrews, 2010), FlamMap (Finney, 2006), which are fire behavior models. For example, Finney et al. (2006) show a simulation system which implements fuel treatments over landscapes to evaluate the impact on potential fire behavior over decades. This type of approach requires variables that are continuously changing, such as wind speed and fuel moisture. If the purpose is to do a long-term plan, it becomes an important limitation. Besides, Marques et al. (2012) explain that including the non-controlled variables did not improve his predictions and also in the work of Verde & Zêzere (2010) the meteorological parameters were not significant when evaluating at long-term. For all these reasons, some of the previous variables mentioned are not oriented to the forest managers, by that I mean they are not easy to acquire, to understand and not focus on the forest. Some research took these issues in consideration by using mainly biometric variables, which are easy to measure and reflect the forest structure, such as basal area, number of trees, and others. (Botequim et al. 2008; Garcia-Gonzalo et al. 2012; Marques et al. 2012; Garcia-Gonzalo et al. 2014; Catry et al. 2010; Garcia-Gonzalo et al. 2011; Rodríguez y Silva et al. 2012; Ferreira et al. 2015). The level of injury is related with fire behavior, tree size and stand structure (Garcia-Gonzalo et al. 2011), for that reason the chosen biometric variables must be highly correlated with fire behavior. Botequim et al. (2008) developed a post-fire mortality model, by first calculating the mortality probability if a wildfire occurs in the stand and second it calculates the degree of mortality caused by wildfire (dead trees proportion in the stand). This model is based on relationships between biometric variables and fire behavior which are expected to occur. For example, the relation between basal area (G) and quadratic mean diameter (dg), which represent a non-linearly related to the number of trees per hectare, points that higher the density greater it will be the death probability. Also, the same model uses location variables such as slope, showing that higher the slope more susceptible is the stand to burn. Already, in Portugal, where the most abundant species are Maritime Pine (*Pinus pinaster*) and Blue Gum (*Eucalyptus globulus*), were developed specific models for each species by Garcia-Gonzalo et al. (2011) and Marques et al. (2012), and also by Botequim et al. (2013) and Marques et al. (2011), respectively. Generic models were also developed by Garcia-Gonzalo et al. (2012) and Botequim et al. (2008), which did not focus in any species in particular.

Particular attention should be paid to the shrub biomass within the forest. Fuel management, not only can limit the fire spread but also decrease impacts on people's assets (Moreira et al., 2011). Consequently, if fuel modification is not applied, the forest fire resistance will be harder to improve (González-Olabarria and Pukkala, 2011). Thus, the integration of the fuel load (shrubs) must not be forgotten (Chuvieco et al., 2010), since without it, the fuel type definition is not well represented (González-Olabarria et al., 2012). Botequim et al. (2015) described a shrub biomass model facilitating the inclusion of shrub management in the forest management plans. The estimation of the shrub biomass is difficult to do due to its structural heterogeneity and dynamic nature. The model is based on shrub (% resprouting, shrub age), stand (basal area) and location (temperature) variables.

Normally, the biometric variables are studied at stand level, however, a new idea was developed by considering also the neighboring stands (Ferreira et al. 2015; González-Olabarria & Pukkala 2011; Kaloudis et al. 2008; González-Olabarria et al. 2012). In that way, the landscape features are taken into account, since the stand susceptibility to fire is influenced naturally by the surroundings. This concept was first developed by González, Palahí, & Pukkala (2005) in Spain and later taken further by Ferreira, M. F. Constantino, et al. (2014) in Portugal. It integrates the spatial context by considering the neighboring stands characteristics, the sharing border percentage between stands, stand relative positions, physical barriers, altitude and aspect.

2 STUDY AREAS

2.1 Chamusca

The study area is situated in central part of Portugal in Chamusca region, which covers 74 600 ha, 124 km North of Lisbon. The Tagus river divides this region, on one side we find the Campo county where the altitudes vary between 15 to 25 m and on the other side we find the Charneca county with the altitude ranging from 100 to 190 m. It includes Vale Cavalos; Parreira and Chouto; Carregueira; Ulme; Pinheiro Grande and Chamusca as parishes.

Chamusca has a Mediterranean climate, presenting dry and hot summers and cold and rainy winters. The mean annual precipitation is about 795.1 mm, being from November to February the wettest months with more than 100 mm per month and August the driest. The mean annual temperature is approximately 15.7 ºC. August is the hottest month and January the coldest (Melo, 2012). In general, it presents a sandy clay soil, quite permeable, with the presence of deep groundwater.

The study area is under the Regional Land Use Plan of Ribatejo and integrated in a Forest Intervention Zone (ZIF) of Chouto-Parreira, including 307 landowners with 330 properties. It is managed by ACHAR forest owner association 21 978 ha (Borges et al., 2014c). It was organized in 15 667 stand units (table 1) by slope, stand and soil type, although only 5 524 were used (table 2). The majority of Chamusca region is composed by forest representing 70% of the land use (table 1), being agroforestry the focal activity. Agriculture represents 18% and the shrubland are next with 11%. As expected, the main forest specie with 34% of the total area is Cork Oak (*Quercus suber*) and the fallowing with 30% is Blue Gum (*Eucalyptus globulus*), with 3% is occupied by Maritime Pine (*Pinus pinaster*) and finally Umbrela Pine (*P. pinea*) with 2%, normally composed in pure stands but there is also some mixed stands. Table 2 shows these information relative to the Chouto Parreira ZIF (inside of Chamusca), which is the exact study area, follows the same order of forest composition in terms of representation. So, cork and eucalypt pulpwood are the main products, then recreation and carbon storage services (Borges et al., 2014b). Maritime Pine is used for sawlogs and Umbrela Pine produces the pine nuts (Borges et al., 2014b).

Table 1- Land Use and forest species in Chamusca represented by number of stand units and area (ha, %). Source: ACHAR (ZIF's database)

Land Use	Forest Stands	No. stand units	Area (ha)	Area (%)
Agriculture			13340	18
Water			925	1
Social			810	1
Unproductive			76	0
Shrubs		2996	8110	11
Forest	Pure Cork Oak	5744	22557	30
	Mixed Cork Oak	858	2707	4
	Pure Eucalyptus	4395	20749	28
	Mixed Eucalyptus	424	1326	2
	Pure Maritime pine	339	1150	2
	Mixed Maritime pine	247	602	1
	Pure Stone pine	285	880	1
	Mixed Stone pine	170	872	1
	Other species	209	496	1
Total		15667	74600	100

Table 2- Forest composition in Chouto Parreira ZIF by number of stands, area and their percentage.

Forest composition	No. stand units	Area (ha)	Area (%)
Cork Oak	3 105	12 162	57
Eucalyptus	1 204	5 270	25
Eucalyptus_Cork Oak	350	1 372	6
Eucalyptus_Maritime Pine	42	122	1
Maritime Pine	174	444	2
Maritime Pine_Cork Oak	571	1726	8
Umbrella Pine	78	260	1
Total	5 524	21 356	100

Relative to the ownership, the most representative part belong to the traditional forest owner's types in which forest and farming can be or not the first source of income (table 3). For example, 40% of forest area belong to the traditional large forest owner that one property has more than 400 ha and they have as first source of income the farm and forest; after, representing 48% of the forest land the farm and forest is not consider as first source of income (12% more than 400 ha and 36 % less than 400). The other part is represented by a forest owner related to the paper pulp industry (12%), which the property is higher than 400 ha. Through table 4, it is possible to see that the majority of the owners (92.1%) have the smallest forest land between 1 and 50 ha, which represents only 6.2% of the total forest area. On the other hand, 64.2% of the total forest area belong to a small number of owners (2.1%), which the forest land is higher than 400 ha.

So, there is a heterogeneous and dispersed land ownership and together with extreme weather conditions during the summer season which it is typical from a Mediterranean climate, wildfires are consider an important threat as it was proved in 2003.

Table 3- Forest owner types with their descriptions and forest area (%). Source: ACHAR (ZIF's database)

Forest owner types	Description	Forest area (%)
Type 1: Small forest owner	Traditional knowledge oriented – cork and timber for sale and own use (<50 ha forest land).	6
Type 2: Medium forest owner	Economic oriented – "Montado"/ multifunctional forest orientation; farming/ forestry not first source of income (50-400 ha forest land).	30
Type 3: Off farm career large forest owner	Economic oriented - *"Montado"*/multifunctionality orientation; farming/forestry not the first source of income (note: closest type to "close-to nature oriented" definition, but not quite so for its primarily economic orientation (>400 ha forest land).	12
Type 4: Traditional large forest owner	Economic oriented – *"Montado"*/multifunctional forest orientation; farming and forestry first source of income (> 400 ha forest land).	40
Type 5: Paper pulp industry forest owner	Economic oriented – eucalyptus for paper pulp focused firm (>400 ha forest land).	12

Table 4-Forest ownership structure in Chamusca. Source: ACHAR (ZIF's database)

Forest area brackets (ha)	No. Forest owners	Forest area (ha)	Forest owners (%)	Forest area (%)
1 a 50	1801	4142	92,1	6,2
51 a 400	113	19805	5,8	29,6
>400	42	42904	2,1	64,2
Total	1956	66850	100,0	100,0

2.2 Vale do Sousa

The study area is situated in north part of Portugal, in Vale do Sousa region (76 680 ha). It is under the Regional Land Use Planning of Tamega which covers 261 963 ha and it is integrated in the Vale do Sousa ZIF (Forest Intervention Zone) with an extension approximately of 14 800 ha (Borges et al., 2014b), located around 50 km east of Oporto city. All the study area was organized in 2 182 stand units (table 5) (Borges et al., 2014b) according to slope, stand and soil type, although only 1 925 were used (table 6). The Paiva ZIF has a total area of 7 619 ha, it is located in Castelo de Paiva municipality. The Entre Douro e Sousa (EDS) ZIF with a total area of 7 223 ha, it is located in Penafiel and Paredes municipalities, integrating from the first Lagares; Fonte Arcada; Paço de Sousa; Oldrões; Galegos; Valpedre; S. Paio da Portela; S. Vicente do Pinheiro; Capela; Canelas; Rio Mau; Sebolido; Figueira and Eja parishes and from the second Recarei, Sobreira e Aguiar de Sousa parishes. Both ZIF's belong to Aveiro district and are separated by the Douro's River.

Vale do Sousa is characterized for being a mountain area near to the sea, having a very wet climate during winter and spring months and dry and hot summers, which makes it really susceptible for occurring wildfires in summer season (Borges et al., 2014a). The average rainfall is high, but then unevenly distributed throughout the year. The driest months are June, July and August (31.1 mm) and the wettest months are October, November and December (170.4 mm). The average temperature varies between 9.5ºC in January and 20.8 ºC in August. In general, soils are poor, well drained and shallow.

Inside of Paiva ZIF, it is found an equally rugged terrain of steep slopes with the highest altitudes between 328 and 640 m. It is an area with high forest road network but not in good conditions, making difficult the accessibility. The mean annual temperature is between 10ºC and 15ºC and the mean annual precipitation is between 1200 and 1600 mm, reaching the maximum temperature and minimum relative humidity in July and August. The predominant area is constituted by schist soils, however granite soils are a small part in the north. In EDS ZIF, it is found less pronounced slopes than the other ZIF with some exceptions and the highest altitudes are around 400 and 700 m. The mean annual temperature is around of 14ºC, reaching the maximum in July, August and September. The months from October to February are the wettest, being December the month with the highest precipitation values (208.7 mm). On the Western half of the ZIF mainly is composed by schist soils, while on the Eastern half has granite soils.

From the photointerpretation done in 2012, more than half of the area has forest as land use (table 5). In this area, it is consider an area with high productive potential for Blue Gum (*Eucalyptus globulus*) and Maritime Pine (*Pinus pinaster*). However, Blue Gum is the predominant specie, which is used for pulpwood. Maritime Pine is used for fuelwood and sawlogs. Besides, it is possible to hunt, to fish, provides recreation services, hardwood volume (chestnuts) and carbon storage. Table 6 shows the precise study area which was used, which 85% of the forest is occupied by Eucalyptus.

Table 5-Landuse and forest species in Vale do Sousa represented by number of stand units and area (ha, %). Source: AFVS (Zif's database)

Land use	Forest Stands	Area (ha)	Area (%)
Agriculture		222	1.49
Water		7	0.05
Social		124	0.83
Unproductive		43	0.29
Shrublands		3141	21.15
Forest	Pure Eucalyptus	8161	54.95
	Mixed Eucalyptus	2309	15.54
	Pure Maritime pine	347	2.33
	Mixed Maritime pine	191	1.29
	Other species	308	2.07
Total		14853	100

Table 6-Forest composition in Paiva and Entre Douro e Sousa ZIF's by number of stands, area and their percentage.

Forest composition	No. stand units	Area (ha)	Area (%)
Chestnut	68	151	1
Eucalyptus	1 513	12 123	85
Eucalyptus_Maritime Pine	209	1 162	8
Maritime Pine	135	780	5
Total	1 925	14 216	100

Relative to the ownership, the highest percentages belong to the two groups with the lowest forest land (less than 5 ha), with a total of 88% (table 7). They are characterized for not doing any investment, none or little management, they can be resident or non-resident and the forest boundaries are unknown to the owners. The rest of the administrative area (12%), it has an area higher than 5 ha which can reach to more than 150 ha, already has a different point of view attached, the owner is more concern to take profit by selling the wood to the industries (mainly pulp and paper). These owners do more investments and are more concerned with the forest management.

Vale do Sousa is an example of owners' absence, where the parcels limits are not clear and properties are considered small (average dimension of 1.5 ha) (Borges et al., 2014a), therefore forest planning and management processes are disturbed by these issues. The establishment of partnerships and the implementation of forest associations were needed, aiming to provide to forest owners all the technical, economic and legal support towards a sustainable forest management. In Paiva ZIF and in EDS ZIF there is a Forest Owner Association called AFVS (Associação Florestal do Vale do Sousa), which is responsible for the management of those areas.

