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Trends in wildfire risk at time-scale: Optimizing fuel treatments configurations in eucalyptus plantations in Portugal

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Abbreviations and acronyms

BP-Burnt Probability
CBD- Canopy Bulk Density
CBH- Canopy Base Height
CC- Canopy Cover
CFA- Crown Fire Activity
CF-Crown Fire
CL-Crown length
DGRF-Direçao Geral dos Recursos Florestales
DTM-Digital terrain Model
FAO- Food and Agriculture Organization of the United Nations
FLI-Fireline Intensity
FL-Flame Length
GPS- Global Positioning System
gPS-Grupo Portucel Soporcel
ICNF-O Instituto da Conservação da Natureza e das Florestas
IFN-Inventário Florestal Nacional
LCP-Landscape file
LTD-Landscape Treatment Designer
ROS-Rate of Spread
t_0-time period in 2015
t_1- time period in 2018
t_2 -time period in 2021
t_3- time period in 2024

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Summary

The increase of forest threats in a global change context encourage fire prevention activities for the role in maintaining diversity and land sustainability as a multiuse system as well as for ensuring the welfare of the Mediterranean people. Silviculture prevention management is a complex, dynamic instrument implying many variables, needing knowledge about the strategic localization of fuel treatments. Optimization is driven by the need of accomplishing an objective (or multi-objective) with a limited number of resources, namely money, time, machinery or human resources. Where to treat? How much? Shape and size? The current framework was driven taking into account the Landscape Treatment Designer (LTD), a decision support tool to spatially explore optimal levels of fuel landscape treatment planning regarding: *i*) objectives as timber value and carbon storage; *ii*) treatment thresholds as fire hazard metrics (e.g. rate of spread, ROS and flame lenght, FL), *iii*) and constraints selected (annual budget restrictions to represent the total treatment allowance - area/ha). The research considered a property (extent ≈ 1500 ha) from the Grupo Portucel Soporcel (gPS), located in Serra do Socorro (Torres Vedras, Portugal), where eucalypt (*E. globulus*) is predominant. The central objective is to minimize the losses from wildfire to strategically allocating and scheduling fuel treatments into a spatial-temporal analysis without encroaching budget constraints, and further creates opportunities for the suppression, taking into account over time, wood supply for the pulp industry and meeting demands of carbon values. While the primary objective is to change stand conditions. The ultimate goal of the fuel treatments allocation is to increase landscape resistance to the severe effects of wildfire at different scales, following certain constraints. Explicitly: *i*) identifying understory fuel composition and stand conditions at temporal stage (t_0,t_1,t_2,t_3 corresponding to 2015, 2018, 2021 and 2024 respectively); *ii*) characterizing temporal fire behavior (t_0,t_1,t_2,t_3) using FlamMap 5. simulator for two weather scenarios (10% and 7% fuel moisture content for average and critical conditions, respectively), crossed with wind speed of 32 km/h; *iii*) examining optimal treatment locations for each temporal stage; *iv*) perform sensitivity analyzes (area treated - two treatment intensities of 70 ha and 100 ha), and *v*) improve spatial-temporal fire resistance at landscape level. The effect of each scenario was changed by a set percentage of optimal parameters to address the identification of thresholds for radical change in fire behavior, and further insight to support hazard-reduction fuel practices. The accuracy of the results provided an overview of effective management strategies for fuel modifications on improving fire resiliency and selecting priority intervention areas in the gPS eucalyptus plantation.

Keywords: Fire hazard, Eucalyptus plantations, planning optimize-fuel treatment scenarios, Landscape Treatment Designer, FlamMap.

1. Introduction

1.1 Background

Portugal is covered by 3.2 million hectares of forest, representing 34.5% of the total mainland area, and ranking eighth position in Europe as highest country with forestlands (ICNF 2013). Portugal differs from the global setting in terms of the weight of private forest ownership (which extends over 94.3%), and in the major contribution of the forest sector to employment and to national gross value added (GVA) (DGRF 2006, Forest Europe 2011). Nowadays plantations dominated by eucalypts (*Eucalyptus globulus* Labill) encompass 812 thousand hectares (26% of the whole forested area), resulting in the main forest cover type in continental Portugal (ICNF 2013). Following, cork oak (*Quercus suber* L.) is presented with 737 thousand hectares (23%) and third maritime pine (*Pinus pinaster* Aiton.) counting with 714 thousand hectares (23%). The remaining area is occupied by holm oak (*Quercus rotundifolia* L., 10.5%), umbrella pine (*Pinus pinea*, 6%) and other broadleaf and conifer species (17%). The decrease in maritime pine areas by $263x10^3$ ha, and the expansion of eucalypt plantation and shrublands by $95x10^3$ ha, were the most significant trends between the National Forest Inventories (NFI) of 1995 and 2010 (ICNF 2013).