Table 7-Forest owner types with their descriptions and forest area (%) in Vale do Sousa. Source: AFVS (Zif's database)

Name	Description	Administrative area (%)
Type 1: Very small forest owner (<2ha forest land)	Outsider and passive forest owner: no investment, zero management, resident and non-resident, often forest estate boundaries unknown to owners, average 0.5ha forest land, most not part of a farming & forestry unit.	39
Type 2: Small forest owner (2 to 5ha forest land)	Traditional knowledge oriented forest owner: no investment, little or zero management, resident and non-resident, often forest estate boundaries unknown to owners, average 1.5ha forest land, most not part of a farming & forestry unit.	49
Type 3: Medium farmer forest owner (5 to 20ha forest land)	Economic oriented forest owner/manager: little investment and management except in the case of eucalyptus plantations, resident and non-resident forest owners, some areas let to paper and pulp industry if suitable to eucalyptus, average 6ha forest land.	5
Type 4: Large farmer forest owner (more than 20ha)	Economic oriented forest owner/manager: some investment, active direct management or areas let to pulp and paper industry for eucalyptus plantations, 20ha or more of forest area, average 30ha forest land.	1
Type 5: Local (parish) administration forest owner (more than 150ha)	Mix of economic and close-to nature (sub profile 1) oriented forest owner/manager: investment, maritime pine forest area let to private companies and/or areas let to pulp and paper companies for eucalyptus plantations; windmills for energy production important source of rent; average 338ha forest area, former common lands.	6

3 Methodology

The work was developed in three steps: research, selection and application of the selected indicator to address wildfire risk in forest management.

The research was made mainly through the Science Direct scientific database, allowing to access to several journal articles. Some of the keywords were: fire risk assessment with 63 334 results; forest fire risk indicators with 15 788 results; cartography fire risk with 605 results; forest fires cartography risk 377 results. Also, it was provided to me, from my two supervisors, some other articles for better understanding and guidance related to what have been done in this field in Portugal and Spain. After some readings, it was possible to understand and group different ways to approach the wildfire risk in forest management. In this way, from several examples the selection was based and accomplished. Four models were chosen, representing shrub biomass; Eucalypt pure stands; Maritime pine pure stands and the last is for the mixed stands and other species which were not mentioned before (generic model). The tree models have the same structure, first evaluating the annual wildfire occurrence probability (Pburn), after predicting whether mortality will occur in the stand (Psd) and finally calculating the proportion of dead trees (Pd). Essentially, they are based on biometric variables and also some location variables.

In both study areas, it was used the three models since it was present Maritime Pine, Eucalypt, and other species as pure and mixed stands. I also had to use the shrub biomass model (Botequim et al., 2015) because it is one of the variables needed for calculating the annual wildfire occurrence probability (Botequim et al., 2013; Garcia-Gonzalo et al., 2012; Marques et al., 2012) . For Vale do Sousa the data was collected from ISA forestry inventory from 2012 (Borges et al., 2015). For Chamusca the data came from several sources, National Forest Inventory of 2005-2006, CELBI and ISA forestry inventory from 1999 and 2010, and it was simulated to the year 2014 (Borges et al., 2015).

$$Sbiom = (32.75 - 0.0239Resp - 0.1528G)(1 - e^{-(0.00108Resp + 0.00249T)\times t}) \qquad (1)$$

The model (equation 1) which calculates the shrub biomass required information about the resprouting percentage ($Resp$, %), stand basal area (G, m^2/ha), annual average temperature (T,ºC) and the shrub age (t, years) . For knowing the resprouting percentage, first we had to know the present shrub species and with the help of the annex list (Botequim et al., 2015), I classify the different species relative to their regeneration strategy (resprouters or seeders), as it is possible to see in table 8. In case the plot had only resprouters species it was given 100%, only seeder species or natural regeneration it was given 0%, and in the case of being resprouter and seeder specie at the same time it was attributed 50%. Using these organized information, we just did an average according to which species regeneration appeared in each stand. In Chamusca, the shrubs species were not available, therefore we did an estimation. we took into account the shrub species that are representative in Herdade de Vale Flor (approximately 60% of resprouting species), which is inside of my study area, and from the plots that were not attributed to the stands but are close located, reaching 100% of resprouting species. At the end, it was decided to do a random estimation between 60% and 100%. The shrub age, which is the time passed since the last disturbance, for Vale do Sousa, we took into account the fires reported in National Forest Inventory (since 2005) and also the historical fire events from 1998 to 2004, which were available in a shapefile. It was not consider data before 1998 because the shrub biomass model does not work well with shrubs with more than 15 years (Botequim et al., 2015). This shapefile was worked in the ArcGis software 10.1, through selection by attributes. From all the data sources, some of the stands in Vale do Sousa did not have information attached, therefore we had to assume that in stands where it was present Eucalyptus the age was randomly estimated between 0 and 5, otherwise, it was considered between 0 and 15. Being, normally, 5 years the limit age for Eucalyptus stands interventions. In Chamusca, we had a different approach because no data were provided. We started to study the historical fire events that happen after 1998 and evaluated which ones intersect with my study area, using ArcGIS software 10.1. However, we did not get useful information, the last fires were in 2003 and it means that the shrubs had 11 years old and from my point of view it seems too much, taking into account that it is an area where prevention is consider relevant (fuel treatments, grazing). Therefore, we decided to do a random estimation between 0 and 5 for the shrub age. The basal area calculated through the formula involving the DBH. The annual average temperature was taken from the Portuguese climate normal (1961-1990).

Table 8- Shrub species and their regeneration strategy. Source: (Botequim et al., 2015)

Shrub species	**Regeneration strategy R=resprouter S=seeder**
Phillyrea latifolia*, *Rhamnus alaternus* or *Phillyrea angustifolia	R
Rosmarinus officinalis	S
Pistacia lentiscus	R
Ilex aquifolium	R
Pterospartum tridentatum	R
Quercus coccifera	R
Quercus lusitanica	R
***Pyrus* spp.**	R
***Adenocarpus* spp.**	S
Cistus ladanifer	S
***Cytisus* spp., *Genista* spp. or *Spartium* spp.**	R/S
Ruscus aculeatus	S
Arbutus unedo	R
***Lavandula* spp.**	S
Cistus salvifolius	S
***Rubus* spp.**	R
Dittrichia viscosa	R
***Ulex* spp.**	R
Thymus vulgaris	S
Dapnhe gnidium	R
***Erica* spp. or *Calluna* spp.**	R
***Juniperus* spp.**	S

$$Pburn = \frac{1}{1 + e^{-(-2.0216+0.02045Slope+0.0597Sbiom-0.0153P-0.5856\frac{G}{Dg})}} \quad (2)$$

$$Psd = \frac{1}{1 + e^{-\left(2.1231+2.3943\frac{G}{Dg}-0.1134AvgDBH\right)}} \quad (3)$$

$$Pd = \frac{1}{1 + e^{-(0.7065+0.00491Alt+0.1158Slope-0.1649AvgDBH+0.1456Sh)}} \quad (4)$$

After we go on with Maritime pine models (equations 2, 3 and 4), from Forest National Inventory we took the slope in percentage ($Slope$), which we had to convert to degrees; the altitude in meters (Alt, m); the DBH (cm) from which we estimate the basal area (G, m^2/ha), the quadratic mean diameter (Dg, cm) and the average DBH (cm); and the height (m) from which we calculate the height standard deviation (Sh, m). Also, it was stablished a relationship between G and Dg, competition index. The last variable needed to complete the Maritime pine model was the number of days with more than 1 mm of precipitation per year which it was taken from the Portuguese climate normal (1961-1990). In Vale do Sousa, there was an issue with the Bigorne meteorological station because there was not precipitation recorded. Therefore, with the help of the ArcGis software 10.1 all the stands under this meteorological station, we attributed one of the other two according to their proximity, Paços Ferreira and Porto/S. Pilar.

$$Pburn = \frac{1}{1 + e^{-(-5.4005 - 0.054hdom + 0.3166\frac{G}{Dg} + 0.3959Sbiom + 0.5372RoadDist)}} \quad (5)$$

$$Psd = \frac{1}{1 + e^{-(-1.1742 + 3.8942\frac{Sd}{Dg})}} \quad (6)$$

$$Pd = \frac{1}{1 + e^{-(0.4654 + 0.00119Alt + 0.0214Slope + 0.00401G - 0.1027Sd)}} \quad (7)$$

Relative to the Eucalypt pure stands (equations 5, 6 and 7), we required the dominant height ($hdom$, m), G, Dg, diameter standard deviation (Sd, cm) as biometric variables (Botequim et al., 2013; Marques et al., 2011), therefore it was taken from the Forest National Inventory the DBH and heights of the trees. In Chamusca, some plots, which were considered too small, did not have heights measured, and this was required for calculating the hdom. For that reason, we used equations to estimate the heights through the hdom which was already simulated. There was an equation for Eucalyptus adjusted to the rotation number (table 9), which we took from Tomé et al. (2007) (equation 1). A relationship was stablished between G and Dg and also between Sd and Dg which showed the tree diameters variability. Besides, we needed to know the road distance ($RoadDist$) from each stand. It was provided to me the shapefile of the roads within Vale do Sousa and also the Portuguese national roads which we use for Chamusca. Therefore, with support of ArcGis software 10.1, we get the nearest distance of the closest road. When the road distance is higher than 1 km the attributed value is 1 if not the value is 0 (Botequim et al., 2013).

$$h = hdom \times e^{\left((\beta0 + \beta1 \times hdom + \beta3 \times dg)\left(\frac{1}{d} - \frac{1}{ddom}\right)\right)} \quad (8)$$

Where:

h is the tree height; $hdom$ is the tree dominant height; d is the diameter at breast height; $ddom$ is the dominant diameter at breast height and $\beta0, \beta1, \beta3$ are the adjusted parameters.

Table 9- Adjusted parameters to calculate Eucalyptus height used in equation 1. Source:(Tomé et al., 2007)

Eucalypt	**β0**	**β1**	**β3**
1st rotation	-1.770086	-0.233239	-0.055274
>1 rotation	-1.729112		
No rotation	-1.778407		

$$Pburn = \frac{1}{1 + e^{-(4.9888 + 0.0433 Sbiom - 0.0279 Dg - 0.00053 N - 0.0124 PHard - 0.0219 P - 0.2192 T)}} \quad (9)$$

$$Psd = \frac{1}{1 + e^{-(-0.7882 + 1.1079 PBr + 2.169 PC - 0.5553 G + 4.328 \frac{G}{Dg} + 3.2549 \frac{Sd}{Dg})}} \quad (10)$$

$$Pd = \frac{1}{1 + e^{-(0.3579 - 0.1361 PEc - 1.3872 PBr + 0.0525 Slope + 0.0017 Alt - 0.0393 AvgDBH)}} \quad (11)$$

The Generic models (equations 9, 10 and 11) required as biometric variables Dg, stand density (N, trees/ha), average DBH, G (Botequim et al., 2008; Garcia-Gonzalo et al., 2012). Plus, the division between Sd and Dg and also between G and Dg. After, it was needed to indicate the presence of hardwoods ($PHard$), conifers (PC). Just when calculating the proportion of dead trees it required to indicate the presence of Eucalyptus (PEc) and broadleaves (PBr) as separate (Botequim et al., 2008).

Some of the stands were not initialized, for that reason the respective biometric variables had to be zero for all the models. This situation happen due to the stands being too young, fire occurrences or an intention of converting the stand composition.

Subsequently, the data also were evaluated according to the given spatial context. It was used equations described by Ferreira et al. (2015) through equation 2.

$$RA_{it} = R_{it} + (1 - w_i) \times \sum_{s \in V\{i\}} \alpha_{is} \, (RA_{st} - R_{it}) \quad (12)$$

Where

RA_{it} is the adjusted resistance level of stand i in period t; R_{it} is the specific resistance of stand i in period t; $(1 - w_i)$ is the weight to reflect the impact of neighbouring stands on the wildfire resistance of stand i; α_{is} is the parameter reflecting the likelihood of a fire that occurs in stand s to spread to stand i; $(RA_{st} - R_{it})$ corresponds to the adjustment of the specific wildfire resistance of stand i (R_{it}) might undergo to address the impact of its spatial context.

First step was to calculate the specific wildfire resistance of the stand with equation 3.

$$r_{itk} = \prod_{u=1}^{d} \left(1 - Pburn_u^{ikt} Psd_u^{ikt} Pd_u^{ikt}\right) \quad (13)$$

Where:

Pburn is the probability of wildfire occurrence in stand i in year u of period t if it is managed according to prescription k; Psd is probability of mortality to occur if there is a wildfire in stand i, being managed according to prescription k, in year u of period t; Pd is proportion of dead trees caused by wildfire in stand i, being managed according to prescription k, in year u of period t.

After, it was assumed that the stands of both study areas were managed, since they are under a forest intervention zones. Therefore, x_{ik} from equation 4 is 1, otherwise it should be 0, resulting in $R_{it} = r_{itk}$.

$$R_{it} = \sum_{k=1}^{Ki} r_{itk} \, x_{ik} \quad (14)$$

Where:

x_{ik} reflects if the stand i is managed by prescription k.

The w_i, which reflects the shape and size of the stands, was calculated by equation 5.

$$w_i = \theta_i \frac{2\sqrt{\pi}\sqrt{Area_i}}{Perimeter_i} \quad (15)$$

Where:

θ_i is the scale-related parameter of stand i ($0<\theta_i\leq1$). The area and perimeter of each stand was calculated with ArcGis software support.

To get θ_i it was used the equation 6.

$$\theta_i = \frac{Area_i}{\rho + Area_i} \quad (16)$$

Where:

ρ is the stand average area.

After, it was calculated α_i to take into account the percentage of border that stand i shares with stand s, the slope, the relative position of stands i and s, and the existence of barriers between the stands (equation 7).

$$\alpha_i = f_{is} m_{is} \quad (17)$$

$$m_{is} = u_{is} p_{is} \quad (18)$$

Where

f_{is} is the fraction of the border of stand i that is shared with stand s; m_{is} is the parameter that reflects the likelihood of wildfire spread from stand s to stand i, taking into account the relative position of i and s (u_{is}) and the existence of barriers between the two stands (p_{is}) (equation 8).