E. globulus plantations in Portugal represent several benefits. These include mainly direct economic benefits for both the industry and the population (which owns much of the land), through timber production essentially for pulp and paper companies (about 5.75 million m^3 of pulpwood per year, DGRF 2006), one of the key businesses in the country (Soares et al. 2007). Additionally, they can also represent other benefits like employment and carbon sequestration. In Portugal all the commercial plantations are single species (i.e. stands are monospecific being problematic plantations), and eucalypt stands are usually regular plantations with high stand densities, and highly prone to fire (Fernandes 2009, Moreira et al. 2009). In terms of the most affected areas nationwide, statistics (1996–2012) indicate that eucalypt stands are flammable forest species that dominate northern and central Portugal, accounting for 35.9% of all forest burned (Conacher & Sala 1998, Fernandes 2007). Indeed, *Eucalyptus globulus* stands are quite hazardous because of the high volume of dead debris they produce, their characteristic disposition of fuels, and their oily foliage. However, under an appropriate forest management eucalyptus stands can reduce fuel volume and alter the forest structure in a way that they become more fire-safe (Botequim et al. 2013).

Some studies have already addressed the problematic of the management scheduling with regards of wildfire risk in *E. globulus* plantations (Ferreira et al. 2012), in such a way that forest and fire management planning are encourage to be combined. A typical eucalypt in a short rotation coppice system comprise between two or three coppiced stands after plantation, having the first and second coppice a faster growth and being more productive than the following ones (FAO[1]). Each coppice cut is followed by a stool thinning in year three of the coppice cycle that may leave an average number of sprouts ranging from one to two per coppice tree or stool (Ferreira et al. 2012). Portuguese stands are managed in a coppice system and usually the harvest cutting cycle ranges from 10 to 12 years (Soares & Tomé 2001, Ferreira et al. 2012). During the rotation several managements are performed besides the stool thinning, for instance, fuel treatments such as shrub cleanings and others cultural treatments like fertilizations or irrigations. When severe wildfires occurs they might pose a significant impact on revenues and costs from the eucalypt management scheduling (Ferreira et al. 2012). This promotes research on modeling to assess wildfire occurrence probability in eucalypt plantations as a function of variables that may be controlled by forest managers (Botequim et al., 2013).

Portugal leads statistics in wildfires events in the Mediterranean basin (Pereira, et al 2014) among southern European countries being specially critical years 2003,2005 and 2013 due to losses, damages and extension caused by wildfires. Only in 2003 about 8% of the forested area in Portugal burned (6º IFN, National Forestry Inventory, preliminary results[1]). Fuel reduction methods for modifying fire behavior have become a central management issue and are actively practiced by many fire and forest managers. However, the successful management of fuel load in Mediterranean region is a complex issue that encourages the integration of forest and fire management activities in order to change wildfire behavior and decrease severity (Botequim et al., 2014). These changes have been a focus issue for many managers as increased in fuel loads alter forest structure turning into vulnerable forests prone to burn (Stephens et al., 2009). Besides that, creating forest structures that can reduce fire severity at a landscape level may decrease the need for an aggressive suppression response and eventually reduce fire suppression costs (Stephens et al., 2009). Climate projections for the next several decades may further complicate fire management by increasing

[1] http://www.fao.org/docrep/004/ac459s/AC459S20.htm

temperatures and fire season length (Westerling et al 2006). This is also the reason why it is interesting to evaluate and quantify fuel treatment effects on potential wildfire severity under specific fire weather scenarios and through a temporal line (Fernandes & Botelho, 2003) . To counteract the negative consequences of wildfires, fuel treatment strategies are proposed as a tool for addressing uncertainty and complexity in choosing from the variety of proposed types and locations of management treatments. These management decisions have been supported by the use of different software tools (wildfire behavior models, growth modeling and optimization approaches), that assist managers in planning and evaluating fuel treatments to ensure they are cost effective in terms of slowing down the growth of future large, severe wildfires[2]. For the evaluation of the feasibility of fuel treatment, costs and decrease in fire risk are critically considered (Hartsough et al., 2008).

Preventive silviculture management is a complex, dynamic instrument implying many variables, needing knowledge about the localization of the critical points to address. Landscape Treatment Designer (LTD) program optimizes fuel treatment planning regarding the objective(s) chosen and constraints selected. Sensitivity analyzes provide trade-offs to better analyze and explore landscape fuel treatment scenarios and planning decisions (Ager et al., 2012). Wildfire simulation methods provide a framework to quantitatively measure performance of the fuel treatments (Ager et al., 2010), evaluating the effects of the fuel treatment planning on fire behavior before and after the fuel treatment design. This is very valuable information on how the fuel management design might affect fire behavior.

The exotic species eucalypt are the major sources of wood products, implying that the high fire incidence to which they are subjected shifts stand age distribution towards younger classes, decreasing the amount of roundwood available for sawn and decreasing the eucalypt industry interest in the production of pulp in Portugal (Rego et al. 2013). Principles and rules on responsible management aim for the forest sustainability in the Portucel Soporcel Group's[3] areas. Over the years, special regards in conciliate environmental (e.g., forest certification), social (e.g., needs of local communities educational and awareness campaigns) and business concerns. Facing these environmental, social and business challenges and dealing in most of the cases with a very flammable species, studies and collaborations with universities and

[2] http://www.firescience.gov/projects/briefs/03-4-1-04_fsbrief43.pdf
[3] http://en.portucelsoporcel.com/

researches center are encouraged (FireEngine project, FireGlobulus project)[4] in order to achieve a sustainable forest management and fire protection. Further, it has been of an increasing interest for governmental bodies and most active industry companies investigations and considerations on carbon flux and carbon storage implications. It may also have practical application for sustainable forest management allowing the estimation of carbon storage and the assessment of how future wildfire emissions will alter in response to fuel treatments, helping to reduce the uncertainty in emission estimates (Botequim et al., 2014).

1.2 Problem statement

Despite of the huge amount of resources invested in fire prevention and suppression across different Mediterranean regions, since the second half of 20th century impact of wildfires has considerably increased (Moreira et al. 2011) leading to important negative ecological and economic consequences (Barreiro, 2011). The rapid rural depopulation that has occurred in Portugal since the 1950s has consequently left behind uninhabited and aged territories (Valente et al., 2015). The increased wildfire incidence, larger and more severe, as a consequence of an increase in fuel accumulation and continuity might be attributed to these recent land use changes derived from socio-economic development with the decline of agriculture practices, grazing and other rural activities, thus increasing forest plantations and biomass accumulation in former agricultural areas (Valente et al., 2015). At the same time, land abandonment have contributed to reduce the risk of fire ignition in many regions. However, these areas, characterized for low population density and less and more distant roads (Catry, Rego, Bação, & Moreira, 2009), are less accessible to firefighters involving a major fire hazard. Moreover, the last century afforestation policies by the Forest Services explain how eucalyptus rose from a situation of almost non existence in the middle of the 19th century due essentially to the direct investment of the pulp and paper companies and to the investment of non industrial private forest owners stimulated by the demand from those companies[5]. As a consequence, a homogeneous fire-prone landscape composed by forests and shrublands with enlarged fuel loads has been expanded in size of burned areas during the recent years (Vega-García & Chuvieco, 2006). In that framework, the improvements of the preventive activities that collaborate with

[4] http://en.portucelsoporcel.com/Sustainability/Sustainable-Forest/Forest-Protection
[5] http://www.metla.fi/eu/cost/e19/finincport.pdf

decreasing risks and facilitating extinction activities are fundamental (Ruíz-Mirazo et al. 2007).

Fire suppression efforts appear to successfully deal with wildfires in mild weather conditions (Rego & Silva, 2014), but under extreme weather suppression activities are generally ineffective (Ager, 2006) and megafires occur independently of the available fire means and are set under control only when the weather conditions improve and facilitate fire fighting (San Miguel Ayanz et al. 2013). In order to avoid this situation, forest management concerning mainly the reduction of fuel load and the change in fuel structure are considered to increase the chances of suppressing large fires in adverse climate conditions (Regos et al 2014). All the more reason, with an increase of forest threats in a global change context, fire prevention activities should be encouraged to role in maintaining diversity and land sustainability as a multi-purpose system as well as for ensuring the welfare of the Mediterranean people.

We have little or no control over most factors in the fire behavior triangles. However, among these, only fuel (e.g. stand density, vertical structure of the canopy and tree size) can be controlled and are useful predictor to be used in forest planning (e.g. Ferreira et al. 2012, 2014). Finney et al. (2006) addressed how fuel treatments placed in random and optimal spatial patterns affect fires behavior. They found that strategic allocation of fuel treatments reduced the predicted growth rates of simulated fires under unfavorable weather conditions more effectively than random placement. Indeed, fire risk and wildfire damage can be reduced by removing or reducing fuels in strategic locations. Where to treat? How much? Shape and size? Optimization is driven by the need of accomplishing an objective (or multi-objective) with a limited number of resources, namely money, time, machinery and human resources. Large, destructive wildfires are a growing threat to forest, people and other values, and it is clear that changes in forest structure and fuel loadings must be carried out in order to significantly alter wildfire behavior, reduce wildfire losses, and achieve longer term fire resiliency in forests (Botequim, 2015).

1.3 Objectives and research questions

Innovative research work was carried out to address some of the main open questions brought to light by the previous reviews, and to collaborate in the development of a science-based approach to spatially prioritize fuel management, aimed at disrupt fire spread and protect eucalyptus areas from burning without ecological and commercial timber values losses.

Where should group Portucel Soporcel (gPS) spatially invest in prevention? Which stands should be assumed for fire prevention treatment management? The main interest was set in obtaining the optimal fuel treatment design to maximize timber production and carbon storage using a limit budget (or area treated) as main constraint, while reducing wildfire risk.

For handling with the complexity of such forest management problem that wildfire risk implies for forest owners and policy-makers, the present research try to answer the above-mentioned questions focusing on spatial-time-investment fuel treatment strategies by measuring the performance of fuel arrangement on eucalyptus stands through four time periods 2015-2018-2021-2024. The current framework was driven taking into account several decision support tools from the United States Wildfire Modeling System for wildfire risk management (FlamMap – Finney, 2003 and Landscape Treatment Designer, LTD - Ager et al. 2012, Ager et al submitted), herein focuses on a three-tiered strategy properly calibrated and implemented in Serra do Socorro (Centre Portugal).

In order to achieve this objective, an integrative research that follows three-steps were applied: (1) estimated growth yield modelling for the case of eucalyptus stands to assess fuel dynamics forest trends and calculate the corresponding timber volume (m^3 ha^{-1}) and carbon storage (Mg ha^{-1}), to coupled with (2) fire behavior characteristics (e.g. spread rate and flame length) obtained through running the FlamMap modeling system, aiming together (3) to explore the optimal levels of fuel treatment configurations over time using the spatial optimization software LTD.

This study aims to cover the following research questions:

-*Fire behavior characterization in the study area.* Fire behavior metrics which might come to terms of severity or growth of the fire.