The f_{is} was calculated with ArcGis software, using the polygon neighbors tool, giving me the shared length in meters between the stands. There were values close to 0 m, for that reason it was filter the information just considering the shared length superior to 5 m. Then, we divided each shared length by the total of each stand perimeter. The u_{is} was calculated through the calculate adjacent fields tool in ArcGis software, the problem was that some adjacent stands were not attributed to one of the cardinal direction, since this works best with regular polygons, which was not the case. Therefore, the stands that were not attributed to a point of the compass were done by hand. After, it was just to follow the table 10, which takes into consideration the elevation; orientation, which was SE for both study areas because according to the Portuguese climate normal (1961-1990) the dominant winds were toward NW at summer season; and slope, which it was organized in 3 classes. The p_{is} was done for both study areas by observation in the map, considering the present roads. Subsequently, we just follow the table 11 to get the respective values for each type of road.

Table 10- Relative position between stand s and i. Source:(Ferreira et al., 2015)

	Elevation			
	s ≥ i		s < i	
	SE orientation			
Slope (º)	Yes	No	Yes	No
0-5	0.25	0.3	0.4	0.35
6-15	0.15	0.2	0.6	0.45
>15	0.05	0.1	0.8	0.55

Table 11- Type of road between s and i. Source:(Ferreira et al., 2015)

	None	**≤5 m**	**>5 m**
p	1	0.8	0.6

After calculating the adjusted resistance level of each stand to the respective inventory years, there was a need to take into account the growth and production of vegetation for the fallowing years, which provide guidelines for a long-term forest management plan. Therefore, it was built yield tables for each specie with a specific model. In the case of Eucalyptus, it was used GLOBULUS 3.1 (Tomé and Oliveira, 2006); for Maritime Pine it was used Pbravo (Páscoa, 2001); for Cork Oak it was used SUBER (Tomé, 2004); for *Castanea sativa* it was used Castanea (Patrício, 2006) and for Umbrella Pine it was used PINEA (Carrasquinho et al., 2010). From there, it was possible to get information related to trees growth, such as hdom, G, Dg, AVGDBH and N, to simulate the adjusted resistance level of each stand to the next years. There was lacking information about diameter standard deviation and height standard deviation, since the models are at stand-level and not at tree-level. In this circumstance, it was used fixed values. Finally, putting together with the simulations done in the work of Borges et al., (2015), it was possible to calculate the wildfire resistance indicator for 2014, 2015 and 2020. The simulations considered one forest treatment randomly selected for each stand in each year, just to simplify. In Chamusca were in total 212 (3 for Umbrella Pine, 4 for Cork Oak, 145 for Eucalyptus and 60 for Maritime Pine) and in Vale do Sousa were 225 (145 for Eucalyptus, 65 for Maritime Pine and 15 for Chestnut). To finish, the landscape wildfire resistance in the each period was calculated for both study areas, through the equation 9.

$$\frac{\sum_{i=1}^{I} A_i RA_{it}}{A_F} = RES_t \quad (19)$$

Where

A_i is the area of stand i in hectares; A_F is the total forest area in hectares.

The presentation of the data was prepared in map form for both study areas, through the ArcGis software 10.1. The values from wildfire resistance indicator were organized and maintained in classes according to the natural breaks of Chamusca in 2014 and of Vale do Sousa in 2014. This option allowed to reduce the variance within classes and maximize the variance between classes and by maintaining the same classes to the future years, it allowed to compare the results with the future years.

4 Results & Discussion

As results, we created maps for Chamusca and Vale do Sousa, approaching the inventory years plus the simulated years (2014, 2015 and 2020), showing the wildfire resistance indicator. Relative to the indicator, the higher the value the more resistant is the stand (one is the maximum) therefore darker will be the green; lower is the value less resistant is the stand (zero is the minimum) so darker will be the red. The darkest red (value zero, the worst case scenario) means that the stand is not consider forest yet, it has a different land use associated, shrublands. These appears because, afterwards, the stands are converted (initialized) to forest lands.

4.1 Chamusca

4.1.1 Year of forest inventory: Specific wildfire resistance indicator

In Chamusca, it was used different years of forest inventory (1999, 2005, 2007, 2009 and 2010), as it is possible to see from figure 1. Thus, it was not possible to calculate the wildfire resistance indicator considering the spatial context. The figure 2 shows the result of the specific wildfire resistance indicator calculated (Annex I).

The indicator is based on forest inventory data. In this case, it can be seen as limitation, since not having the forest inventories done in the same period, the neighbour's stands influence cannot be taken into account. Besides, it is not possible to do forest inventories frequently, therefore using the yield tables can be a helpful source of information.

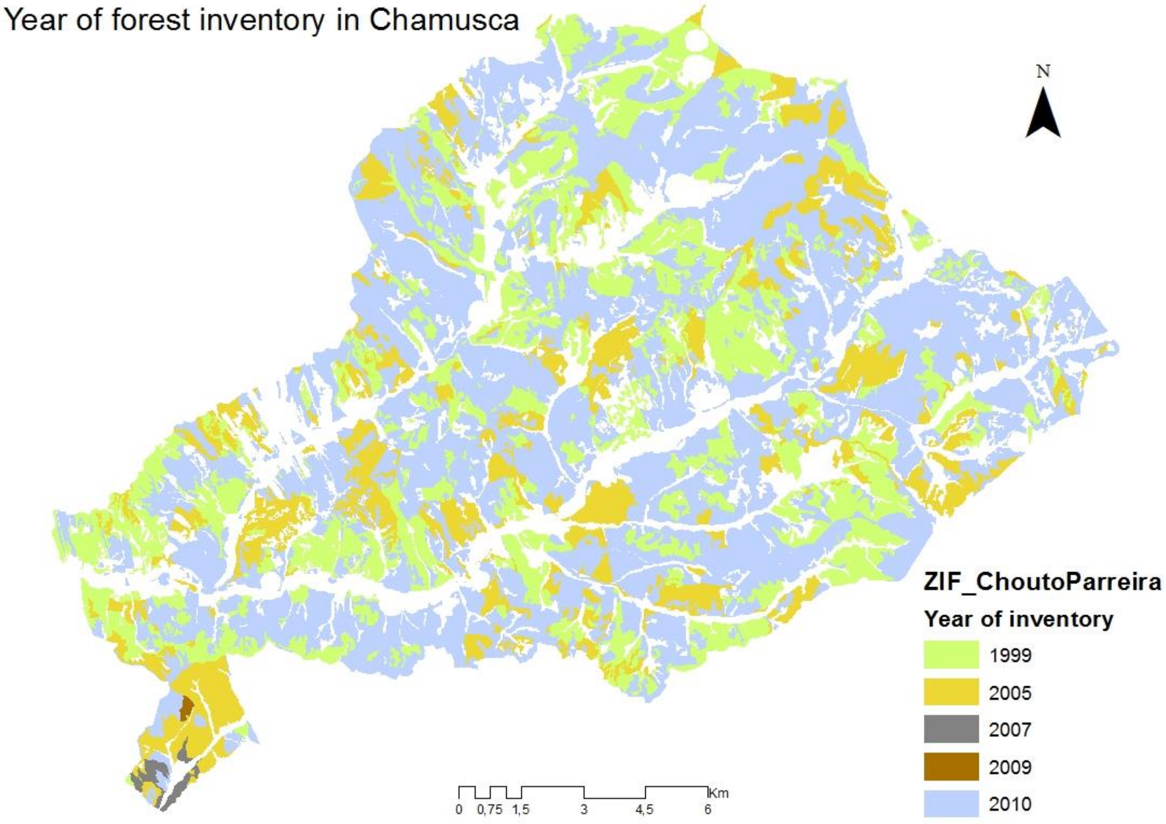

Figure 1- Years of forest inventory available used to calculate the specific wildfire resistance indicator in Chamusca.

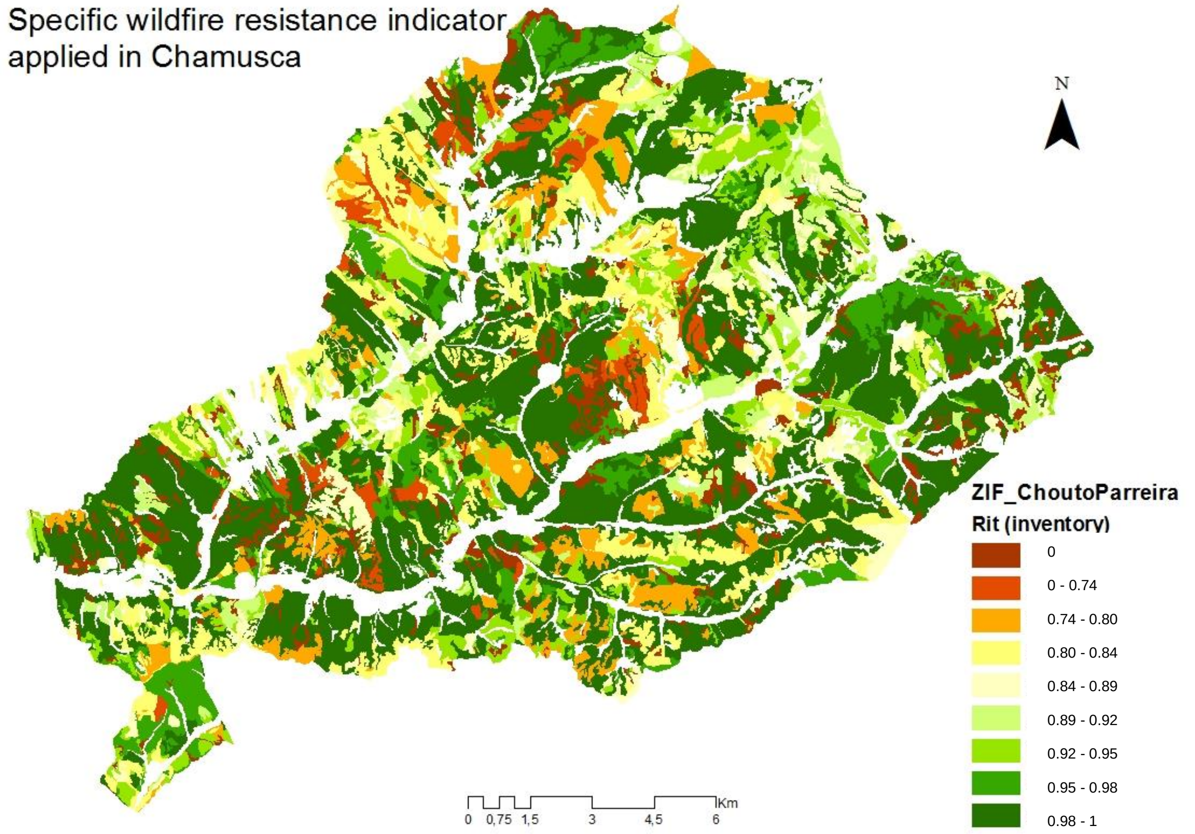

Figure 2- Specific wildfire indicator (R_{it}) applied in Chamusca.

4.1.2 Simulated years: Adjusted wildfire resistance indicator

These results were based on simulated data of 2014, 2015, and 2020, from which was calculated the adjusted wildfire resistance indicator in Chamusca study area (Annex II).

Table 12-Number and percentage of stands with $0 < RA_{i2014} < 0.81$ (3 lowest classes) and $RA_{i2014} > 0.96$ (2 highest classes), in Chamusca. Excludes the initialized stands.

Species	**No. stands**	**$0 < RA_{i2014} \leq 0.81$**	**%**	**$RA_{i2014} \geq 0.96$**	**%**
Cork Oak	2842	2	2	2144	75
Eucalyptus	1182	49	49	433	37
Eucalyptus_Cork Oak	350	7	7	173	49
Eucalyptus_Maritime Pine	42	0	0	19	45
Maritime Pine	142	13	13	103	73
Maritime Pine_Cork Oak	330	3	3	250	76
Umbrella Pine	78	2	2	64	82

From table 12, based on figure 3, the specie which is mainly within the three lowest classes is Eucalyptus as pure stand (49%), in second place is Maritime Pine (13%). The species less present are the Cork Oak (2%) and Umbrella Pine (2%). On the other hand, now, the species most present at the two highest classes are Umbrella Pine (82%), Cork Oak (75%) and also Maritime Pine (73%) (table 12). Besides, the stands where Eucalyptus specie is present tends to be not so much present at the highest classes comparing with other forest compositions.

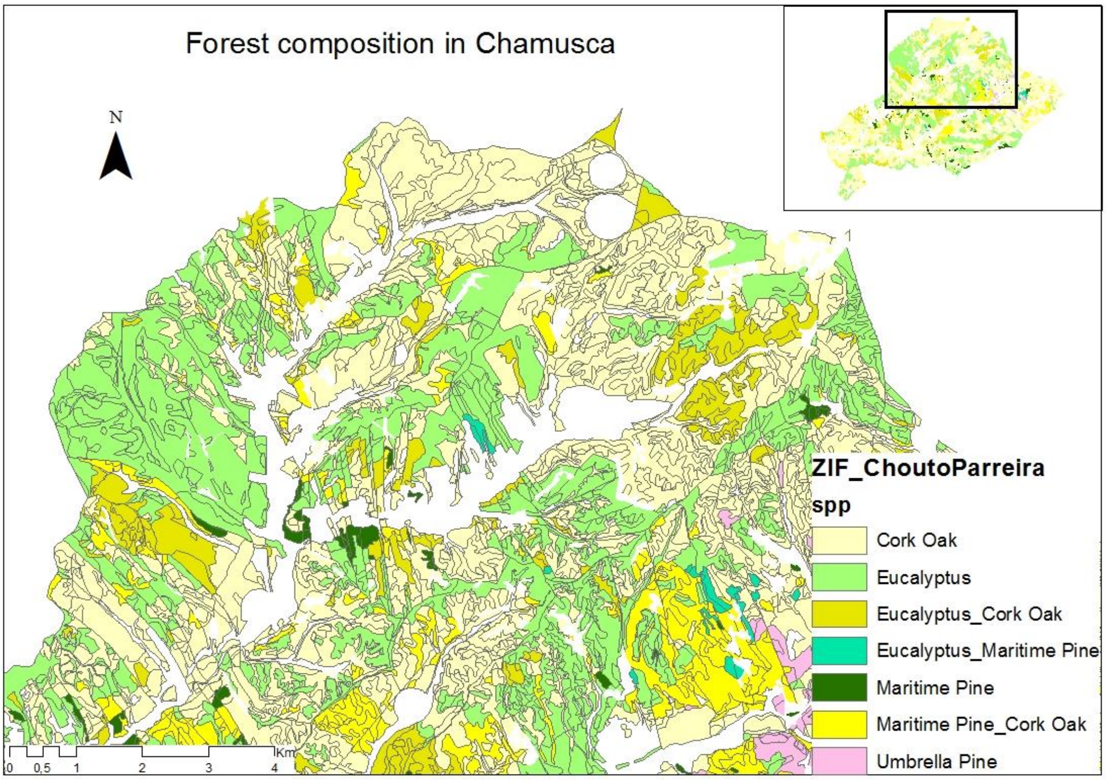

Figure 3- Forest composition in Chamusca.

The wildfire resistance indicator from the perspective of each forest composition structure, seems to have an agreement between species and their relation to fire. Obviously, each specie has their own structure and this can be seen especially for Eucalyptus and Maritime Pine stands, since they have their own models. For instance, Eucalyptus is one of the species that is more prone to burn compared to the others because it is associated to a high growth rate and density (Silva et al., 2009), therefore it makes sense that Eucalyptus is predominant at the lowest classes. The opposite thinking may be done for Cork Oak, being a species associated to the agro-forestry system (less tree density and grazing activities) (Barros and Pereira, 2014; Silva et al., 2009). As well as Umbrella Pine, since the objective is the production of pine nuts, the stand density should be smaller, when compared to Maritime Pine or Eucalyptus.

The figure 4, in general, it is not so obvious to distinguish the differences of the forest wildfire resistance between 2014 and 2015. Several stands were converted to forest lands in 2015, for that reason appears stands with wildfire resistance of zero (darkest red). Only happen for Cork Oak, Eucalyptus pure stands and mixed stands of Maritime Pine and Cork Oak.

Through the comparison between figure 4 and figure 5, the circle 1 indicates an Eucalyptus stand, which the wildfire resistance increased from 0.86 to 0.92 with a shrub cleaning, taking out ≈ 11 Mg/ha. This can be justified by the fact that the shrub biomass is a significant variable when calculating the annual wildfire occurrence probability (Botequim et al., 2013). The stand mortality probability and the proportion of dead trees almost remain constant. The spatial context had a negative effect in both years, because as it is possible to see in figure 4, the stand has neighbour's stands with lower resistance than itself, being lower in 2014 than in 2015. The circle 2 and the circle 3 show mixed stands composed by Cork Oak and Eucalyptus, and the wildfire resistance increased with an increase of shrub biomass (≈ 5 Mg/ha). Although, circle 3 remain in the same class and circle 2 changed to the next higher class. This was due to spatial context, since the specific resistance decreased as expected. In circle 2, it increased from -0.055 to -0.02 and in circle 3 increased from -0.004 to 0.036. The circle 4 points to a Eucalyptus pure stand in which the decreasing of wildfire resistance (0.86 to 0.85) matches with an increase of shrub biomass of ≈ 2 Mg/ha, it was a small increment but already this stand have high shrub biomass (≈ 11 to 13 Mg/ha). For that reason, the annual wildfire occurrence probability increased even more. Despite all that, the spatial context was the main responsible to a low wildfire resistance since the specific resistance have higher values (0.96 to 0.93). A negative influence from neighbours' stands occurred.

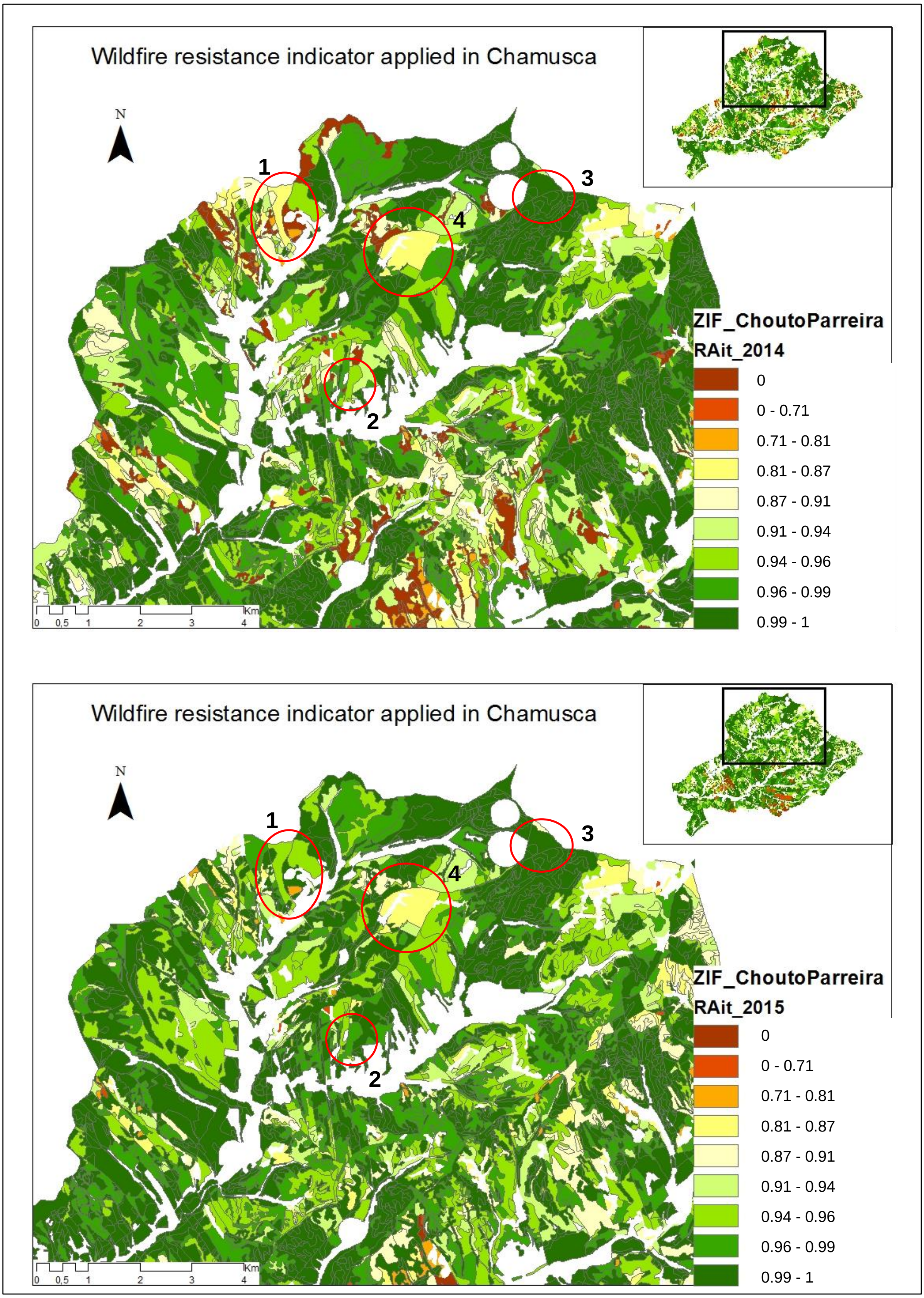

Figure 4- Variation of the wildfire resistance indicator in Chamusca between 2014 and 2015.

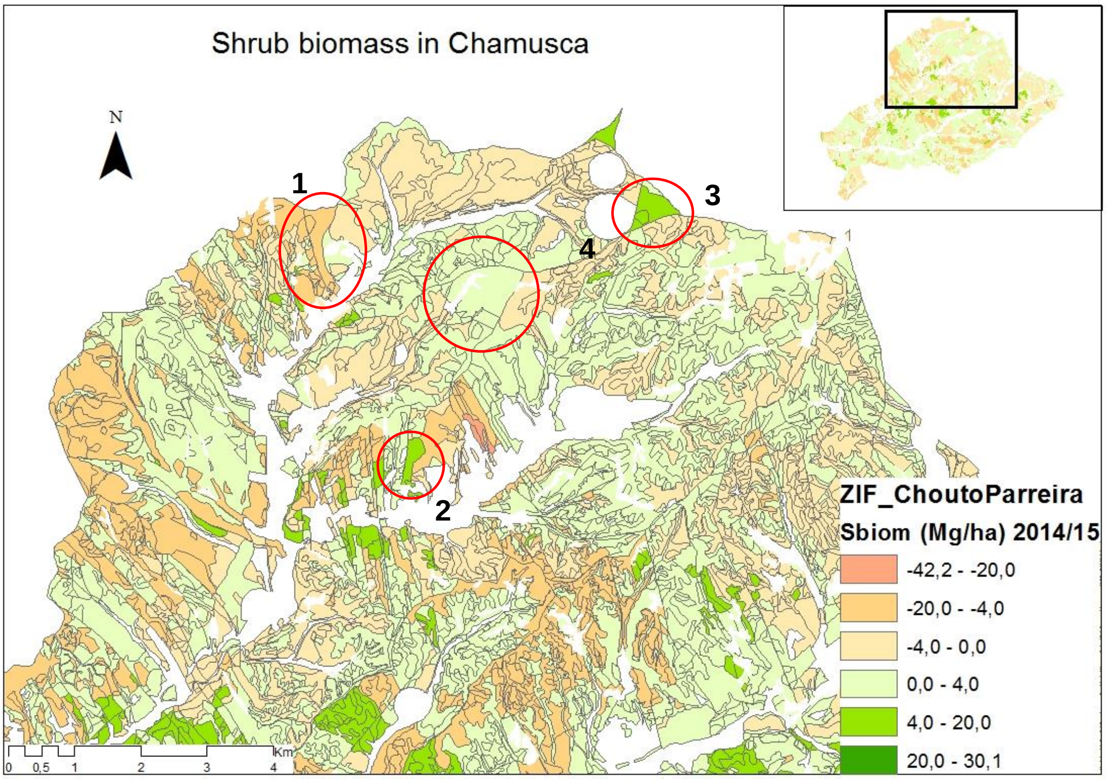

Figure 5 Shrub biomass in Chamusca, between 2014 and 2015.

Table 13- Higher wildfire resistance ($RA_{it} \geq 0.96$) classes analysis for each forest composition, excluding the initialized stands: number and percentage of stands that change to the two highest resistance classes from 2014 to 2015, percentage of stands that are within the two highest classes in 2014, and the total number and percentage of stands that are within the two higher classes in 2015.

Species	No. stands	RA_{i2014} to $RA_{i2015} \geq$ 0.96	%	$RA_{i2014} \geq$ 0.96 (%)	$RA_{i2015} \geq$ 0.96	%
Cork Oak	2842	60	2	75	2078	73
Eucalyptus	1182	363	31	37	596	50
Eucalyptus_Cork Oak	350	101	29	49	243	69
Eucalyptus_Maritime Pine	42	17	40	45	36	86
Maritime Pine	142	2	1	73	97	68
Maritime Pine_Cork Oak	330	8	2	76	249	75
Umbrella Pine	78	2	3	82	64	82

From the table 13, it is possible to see that Eucalyptus pure stands have the lowest representativeness at the highest classes of resistance in 2014 and 2015 with 37% and 50%, respectively. Eucalyptus pure stands are also showing the highest transition from 2014 to 2015 (31%) to the two highest classes of wildfire resistance. This can be related to the fact that

Eucalyptus stands are associated to an intensive management and protection (high economic value), usually having 2 to 3 coppice cuts plus followed by stool thinning, during 10 to 16 years (Ferreira et al., 2012). Also, this could be the same justification for mixed stands where Eucalyptus makes part of the composition, since all of them have high transitions. The rest of the forest compositions have almost no transitions, being between 3 and 1%. Cork Oak, Maritime Pine and Umbrella pine continued be consider as the highest resistance species (table 13).

From figure 6, it is not so easy to notice the changes in 2015 and 2020. Comparing figure 6 with figure 7, in circle 1 and circle 3, it is possible to see a decrease of wildfire resistance with an increase of shrub biomass in Eucalyptus stands. In circle 1, in 2017, it occurs a final cut and since then, the shrub biomass increased, causing a high impact on wildfire resistance (≈ 1 to 0.88). The circle 3, in 2018 occurs also a final cut, consequently with an increase of shrub biomass around 7 Mg/ha, the annual wildfire occurrence probability increase even more and the wildfire decrease from 1 to 0.96. The circle 2 points to one Maritime Pine pure stand that until 2020 it was consider to have small trees, having no registered data about DBH. Therefore, in this case it was like the stand did not have trees, so, in 2020, the prediction of mortality increased substantially, from zero to almost 1. As a result, the wildfire resistance decreased (1 to 0.96). Most of the Maritime Pine stands are in this situation, and for that reason they appear in classes of high wildfire resistance. The circle 4 points two situations. The first is an increase of resistance from one Eucalyptus stand with a low difference of shrub biomass (- 0.5 Mg/ha) because in 2017 it happen a shrub cleaning around 10 Mg/ha. The second case is that the resistance of one Cork Oak stand maintained almost the same wildfire resistance with an increase of shrubs biomass around 13 Mg/ha. The same situation can be seen in circle 5 which points Cork oak stands as well. The circle 6 shows an Umbrella Pine stand that the increase of shrub biomass did not affect significantly the wildfire resistance. However, it is an example that the spatial context had its influence, since the specific wildfire resistance (≈ 0.99) was higher than the wildfire resistance (≈ 0.98). There was a negative influenced from the neighbours' stands. The forest composition appear to be relevant, as it was exposed that Cork Oak or Umbrella Pine stands compared to Eucalyptus stands are less sensitive to shrubs biomass variation and overall more resistant to wildfires.