- *Where should gPS spatially allocate fuel treatments over time? Where to act? Where not to act?* Priorization fire-manegement strategies over time according to the conditions imposed (i.e. prior setting goals and constraints for the study area).

The key lies in the exhaustive and quantitative exploration of the variables and process involved. Explicitly, *i*) identifying understory fuel composition and stand conditions at temporal stage (t_0,t_1,t_2,t_3 corresponding to 2015, 2018, 2021 and 2024 respectively); *ii*) characterizing temporal fire behavior (t_0,t_1,t_2,t_3) using FlamMap 5. simulator for two weather scenarios (10% and 7% fuel moisture content for average and critical conditions, respectively), crossed with wind speed of 32 km/h; *iii*) examine optimal locations of treatments for each temporal stage; *iv*) perform sensitivity analyzes (area treated - two treatment intensities of 70 ha and 100 ha vs annual budget schemes) and *v*) improve spatial-temporal fire resistance at landscape level.

First objective: characterize wildfire risk and fire behavior potentials

A general objective, based on land management goals, aims to reduce the impact of fire defined as fire behavior characteristics such as flame length, fireline intensity, rate of spread, crown fire activity or burnt probability which eventually turn into fire severity, fire growth and fire damage. A qualitative and quantitative risk assessment arise as a helpful way to prioritise and measure the effectiveness of proposed fuel treatment. Risk is defined as "*the expected value change from a fire, calculated as the product of the fire probability at a specific intensity and location, and the financial or ecological value change*". The expected value definition "*accounts for landscape scale wildfire spread, intensity, and damage in a single measure, providing a relatively robust metric for comparing the effects of fuel treatment scenarios*" (Ager et al., 2006). Addressing fuel treatments, and forest structure might help to tackle fire probability and value at risk change. This hazard assessment, in combination with predictions of fire behavior, will also be useful for estimating suppression difficulty and overall fire threat.

Second objective: optimal fuel treatment arrangement

Landscape strategies for fuel treatments can be discriminated when aiming to contain fires (e.g. arranging fuel treatments as fuel breaks designed to facilitate active fire suppression) or modify fire behavior (Finney, 2004) when acting directly on fuel. The latter approach is addressed in this study when aiming at modifying fire behavior potentials and fire progress across landscapes through strategic placement of treatments (Finney, 2004), according to certain constraint or others operational limitations. Objectives and needs might come from private forest managers, associations of private owners, different sized companies or public lands to explore fuel treatment optimization at landscape or local scale.

The central objective in this work is to strategically allocate fuel treatments to reduce wildfire risk and fire hazard at landscape level and indireclty create oportunities for the suppression brigades when taking into account timber supply for the pulp industry, and carbon storage. That is, minimize the losses from wildfire when distributing and scheduling fuel treatments into a spatial-temporal analysis. While the primary fuel treatment objective is to change stand conditions, the ultimate goal of the fuel treatments allocation is to increase landscape resistance to the severe effects of wildfire in different scales.

Such research is considered of key importance (i) to improve understanding of the relative role of biometric variables (e.g. through forest fuel load, stand structure and composition) in fire behavior characteristics, framed by the challenge of incorporating such knowledge into fire-management planning; and (ii) to help policy makers define fire- management approaches and prioritize their interventions.

1.4 Structure of the thesis

In order to stress the importance of the subject **Chapter 1** sets out the research problems based on the background information in wildfire risk and strategic fuel treatments configurations in eucalyptus forests in the context of the Mediterranean region and the Portuguese forestry sector. The research objectives and questions are then stated in the following section, organised in the two main goals aimed to achieve with the present work.

Chapter 2 describes the materials and methodology. Definition of concepts and a literature review on key issues of the study are provided. After a brief description of the area subject of study, data collection section is presented defined by several sub indexes with all the tools and processes carried out. Furthermore, a data input diagram is given for further understanding the “picture” of the methodology.

Details of the results are presented in **Chapter 3** addressing the two objectives. The discussions are presented in this chapter together with the main findings, as most frequently, discussions need support for a better understanding from figures and tables.

Chapter 4 apart from stressing the importance of the study to the forest sector contains final remarks, summarizing the main finding the study conducted and outlining research challenges in this domain. Finally, limitations of this study and future research challenges are presented.

The conclusions that have been drawn from the results of fire behavior modelling and optimization processes are found in **Chapter 5**. Besides, the importance and novelty of the contribution of this research is presented as a support system methodology for eucalyptus plantations in farms of gPS.

2. Material and methods

2.1 Research approach

The gathering of information started with an extensive literature review by name of relevant authors in the theme and key words. Afterwards, from this group of papers found, some of them were selected regarding its relevance with the topic of interest. Finally the information in each paper was carefully revised with the aim of establishing a final collection of the most important bibliography of fire simulator systems and optimization softwares in order to identify approaches and developments that may prove very promising in relation to support challenges in forest management. Furthermore, the study employs case studies analysis, qualitative expert opinion and field and local knowledge.

A more comprehensive description regarding the quantitative data provided by growth and yield models, fire behavior system, and the optimization software were subjected to further analysis processes in the correspondent sections.

2.2 Serra do Socorro: Site description and fire history

The study area is located in Serra do Socorro in Central region of Portugal and comprise a total of 1449,40 hectares (municipality of Torres Vedras). The hermitage of the “Nossa Senhora do Socorro” located at the central zone of the area hold the geographic coordinates 39º01'08'' North and 09º13'30'' West (Figure 1).

Figure 1. Localisation of the study area (own elaboration. Source: http://www.igeo.pt/).

The main forest vegetation are *Eucalypus globulus* plantations (174,84 ha) which are embebed in a matrix of shrublands and uncultivated land areas (Figure 1.). These *Eucalypus globulus* plantations belongs to one of the properties of pulp mill's from the Grupo Portucel Soporcel (gPS)[6], an European company dedicated to produce and market high quality paper for office and offset uses.

The study area presents a variability in land use being in ascending order of cover area: non burnable areas (85.92 hectares, 5.9%), *Eucalypus globulus* plantations (174.84 hectares, 12%), extensive agricultural lands and pasturelands (822.21 hectares, 56.7 %), shrublands (349.26 hectares, 24%), pine stands (3.47 hectares, 0.24%) and others (13.67 hectares, 0.94%) (Table 1).

[6] http://en.portucelsoporcel.com/

Table 1. Description of Land cover type in Serra do Socorro (t_0, 2015 time period).

OCCUPATION	HECTARES
***Eucalyptus globulus* plantations**	174,84
Shrublands	349,26
Agriculture	822,21
Unburnable	85,92
Pine stands	3,47
Others	13,67

Topography is dominated by uplands and lowlands ranging from 51 meters to a maximum of 389 meters elevation, with an average value of 168 meters (DTM, Digital Terrain Model). Serra do Socorro is one of the steepest areas in the municipality of Torres Vedras (The Municipal Plan to Protect Forests from Fires in Torres Vedras 2008-2012[7]). According the climate characterization of the municipality of Torres Vedras (1964 to 1990 historic period) given in the Municipal Plan to Protect Forests from Fires, the area is characterized by a strong Atlantic wind influence which normally results in a fresh summer and mild winter. Throughout the whole year the humidity remains high which is especially noticeable in summer when compared with other regions in Portugal. Consequently higher productivities occurs in these regions with more precipitations and low number of days with frost (Tomé et al, 2001). In terms of temperature, the maximum is reached during July to September with an average value of 20º C. The relative humidity is between 75 and 80 % (when measuring at 9.00 am or at 18.00 pm) for the critical period. In terms of precipitation, in the fire season values are measured with a precipitation of 23.5 mm in June, 5 mm in July, 7.6 in August and 29.4 in September (The Municipal Plan to Protect Forests from Fires in Torres Vedras 2008-2012[7]).

The municipality of Torres Vedras is framed under a low intensity fire regime with a long fire season. Torres Vedras fire regime is also characterized by a large number of fires but with small size and mainly distributed in winter season, when essentially shrublands and agricultural lands are burned (Marques et al, 2014). Social and demographical factors also play a determining role in Serra do Socorro fire regime,

[7] http://www.cm-tvedras.pt/ficheiros/urbanismo-pp/pmdfci/PMDFCI_2008_2012_TorresVedras.pdf

given the strong links between population and agricultural activities and the common use of fire irrespective of season (Raínha & Fernandes, 2002). Statistical data from ignitions and burnt area in Dois Portos and Turcifal (Torres Vedras) during 2001-2010 period showed an increased number of ignitions in summer late and autumn months of August, September and October, specially the two latter, months typically out of the extreme fire season (ICNF, Institute for Nature Conservation and Forests of Portugal[8]).

The majority of the wildfires started and burned eucalyptus forested areas (Figure 2). Small burned areas on the northern area of the study might respond to the placement of other eucalyptus plantations situated there.

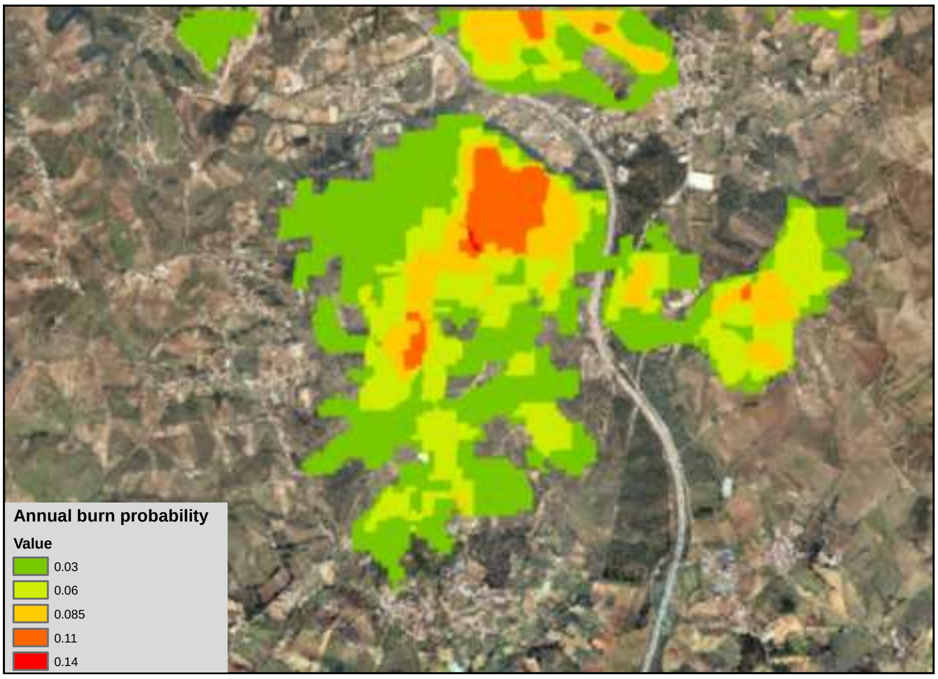

Figure 2. Recurrence of fires in the study area for the period 1975-2013.