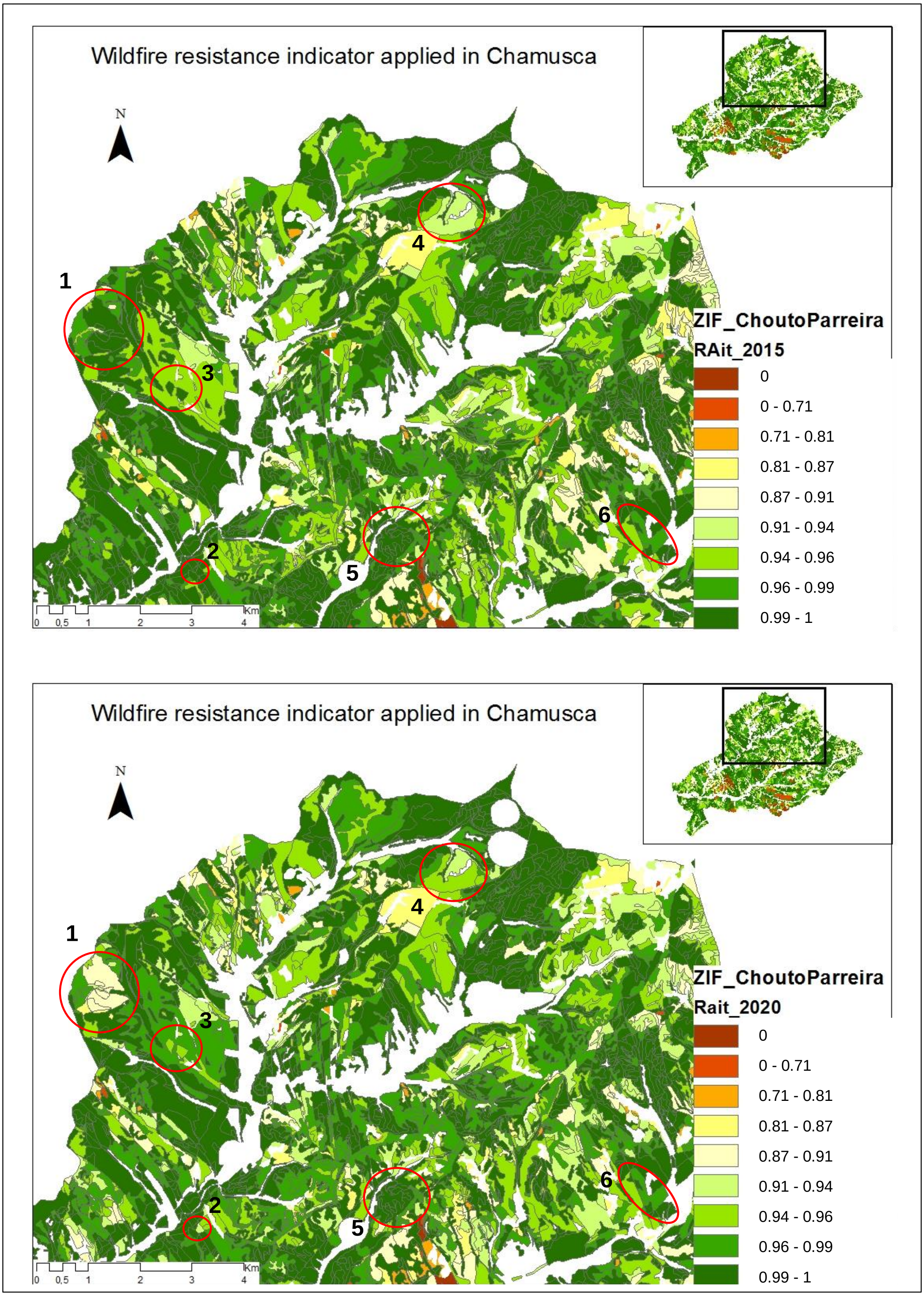

Figure 6- Variation of the wildfire resistance indicator in Chamusca between 2015 and 2020.

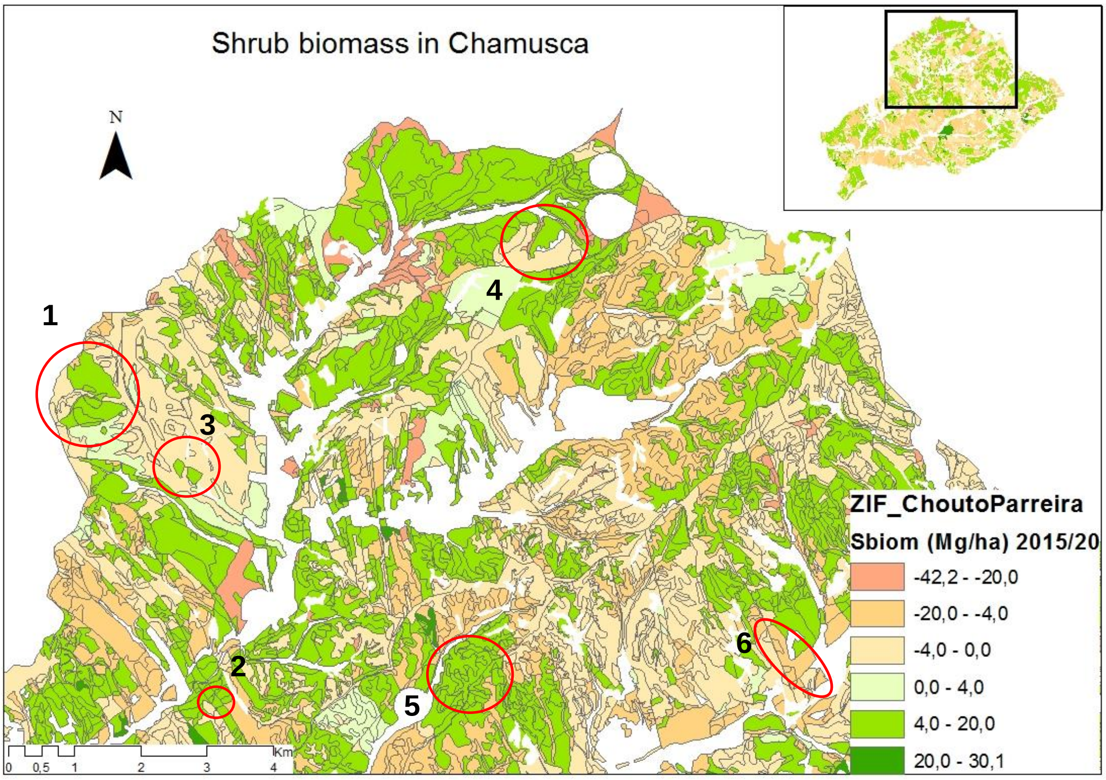

Figure 7- Shrub biomass in Chamusca, between 2015 and 2020.

Table 14- Higher wildfire resistance ($RA_{it} \geq 0.96$) classes analysis by forest composition, excluding the initialized stands: number and percentage of stands that change to the highest resistance class from 2015 to 2020, percentage of stands that are within the two highest classes in 2015, and the number of stands that are within the highest resistance classes in 2020 and its percentage.

Species	No. stands	RA_{i2015} to $RA_{i2020} \geq 0.96$	%	$RA_{i2015} \geq 0.96$ (%)	$RA_{i2020} \geq 0.96$	%
Cork Oak	2842	1	0	73	2070	73
Eucalyptus	1182	118	10	50	609	52
Eucalyptus_Cork Oak	350	0	0	69	233	67
Eucalyptus_Maritime Pine	42	0	0	86	31	74
Maritime Pine	142	0	0	68	77	54
Maritime Pine_Cork Oak	330	3	1	75	224	68
Umbrella Pine	78	0	0	82	64	82

Through the table 14, it is possible to see that there is less transition to the higher class of wildfire resistance than in table 13, which the maximum was reached by Eucalyptus pure stands (10%). Except Cork Oak and Umbrella Pine, all the others compositions suffer some changes in 2020 but not in terms of adding more stands to the highest class, actually, the stands of these specific forest compositions decreased. In the case of Eucalyptus stands the increase was superior to the decrease in stands number. Maritime Pine pure stands reached the maximum value of decreasing (14%). Cork Oak and Umbrella Pine still maintains to be the most stable composition.

4.1.3 Landscape wildfire resistance

Figure 8, shows the landscape wildfire resistance of Chamusca in 2014, 2015, 2020. In 2014, it was when reached the maximum value, after it remains constant. This can be explained by the conversions that happen from 2014 to 2015 that subsequently would influence the spatial context of the others stands. Overall, the landscape wildfire resistance seems to be high, being within the third highest class, because it was applied one prescription in each stand in each year. The standard deviation was 0.06, 0.15, and 0.15, respectively to each year. If only depended on Cork Oak species, the landscape wildfire would be higher. Although, as Eucalyptus is the second more representative specie in Chamusca, the landscape wildfire resistance decreased.

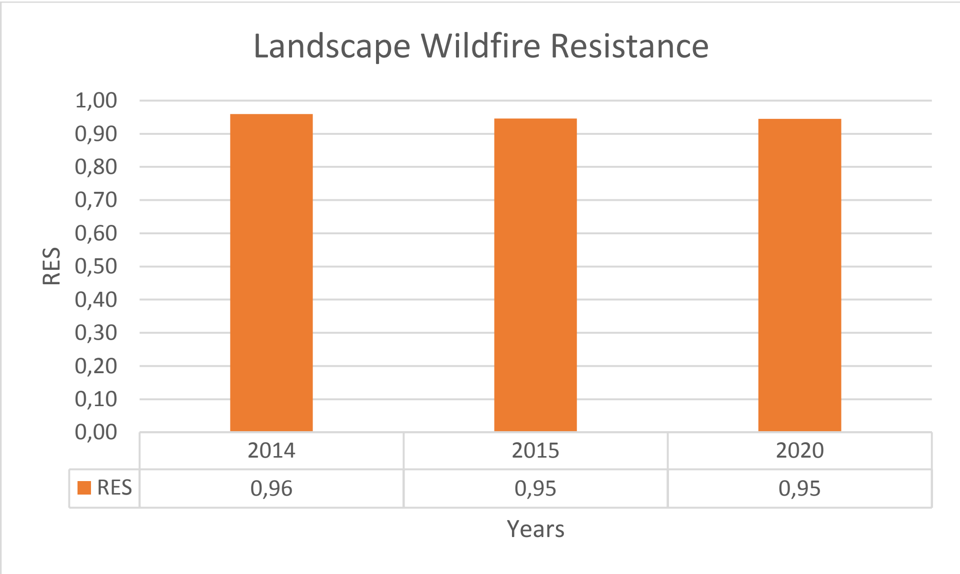

Figure 8- Landscape wildfire resistance on 2014, 2015 and 2020 of Chamusca.

4.2 Vale do Sousa

4.2.1 Year of forest inventory: Specific and adjusted wildfire resistance indicator

In Vale do Sousa, contrary to Chamusca study area, the forest inventory is done in the same period (2012). Again, using the yield tables to get the trees growth for the next years is one solution to the lack of inventory data. In this study area, it was possible to calculate the specific and adjusted wildfire indicator (Annex III), as it is possible to see from figure 9 and figure 10, respectively. The specific wildfire resistance indicator (figure 9) detects more stands with less resistance to fire than the adjusted wildfire resistance indicator (figure 10). The integration of spatial context works as a filter, can maintain the same class (circle 1) or change class by decreasing (circle 2) or increasing the wildfire resistance (circle 3).

There were two sources of information, from forest inventories or from simulation and the calculation method of the adjusted wildfire resistance indicator of mixed stands changed. The data from simulation included the prescriptions and because different species have their own prescriptions, the simplification was to calculate by specie and, then, doing an average of the indicator result. Since the data from forest inventory only gives information about the state of the forest in that moment, it did not include prescriptions. In this case, the indicator was calculated by stand.

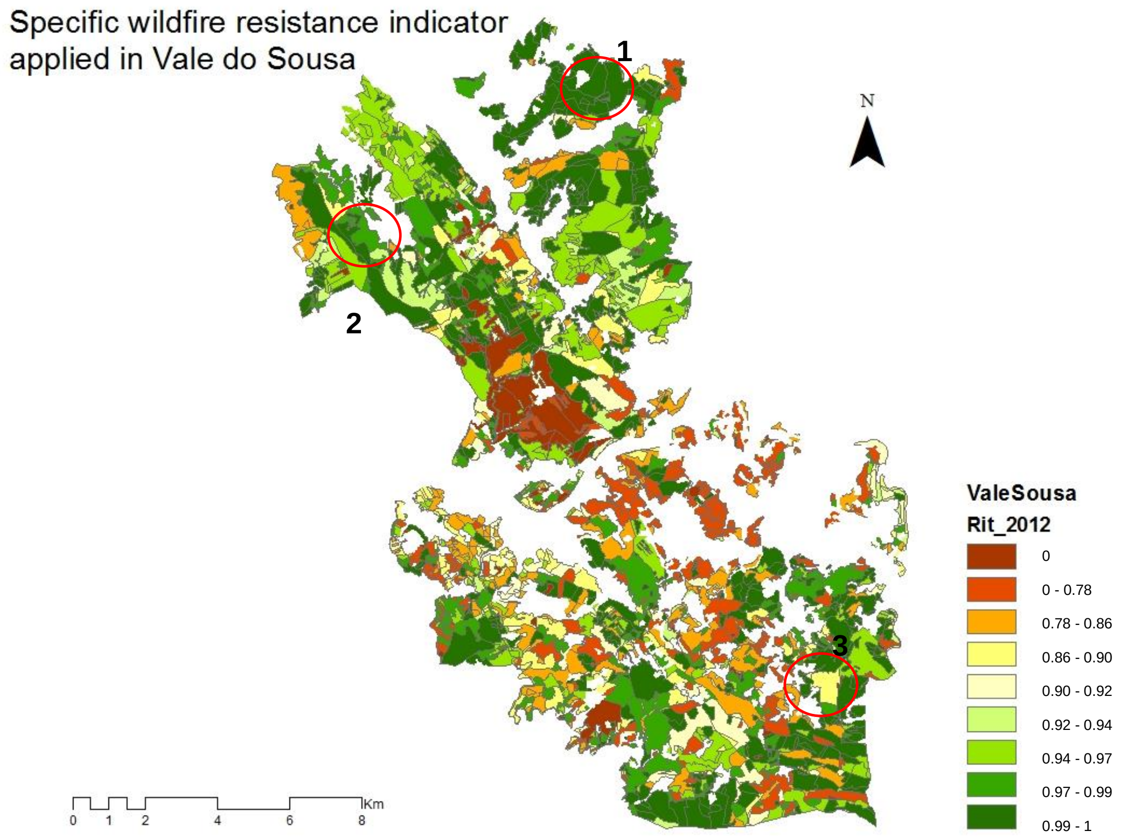

Figure 9- Specific wildfire resistance indicator applied in Vale do Sousa.