2.3 Data collection

The first step and the most important was learning about the dataset used as inputs in the following processes in order to better understand the area and to be able to build real and new variables required for the latter procedures.

2.3.1. Analyzing current land use state

Land uses changes in the current state were supported by field inspection of the study area (Figure 3), digital photography with GPS information data and qualitative expert

[8] http://www.icnf.pt/portal/florestas/dfci

opinion from fire and forest managers in order to check whether there had been any harvest or land cover change. Two main cases in land use changes were observed, the first one derived from the abandonment of the eucalyptus plantations exploitation converting the areas in shrublands, and the second one, new eucalyptus plantations from former shrublands.

Figure 3. Photography set of different stages of eucalyptus plantations in Serra do Socorro. a) Overview of the area of Serra do Socorro, b) and c) Eucalyptus young plantations, and d) forest trails within and old plantation.

Surface fuel

The spatial fuel types were previously collected "in loco" under the Fire-engine Project - Flexible Design of Forest Fire Management Systems[9], running during 2011 –2014 August, as part of the Massachusetts Institute of Technology (MIT) programme in Portugal. Further, fuel models covers were defined from a set of 18 customized fuel models developed for Portugal conditions by Fernandes et al. 2009, and Cruz 2005 for the case of eucalypt slash. For more details, see Annex 3 – Identification key for fuel

[9] http://en.portucelsoporcel.com/Sustainability/Sustainable-Forest/Forest-Protection

models in Portugal. Urban areas and structures, water streams, irrigated agricultural lands, roads and forest roads were classified as non-burnable (fuel model 99); short grass (fuel model 232) was assumed for greenhouses, golf facilities, isolated homes, vineyards, agro-forestry systems, fruit orchards, olive groves and natural pastures; and in high grass fuel type (fuel model 231) were included non-irrigated agricultural lands and others natural pastures. Besides that, two more classifications were introduced to define a region with riparian vegetation (fuel model 221) and small patches with pine forest of *Pinus pinaster* Ait. and *Pinus pinea* L (227 and 213) (Figure 4.). For more details, see Annex 3 – Identification key for fuel models in Portugal.

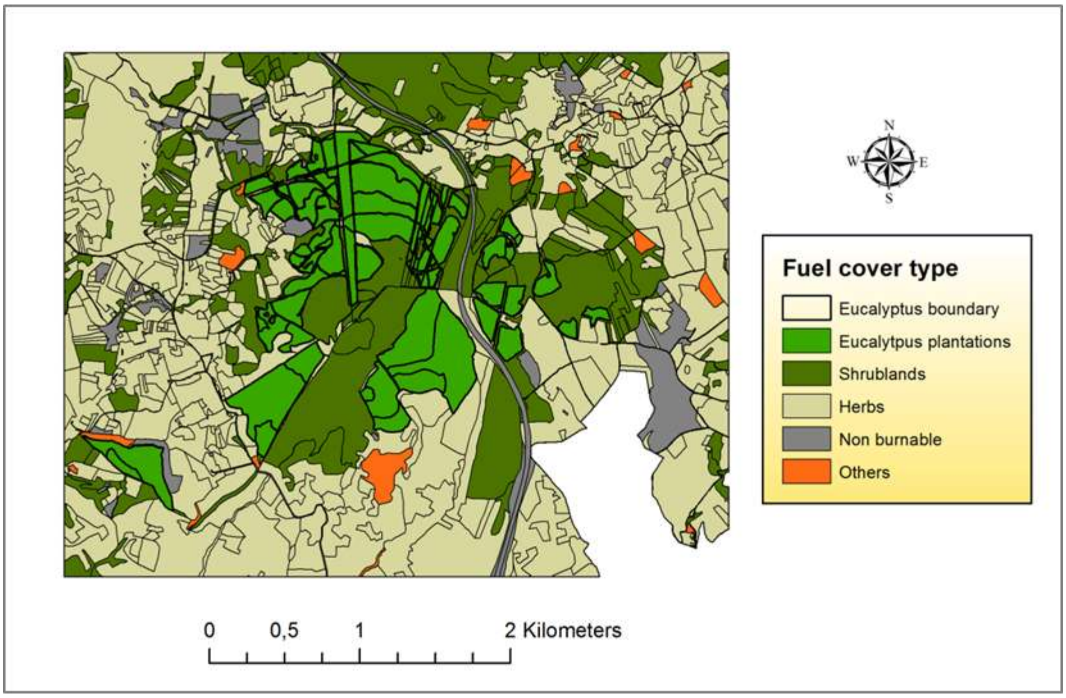

Figure 4. Fuel type distribution in Serra do Socorro (2015 time period).