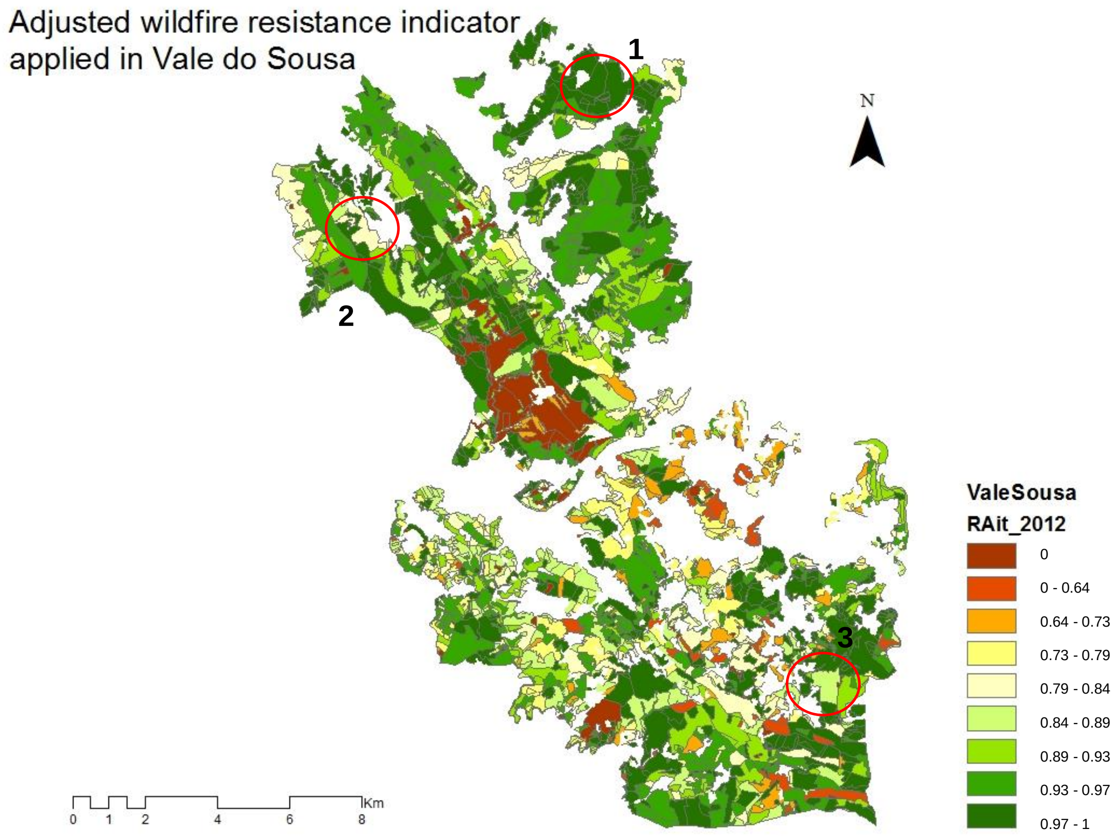

Figure 10- Adjusted wildfire resistance indicator applied in Vale do Sousa.

4.2.2 Simulated years: Adjusted wildfire resistance indicator

These results were based on simulated data of 2014, 2015, and 2020, from which was calculated the adjusted wildfire resistance indicator in Vale do Sousa study area (Annex IV).

Table 15- Number and percentage of stands with $0 < RA_{i2014} \leq 0.86$ (three lowest classes) and $RA_{i2014} \geq 0.97$ (two highest classes), in Vale do Sousa. Excludes the initialized stands.

Species	No. stands	$0>RA_{i2014} \leq 0.86$	%	$RA_{i2014} \geq 0.97$	%
Chestnut	52	0	0	47	90
Eucalyptus	1426	101	7	676	47
Eucalyptus_Maritime Pine	208	24	12	48	23
Maritime Pine	135	6	4	91	67

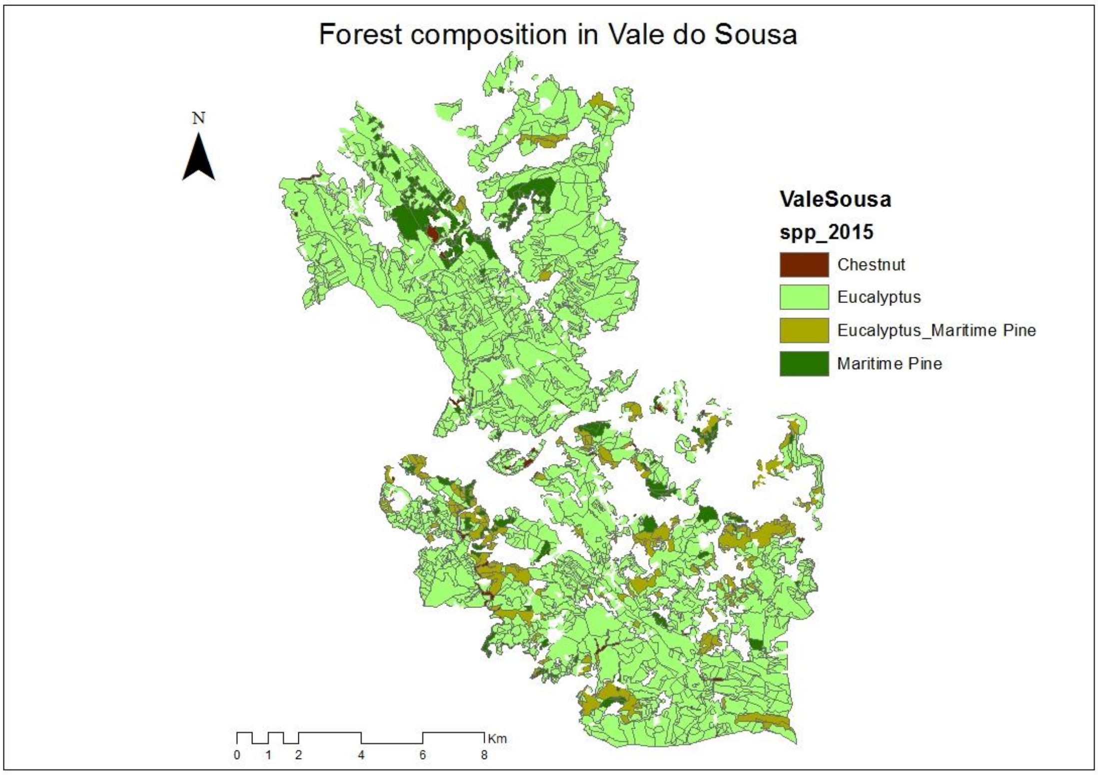

Figure 11- Forest composition in Vale do Sousa.

As it is possible to understand from the table 15 based on information from figure 11, the specie which mainly are within the three lowest classes, is Eucalyptus as pure (7%) and as mixed stand with Maritime Pine (12%). Noticing no presence of Chestnut. On the other hand, the two highest classes of wildfire resistance (darker green) are composed mainly by Chestnut with 90% (table 15). Maritime Pine and Eucalyptus pure stands appear approximately with 67% and 47%, respectively and the mixed stands of these same species has 23%, being the lowest percentage.

Again, interpreting according to each forest composition structure, it makes sense that Eucalyptus and Maritime Pine species as pure and mixed stands are present at the lowest classes, since they are prone species to burn (Silva et al., 2009). As well as Chestnut is not present, for being a broadleaf and typically associated to agroforestry systems (Silva et al., 2009).

From the figure 12, it is visible that the forest wildfire resistance changed from the year to the other. In 2014 and 2015 are the years that have stands in which wildfire resistance is zero, since it is where it will occur a conversion from shrublands to forest land. The species in this situation are Chestnut, Eucalyptus as pure stand and as mixed with Maritime Pine. Comparing figure 12 with figure 13, the circle 1 and in circle 2 indicates Eucalyptus stands, which occurred an increase of shrub biomass approximately of 2 Mg/ha and consequently the specific wildfire resistance decreased. The main reason was that the annual wildfire occurrence probability increased with the increase of shrubs biomass. Although, it was not enough to change class. The circle 3 and 5 show two situations (Eucalyptus stands) in which the wildfire resistance decreased with an increase of shrub biomass. Contrary, the circle 4 points to an increase of wildfire resistance in a Eucalyptus stand from 0.91 to 1 with a decrease of shrub biomass (≈ 11 Mg/ha).

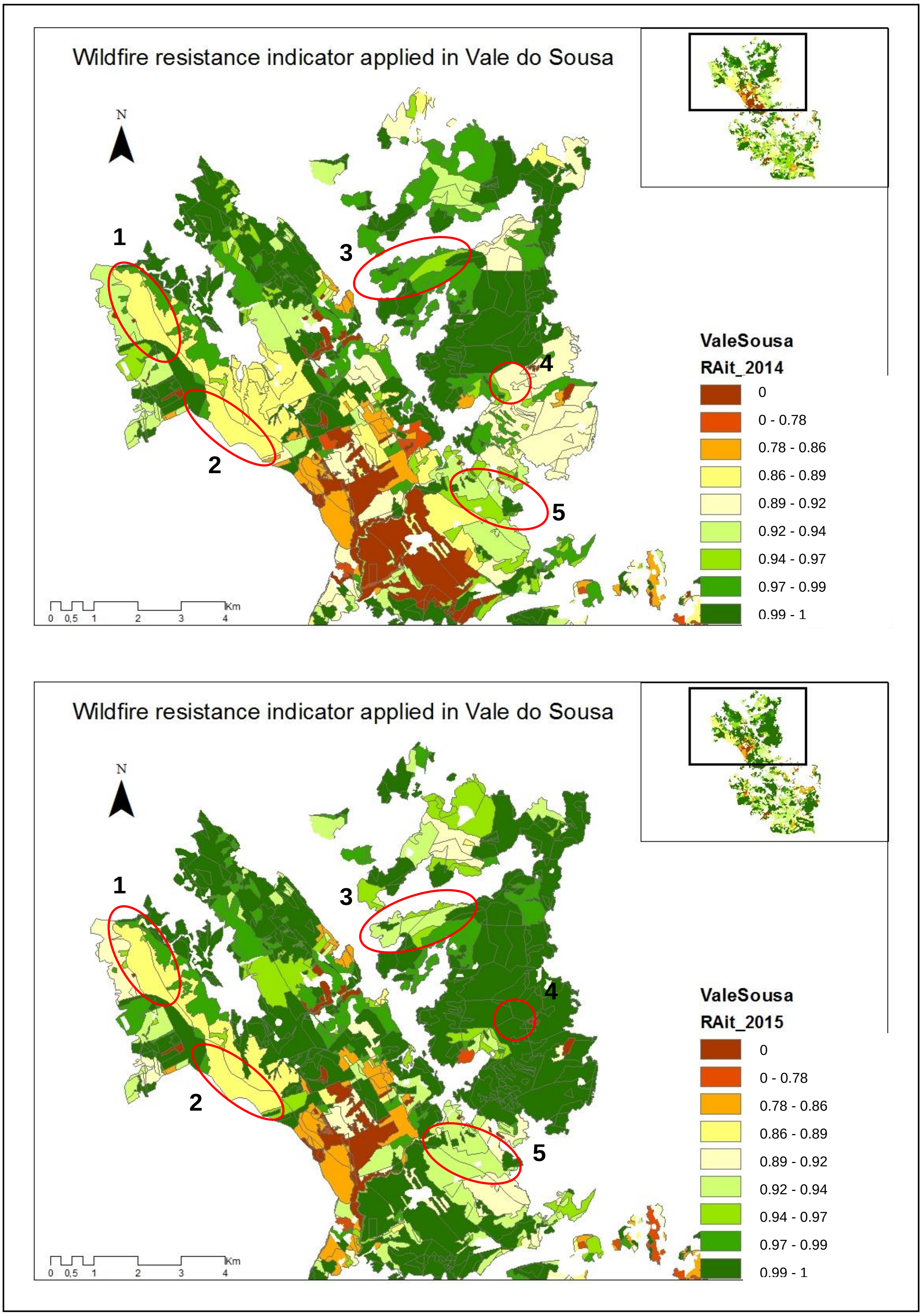

Figure 12- Variation of the wildfire resistance indicator in Vale do Sousa between 2014 and 2015.

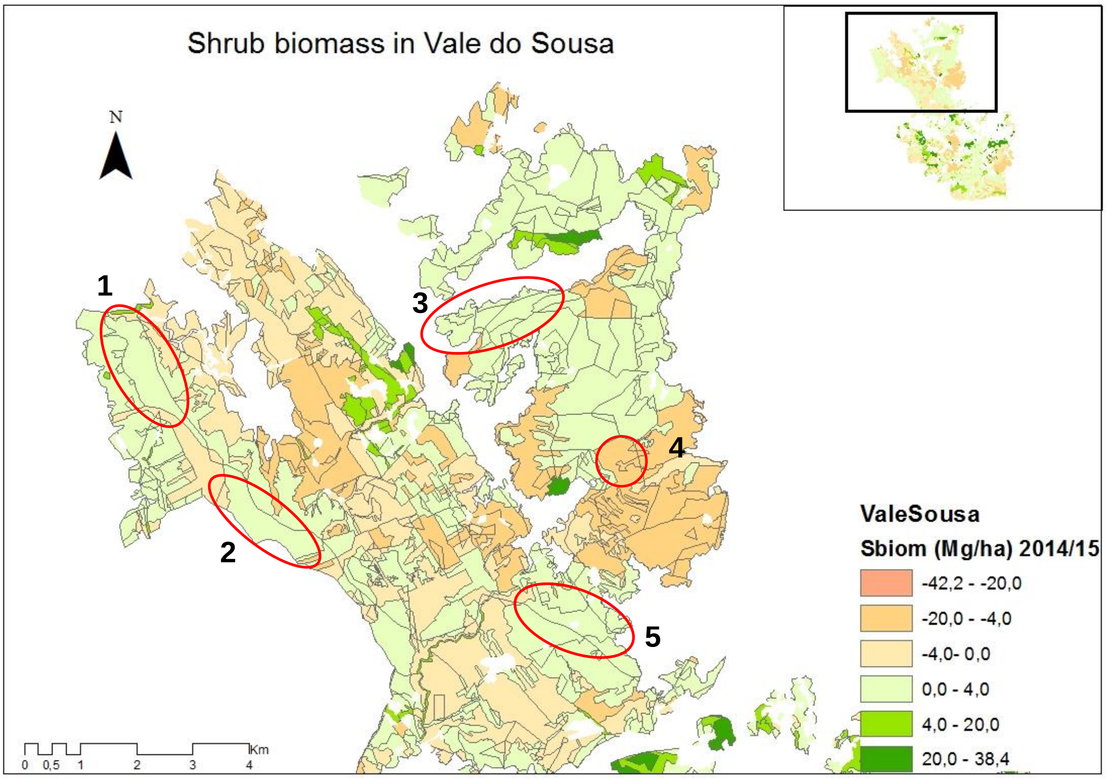

Figure 13- Shrub biomass in Vale do Sousa, between 2014 and 2015.