Status of the eucalyptus stands

The percentage of canopy cover data (84%,60%,44%,22%) assigned to each stand in the current landscape came from previous analysis of the National Forest Inventory plots (Fernandes, 2009) associated with field visit (Figure 5). Field inventory records were not covering all stands and, facing complete absence of field records, assumptions on biometric variables were performed in a small number of stands based on both well-defined, qualitative expert gPS opinion and in quantitative field data with special consideration of age, rotation and proximity of other defined stands. ArcGis 10 software was utilized for extrapolating to the stands polygons the biometric variables gathered in plots from an field inventory in the 2013 year. The forestry inventory data were analyzed and filtered out for biometric variables, such as diameter, height and basal area for a stand level.

Figure 5. Photography set of different stages of eucalyptus plantations in Serra do Socorro. a) Overview of the area of Serra do Socorro, b) and c) Eucalyptus young plantations, and d) forest trails within and old plantation.

Young eucalyptus stands

Data were updated with the information of recent harvested stands in November 2014 and new plantations in 2013. The land use forest change, that is, fuel model type (224, Annex 2) and canopy cover percentage (22% and 44%), was supported using georreferenced digital photography, expert local knowledge and field visit (Figure 5).
For the case of the new biometric status of the recently harvested plantations and second rotation coppice, Web Globulus Model 3 (Tomé et al, 2006) assists in approximating height, diameter and basal area[10] at stand level. The input data are as follows:
-Climatic data, such as precipitation and altitude.

[10] http://home.isa.utl.pt/~joaopalma/modelos/globulus30/

-Harvest age. The optimal rotation age was set at 12 years old.

-Initial planting density 1250 seeding per hectare (Tomé et al., 2001).

-Stump mortality is set at rate 0.1 (10%) as this area is regarded as good quality for the development of vegetation (personal communication Dr. Paula Soares, 2015).

-Number of shoot per stump to maintain is set in 1.6 (personal communication Dr. Paula Soares, 2015).

-Site Index from inventory data (based on average value for the Central region in Web Globulus 2.1 [11]).

2.3.2. Input data processing

Data given by the pulp and paper company grupo Portucel Soporcel (gPS) was as following: forestry inventory data (biometric data, fuel custom type - year 2013); variables of elevation, slope, and aspect were extracted from the digital elevation model (DEM), and identification data for stand location polygons in vector format. These data were analyzed and classified with special consideration on the fuel type descriptions (model), percentage of canopy cover and biometric data.

The diagram in Figure 6 outlines the input data and processing steps carried out during the data collection for the phase t_0, corresponding to year 2015. Parallel to situation t_0, temporal analysis comprises three more periods (t_1, t_2, t_3). The following years 2018 (t=1), 2021 (t=2) and 2024 (t=3) are analyzed at landscape level in terms of changes in fire potentials, timber volume and carbon storage based on the growth (growth and yield modeling) and development of the eucalyptus plantations (dynamic fuel population).