Table 16- Higher wildfire resistance ($RA_{it} \geq 0.97$) classes analysis by forest composition, excluding the initialized stands: number and percentage of stands that change to two highest resistance classes from 2014 to 2015, percentage of stands that are within the highest class in 2014, and the total number and percentage of stands that are within the two highest resistance classes in 2015.

Species	No. stands	RA_{i2014} to $RA_{i2015} \geq$ 0.97	%	$RA_{i2014} \geq$ 0.97 (%)	$RA_{i2015} \geq$ 0.97	%
Chestnut	52	3	6	90	50	96
Eucalyptus	1426	228	16	47	805	56
Eucalyptus_Maritime Pine	208	7	3	23	26	13
Maritime Pine	135	17	13	67	100	74

From the table 16, it is possible to understand that there is not a composition type that suffers a huge transition to the two highest classes of resistance from 2014 to 2015. The higher percentage (16%) was from the Eucalyptus pure stands, the lowest percentage was from the mixed stand composed by Eucalyptus and Maritime Pine (3%) and Chestnut stands (6%). Looking to the table 16, Chestnut stands present the highest wildfire resistance (96%) compared to the others. Besides, Chestnut stands as it was referred before, they have one of the lowest transition percentage. For that reasons, it suggests that this specific forest composition is more stable and resistant to forest fires. This can be supported for being a broadleaf, presenting a low fire proneness (Silva et al., 2009).

After 2015, it is still visible the changes between 2015 and 2020 in terms of wildfire resistance (figure 14). In 2020, already do not exist stands missing to be converted to forest land. From figure 14 and figure 15, in circle 1 it is possible to see that the Maritime Pine stand increased resistance in 2020 from 0.95 to 0.99, even when the shrub biomass increased (≈ 9 Mg/ha). The annual wildfire occurrence probability increased but the prediction of stand mortality decreased and this should be due to stand structure. In circle 2, two phenomenon's happen. One stand in 2015 was shrubland and in 2020 was converted to Eucalyptus pure stand, for that reason the wildfire resistance passed from 0 to 0.96. All the shrublands were assumed to have zero as wildfire resistance, considering the worst case scenario. The other case is one Eucalyptus stand that the shrub biomass decreased (≈ -11 Mg/ha) and the wildfire resistance increased from 0.81 to 1. The neighbour's influence from this last case become more positive in 2020 (-0.006 to -0.003), since, as it was mentioned before, the other stand was converted. In other words, the resistance of the neighbour's stands increased.

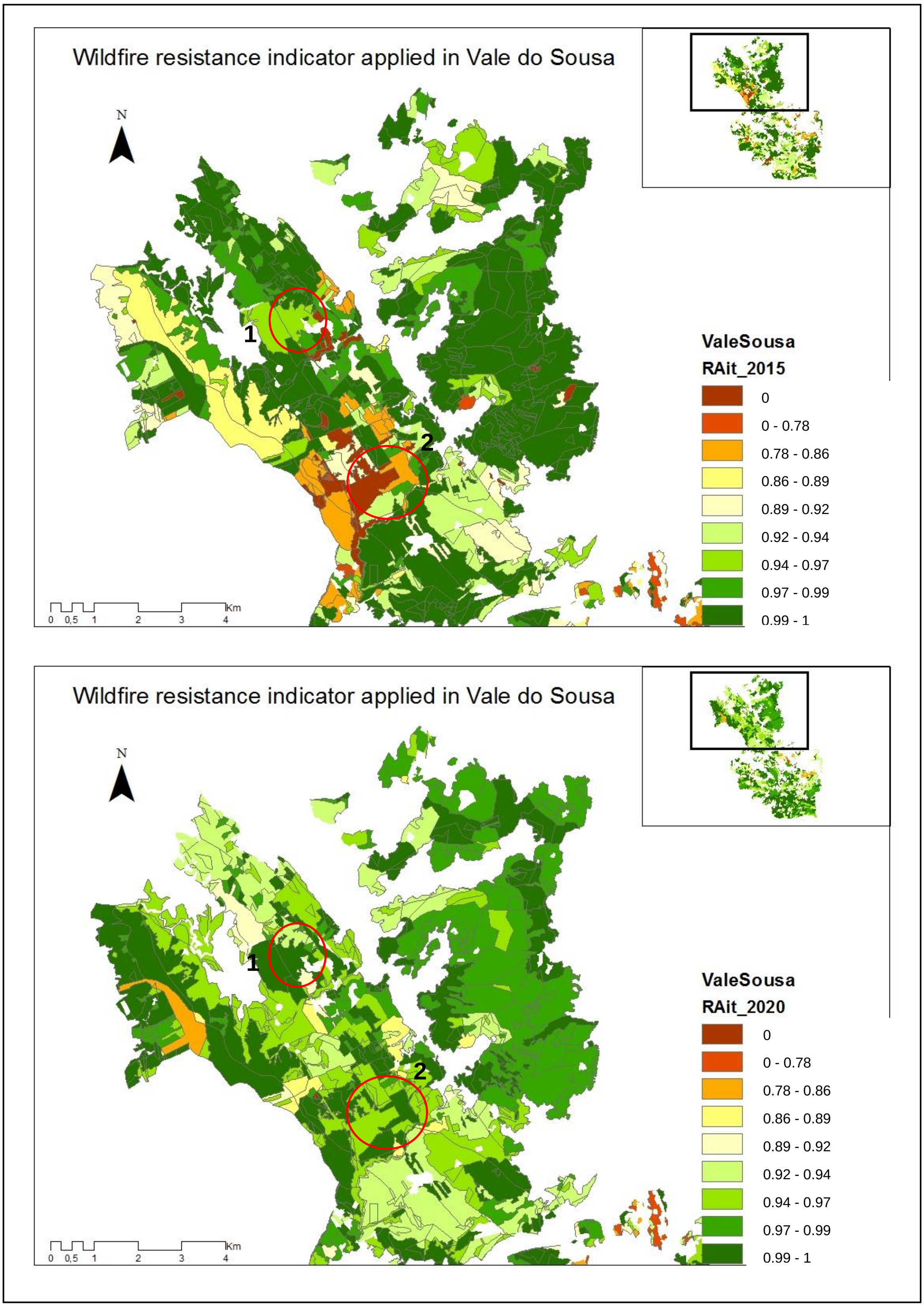

Figure 14- Variation of the wildfire resistance indicator in Vale do Sousa between 2015 and 2020.

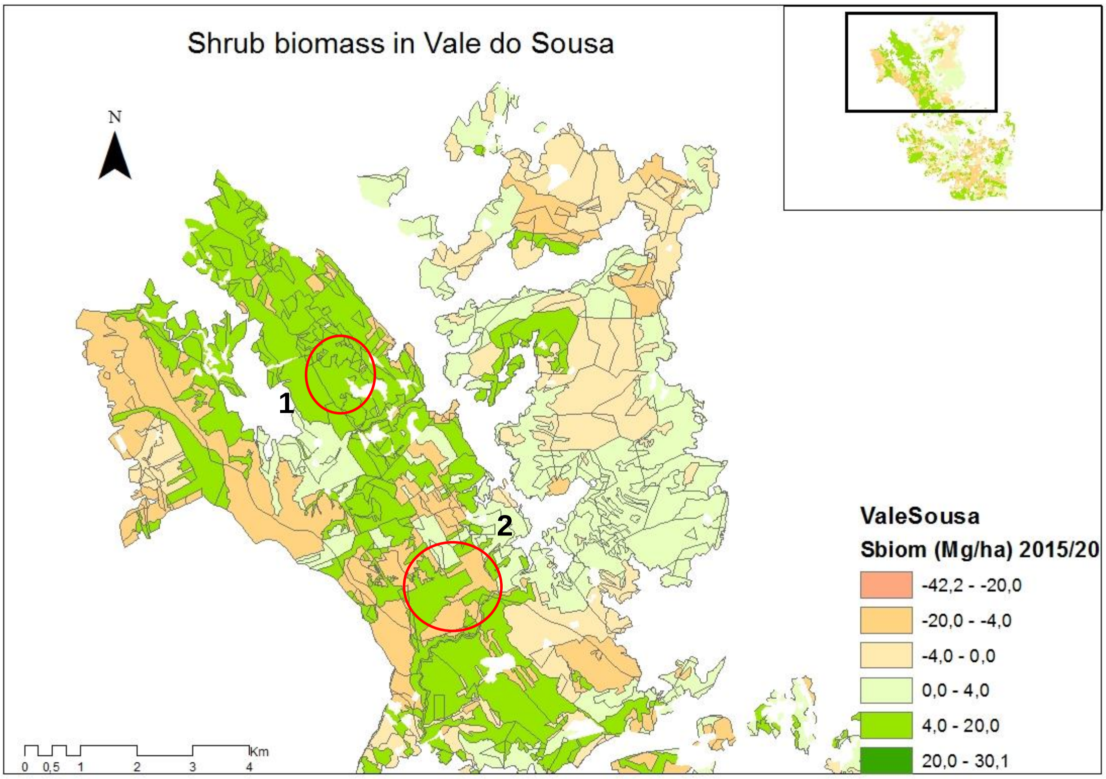

Figure 15-Shurb biomass (Mg/ha) in Vale do Sousa, between 2015 and 2020.

Table 17- Higher wildfire resistance (RA_{it} ≥ 0.97) classes analysis by forest composition, excluding the initialized stands: number of stands that change to the higher resistance classes from 2015 to 2020 and its percentage, percentage of stands that are within the higher classes in 2015, and the number of stands that are within the two most resistant classes in 2020 and its percentage.

Species	No. stands	RA_{i2015} to RA_{i2020}≥ 0.97	%	RA_{i2015}≥ 0.97 (%)	RA_{i2020}≥ 0.97	%
Chestnut	52	0	0	96	1	2
Eucalyptus	1426	418	29	56	837	59
Eucalyptus_Maritime Pine	208	45	22	13	57	27
Maritime Pine	135	34	25	74	126	93

From the table 17, it is possible to see that there is some changes comparing to the information given in table 16. The transition to the two higher classes of resistance, overall, increased and considering the number of stands within the higher classes in 2020, it occurred an abrupt decrease of resistance from Chestnut stands and the other forest compositions increased. In other words, in the case of chestnut, consider before as the most resistant composition (96%), now it has only 2% of stands within the higher classes (94% of loss). This can be due to the prescriptions randomly selected being not the most suitable for this specie. In 2020, Maritime Pine stands appears as most resistant, having 93% of stands at the highest classes.

The Chestnut and Maritime Pine stands are not so sensible to an increase of shrub biomass when compared to other species, such as Eucalyptus. Although, Maritime Pine stands normally have lower wildfire resistance than Chestnut. The reasons can be related to Chestnut being a broadleaf (more resistance) and Maritime Pine a conifer (less resistance). The difference between Eucalyptus and Maritime pine can be due to the forest structure, since Eucalyptus is explored through coppice and Maritime Pine as high forest.

4.2.3 Landscape wildfire resistance indicator

The figure 16, shows the landscape wildfire resistance of Vale do Sousa in 2014, 2015, 2020. Among all the study period, the landscape wildfire resistance increased continuously. This can be due to the conversions that happen from 2014 to 2015 that subsequently would influence the spatial context of the others stands by increasing the resistance and also increase the forest area. Since it was given to the non-forest lands zero for their specific wildfire resistance (worst case scenario). Overall, the landscape wildfire resistance is between the fourth and third highest classes, this can be due to the fact that the main specie is Eucalyptus. It fallows more and less the mean of Eucalyptus stands wildfire resistance for each year. The standard deviation was 0.05, 0.06, and 0.04, respectively to each year.

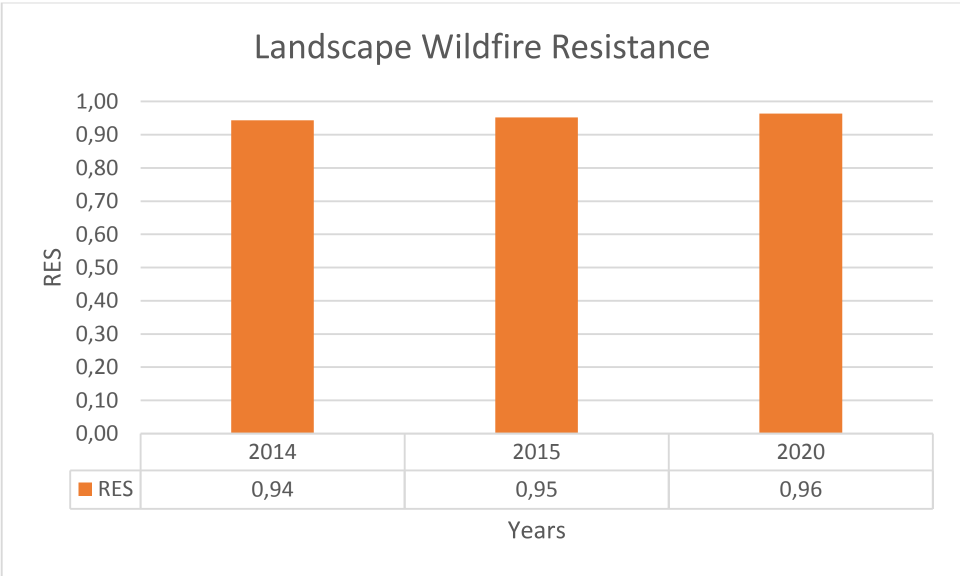

Figure 16- Landscape wildfire resistance on 2014, 2015 and 2020 of Vale do Sousa.

4.3 Positive and negative aspects of the wildfire resistance indicator

The aim was to address the wildfire risk into forest management planning. Some indicators evaluate the wildfire risk but are not focus on forest management (Aretano et al., 2015; Lampin-

Maillet et al., 2011, 2009; Sauvagnargues-Lesage et al., 2001). In contrast, the selected wildfire resistance indicator is based on biometric variables, which can be controlled by the forest manager, and possible to get in forest inventories (Botequim et al., 2008). In that way, the forest manager is able to control the variables and to acquire them easily.

It was used the three step approach which takes into consideration that fire occurrence does not mean that mortality will necessarily happen. The approach starts by evaluating the annual wildfire occurrence probability, by predicting whether mortality will occur in the stand, and finally by calculating the dead trees proportion (Botequim et al., 2008; Garcia-Gonzalo et al., 2011).

Others indicators have different methodologies. Mokhov and Chernokulsky, (2010) shows an indicator mainly based in meteorological data, Grishin and Filkov, (2011) which is an improvement of the first, by considering vegetation (thermos-physical and thermo-kinetic constants, forest fuel mass, moisture content), however the inputs are difficult to acquire and to understand. Catry et al., (2010) presents variables correlated with fire damage, but, again, it consists in using fire injury variables, which are difficult to get and not practical for forest management.

The wildfire resistance indicator is based on wildfire occurrence and damage models, which follows the same framework of Chuvieco et al., (2010). The damage prediction is essential by providing the forest fires impact under different forest conditions, in other words, different silviculture strategies. Thus, an indicator based on wildfire risk and damage models, is consider more realistic for estimating forest outputs. Some forest fire indicators do not evaluate this, but focus only in wildfire occurrence models (Boubeta et al., 2015; Fuentes-Santos et al., 2013). In Mbow et al., (2004) work, they used remote sensing and a fire simulator to do fire risk assessment. In this case, they considered fire occurrence probability and the potential fire damage, but it has some limitations: it depends of image resolution, and ignitions points. Other works depend on image resolution as well (Hernandez-Leal et al., 2006; Maeda et al., 2011). The selected wildfire resistance indicator does not have this kind of limitations, since it uses forest inventories and it is independent of the ignition point (Ferreira et al., 2015).

The selected indicator measures the resistance of each forest stand, considering also the spatial context (Ferreira et al., 2015). González et al., (2005) defended that the landscape metrics related to fire risk (arrangement and connectivity of different types of forest stand), can play a major role in integrating fire risk considerations in forest planning and in addressing the problem at landscape level. The idea of doing fire risk assessment at landscape level was suggested by other authors (Ferreira et al., 2012; Garcia-Gonzalo et al., 2012; González-Olabarria and Pukkala, 2011; Marques et al., 2012).

The wildfire resistance indicator has some limitations to be considered. For not including other land uses in addition to forest, it can miss information related to the spatial context. The different land uses are a common concern in several indicators (Fuentes-Santos et al., 2013; Sauvagnargues-Lesage et al., 2001; Verde and Zêzere, 2010). Again, the spatial context fails when the stands are at the border of the study area. For that reason, a buffer around the study area should be taken into account to do a more accurate landscape analysis. As mentioned before, the input data is acquired through forest inventories. Despite, it is an available way to access the needed information, forest managers should be aware that some errors and omission of relevant information might take place. For example, information related to shrubs is essential, as it was proven before, due to shrub biomass is one of the most significant variables within the indicator. Some research highlights the importance of fuel load (Chuvieco et al., 2010; Garcia-Gonzalo et al., 2014). The selected indicator integrated the shrub biomass within the model developed by Botequim et al. (2015). There is one important constrain to keep the model accurate: it is restricted to 15 consecutive years without any forest intervention. If it is considered longer periods, the results will be compromised. For example, in both study areas, the shrub age was not directly available, and the solution was to consider the last fire disturbance. And then the problem was when the last fire disturbance exceeded the 15 years and some assumptions had to be done.

5 CONCLUSION

Forest fires might be predicted, then the application of efficient preventive measures are required for several reasons. First, the available investment is always consider as limited resource for that reason knowing where and what the owner has to focus on it will be helpful. Second, the forest fires are expected to become larger and more frequent, since there is predictions about having longer fire seasons and drier conditions. Third, the ecological damage and economic losses that causes. Therefore, undergoes from identifying not only where it is more susceptible to occur fires but also where there is more damage, after, it is needed to conciliate the wildfire risk with forest management. The wildfire resistance indicator seeks to show where there is less or more wildfire resistance. The singular characteristic is its capacity to take into account the surrounding stands effect, in other words, the spatial context of each stand is insert. In this way, a more realistic approach is done. In sum, this study shows one possible way to address wildfire risk in forest management.

Each forest composition structure was relevant in terms of wildfire resistance in Chamusca and Vale do Sousa. The main specie in Chamusca is Cork Oak and in Vale do Sousa is Eucalyptus. Cork Oak stands compared to Eucalyptus stands were more resistant when facing lack of management, particularly shrub cleanings. This can be explained due to the fact that shrubs biomass is a significant variable in all of the models used for calculating the annual wildfire occurrence probability. In sum, the indicator allows to understand that Cork Oak, Umbrella Pine and Chestnut normally presents higher wildfire resistance. Maritime Pine is also appearing with high resistance but lower when compared to the previous species, when forest management is existent. Eucalyptus shows as the most sensitive to shrub biomass and for that reasons presenting more variations in terms of wildfire resistance. The spatial context was felt in both study areas, by intensifying or inhibit the specific wildfire resistance, sometimes changing the expectable results.

This indicator is mainly based on biometric variables and so obviously the quality of the results will depend on the quality of the data provided by forest inventories. This can be seen as an opportunity to know where it is necessary to improve the forest inventories. For example, the major constrain that happen on calculating the indicator was the lack of available data from the National Forest Inventory related to shrubs, in terms of not having any plot matching with Chamusca study area. Particularly, it was a limitation on knowing the shrub species.

In the future, it could be included as part of the spatial context not only forest stands but also other type of land uses, for instance agriculture lands, which it is where most of the times can start a fire. Besides, should be taken into account a buffer around the study area, to be able to do a more accurate landscape analysis within the study area, since at the border the stands are also influenced by their neighbors.

The next step, should be the integration of this same wildfire resistance indicator into a study already developed, which used Pareto Frontier to illustrate trade-offs between several goals in Chamusca and Vale do Sousa (Borges et al., 2015). In this way, a more complete assessment of the different scenarios will be done in terms of ecosystem services provision.

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Annex I- Chamusca example of specific wildfire resistance indicator calculation results, based on forest inventory data (1999, 2005, 2007, 2009 and 2010).

Stand Units (i)	Pburn	Psd	Pd	R_{it}	Inventory year
200001	0,793971	0,236097	0,663078	0,875703	2005
200002	0,793971	0,236097	0,691718	0,870335	2005
200003	0,6925	0,236097	0,665656	0,891167	2005
200004	0,6925	0,236097	0,67111	0,890276	2005
200005	0,6925	0,236097	0,684978	0,888008	2005
…	…	…	…	…	…
203505	0,729431	0,4622	0,631024	0,787254	2005
203506	0,082149	0,619685	0,233839	0,988096	2005
203507	0,016684	0,043546	0,15634	0,999886	1999
…	…	…	…	…	…
205884	0,405357	1	0,223067	0,909578	2010
205885	0,366149	1	0,18109	0,933694	2010
205886	0,719358	0,397469	0,631112	0,819551	2005
205887	0,241942	1	0,181255	0,956147	2010

Annex II- Chamusca example of wildfire resistance indicator calculation results for 2014, 2015 and 2020, based on simulations data.

Stand Unit (i)	R_{i2014}	$\Sigma\alpha(RA_{s2014}-R_{i2014})$	RA_{i2014}	R_{i2015}	$\Sigma\alpha(RA_{s2015}-R_{i2015})$	RA_{i2015}	R_{i2020}	$\Sigma\alpha(RA_{s2020}-R_{i2020})$	RA_{i2020}
200001	0,99993	-0,06075	0,94435	0,87234	-0,03992	0,83581	0,90555	-0,03992	0,86902
200002	0,99993	-0,21406	0,84517	0,99411	-0,18663	0,85918	0,99669	-0,18663	0,86176
200003	0,99993	0,00000	0,99993	0,99616	-0,00027	0,99601	0,99749	-0,00027	0,99734
200004	0,99993	0,00001	0,99994	0,99719	0,01946	1,00000	0,99814	0,01946	1,00000
200005	0,99993	0,00000	0,99993	0,99712	0,00248	0,99882	0,99823	0,00248	0,99993
…	…	…	…	…	…	…	…	…	…
203505	0,91670	0,01265	0,92830	0,99675	0,03481	1,00000	0,90401	0,03481	0,93594
203506	1,00000	-0,00001	0,99999	1,00000	-0,02330	0,98144	1,00000	-0,02330	0,98144
203507	1,00000	0,00000	1,00000	1,00000	-0,00002	0,99998	1,00000	-0,00002	0,99998
…	…	…	…	…	…	…	…	…	…
205884	0,96419	0,00249	0,96646	0,99823	0,00760	1,00000	0,99774	0,00760	1,00000
205885	0,95495	0,00764	0,96149	0,99808	0,00127	0,99917	0,99764	0,00127	0,99873
205886	0,92716	0,00197	0,92907	0,99715	0,00928	1,00000	0,99691	0,00928	1,00000
205887	0,99987	-0,00180	0,99821	0,99990	-0,02412	0,97773	0,99975	-0,02412	0,97758

Annex III – Vale do Sousa example of wildfire resistance indicator calculation results in 2012, based on forest inventory data.

Stand Unit (i)	Pburn	Psd	Pd	r_{itk} (%)	x_{ik}	R_{it}	Area (m2)	Perimeter (m)	w_i*Θ_i	$\Sigma\alpha(RA_{st}-R_{it})$	RA_{it}
1	0,42426	1,00000	0,75380	0,68019	1	0,68019	15659,8	607,5	0,18029	0,00215	0,68195
2	0,15099	0,97641	0,63559	0,90629	1	0,90629	40178,7	1058,2	0,30678	-0,00496	0,90286
3	0,15099	0,97641	0,63559	0,90629	1	0,90629	40002,7	1141,1	0,28319	-0,00231	0,90464
4	0,15099	0,97641	0,63559	0,90629	1	0,90629	5834,4	331,2	0,08900	0,00000	0,90629
5	0,15099	0,97641	0,63559	0,90629	1	0,90629	44906,7	1270,4	0,28654	-0,01963	0,89229
…	…	…	…	…	…	…	…	…	…	…	…
1725	0,05866	0,93049	0,64305	0,96490	1	0,96490	32009,9	792,6	0,30341	-0,00122	0,96405
1726	0,07984	0,23610	0,78268	0,98525	1	0,98525	23988,0	741,3	0,15846	0,02490	1
1727	0,07984	0,23610	0,78268	0,98525	1	0,98525	35283,7	1082,8	0,17581	0,02563	1
…	…	…	…	…	…	…	…	…	…	…	…
2178	0,18204	0,57925	0,34289	0,96384	1	0,96384	201379,0	3662,3	0,35110	-0,00389	0,96132
2179	0,42426	1,00000	0,75380	0,68019	1	0,68019	235179,0	5097,6	0,28031	0,00000	0,68019
2180	-	-	-	0	1	0	-	-	-	-	0
2181	0,34016	0,99413	0,26078	0,91181	1	0,91181	5198,6	325,0	0,07720	0,00107	0,91280
2182	0,38973	0,99997	0,60181	0,76547	1	0,76547	9779,8	425,6	0,14001	0,00150	0,76676

Annex IV- Vale do Sousa example of wildfire resistance indicator calculation results for 2014, 2015 and 2020, based on simulations data.

Stand Unit (i)	R_{i2014}	$\Sigma\alpha(RA_{s2014}-R_{i2014})$	RA_{i2014}	R_{i2015}	$\Sigma\alpha(RA_{s2015}-R_{i2015})$	RA_{i2015}	R_{i2020}	$\Sigma\alpha(RA_{s2020}-R_{i2020})$	RA_{i2020}
1	0,89949	0,00001	0,89950	0,87704	-0,00207	0,87535	0,81614	-0,00234	0,81423
2	0,99967	-0,01736	0,98763	0,99979	-0,02117	0,98512	0,99940	-0,00887	0,99326
3	0,99967	-0,02643	0,98072	0,99968	-0,02946	0,97856	0,99966	-0,02481	0,98188
4	0,99967	0,00000	0,99967	0,99976	0,00000	0,99976	0,99936	0,00000	0,99936
5	0,99967	-0,02751	0,98004	0,99979	-0,03323	0,97609	0,99940	-0,01357	0,98972
…	…	…	…	…	…	…	…	…	…
1725	0,93254	0,04043	0,95999	0,96647	0,02007	0,98010	0,99479	-0,04404	0,96489
1726	0,99991	0,00000	0,99991	0,99991	0,00000	0,99991	0,95236	0,00000	0,95236
1727	0,99991	-0,07206	0,94668	0,99991	-0,07206	0,94668	0,95236	-0,06864	0,90166
…	…	…	…	…	…	…	…	…	…
2178	0,96031	-0,00213	0,95893	0,92519	0,00043	0,92546	0,94417	0,00086	0,94472
2179	0,84081	0,00000	0,84081	0,69951	0,00000	0,69951	0,67377	0,00000	0,67377
2180	0	-	0	0,97497	0	0,97497	0,93039	0	0,93039
2181	0,98683	0,00018	0,98700	0,98136	0,00026	0,98160	0,85907	0,00119	0,85932
2182	0,98066	0,00006	0,98071	0,97509	0,00006	0,97515	0,90635	-0,00049	0,90641