[11] http://home.isa.utl.pt/~joaopalma/modelos/globulus/

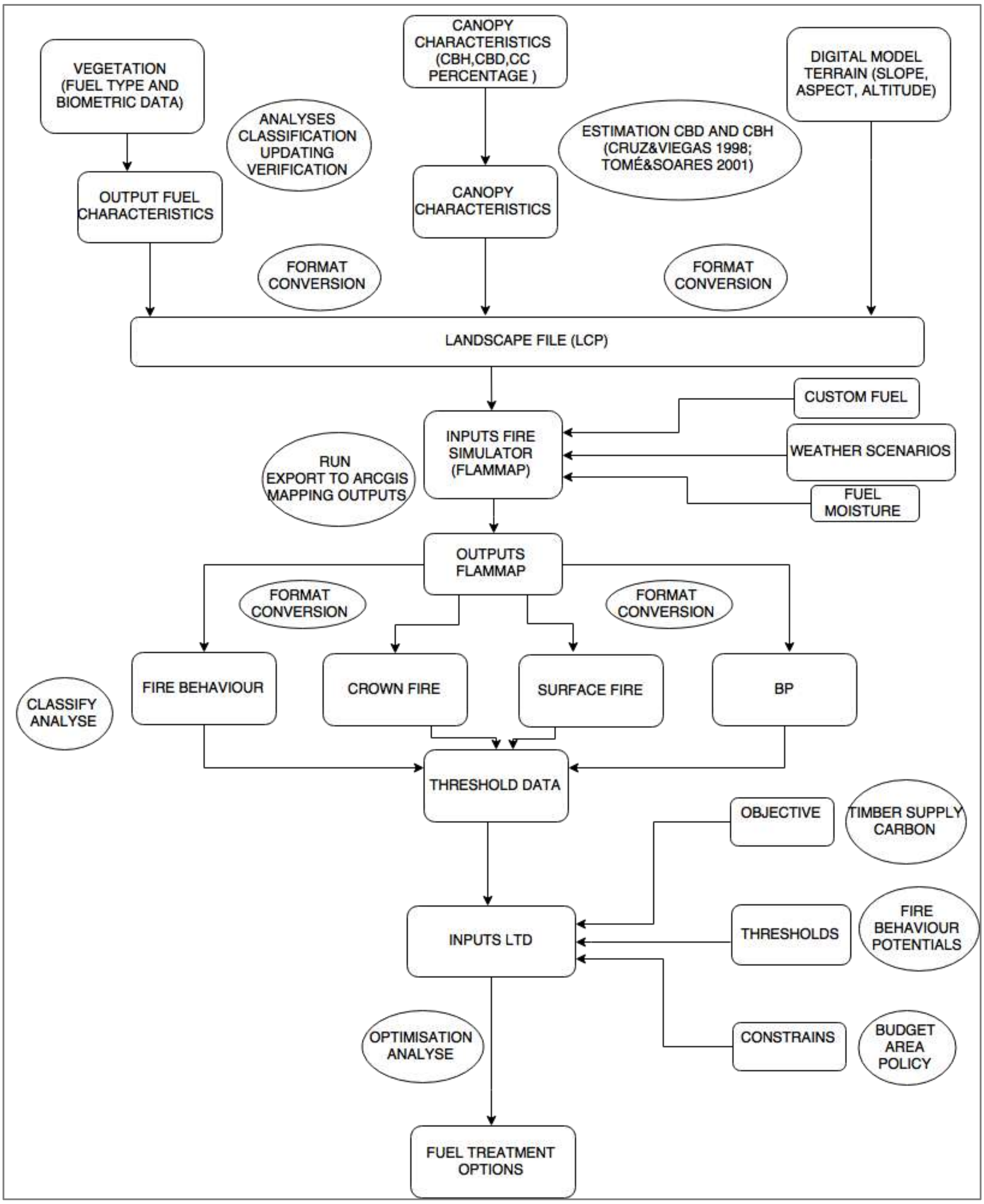

Figure 6. Diagram with input data and processing steps.

The process above described belongs to the first stage, the baseline current conditions of the study area (t_0 or year 2015). Once the area is characterized and classified (t_0), different scenarios (t_1, t_2, t_3) are designed and explored over time. Data management and processing steps for the temporal scenarios is as follows:

1) Simulating stand level growth: biometric variables (quadratic stand diameter, dominant stand height, stand basal area), timber volume and carbon storage (Growth model Globulus 3.0, Tomé et al., 2006) over time. For the case of recently harvested

stands, in the current status as no available inventory data, was required to simulate variables of initialisation.

2) Canopy characteristics following equations in Cruz and Viegas (1998) and Soares and Tomé (2001) for canopy bulk density (CBD) and canopy base height (CBH) based on the previous calculated biometric data. Canopy cover (CC) percentage change based on local experience and inputs from fire managers was also qualitatively estimated over time.

3) Dynamic fuel population (fuel model change over time) following fuel model descriptions and expert knowledge from fire and forest managers.

4) Inputs data in FlamMap based on canopy biometric data calculated with the growth and yield modeling over time, fuel model and canopy data over time, DMT data and weather inputs based on information from weather stations and qualitative expert knowledge and local experience, generate information about the characterization of the area in terms of fire behavior potential (i.e. burnt probability, flame length, rate of spread, crown fire activity and fireline intensity).

5) For achieving optimal fuel treatment locations, Landscape Treatment Designer (LTD) program is chosen. Outputs from FlamMap (i.e. fire behavior potentials) help to prioritize location of fuel treatments in the latter form of objectives, constraints and treatment thresholds.

2.3.2.1 Temporal analyzes: eucalyptus growth model

The use of simulators for scenario analysis can be a powerful instrument to explore future management options and to illustrate the consequences of different management alternatives (Barreiro, 2011). The temporal simulations help to understand the necessity of both, maintenance of existing units and implementation of new units for the optimization of spatial treatment patterns successive in the future (Finney et al., 2006). The state of the forest system is mainly determined by the fuel biomass. This fuel load increases with a certain growth rate, while decreases when wildfires and treatments occurs (Marques et al, 2014). Understand the long-term efficacy of fuel treatments on fuel status and the changes in fire behavior generated is elemental for properly scheduling future management activities and thus, also maintenance of the desired status of the forest can be determined (Finney, 2004). The key questions about how, when and where to proceed with the treatments, prescriptions or other actions call for the support of tools that provide with future fuel characterization expectations.

In this case four scenarios over time are analyzed (t_0, t_1, t_2, t_3) in terms of changes in fuel loads, carbon storage and wood production. For that purpose, a temporal time line with the development of the growth vegetation was estimated following growth and yield model simulation in eucalyptus plantations (Tomé et al., 2006) for a three years lapse analyzes. The Globulus 3.0 growth and yield model is a forest simulator for eucalyptus growth principally driven by environmental-climatic data, stand characteristics related to the management regime and biometric data intrinsic to the stand. It was developed to predict the growth evolution of the eucalyptus forest plantations in Portugal by combining forest inventory data with growth models giving outputs such as biometric data at stand level or wood volume and carbon biomass (Tomé et al., 2006). The modeling approach adopted in this study provide valuable information to integrate risk considerations in eucalypt forest management planning, evaluating the impact of silviculture treatments (e.g., coppice cuts and fuel treatments) on wildfire risk and providing an important tool to define management options aimed to reduce wildfire occurrence and develop effective fires prevention strategies (Botequim et al 2013).

For the case of eucalyptus plantations in first and second rotation coppice, Web Globulus Model 3 (Tomé et al., 2006), implemented in the web, was used to estimate height, diameter and basal area[12] at stand level. The input data are as follows:

-Climatic data, such as precipitation and altitude.

-Harvest age. The optimal rotation age was set at 12 years old.

-Initial number of trees per hectare, age, rotation, height and basal area. This data was unique for every stand and was derived from inventory plots or assumed when missing data based on proximity or fuel model, age and rotation.

-Stump mortality is set at rate 0.1 (10%), for the change to second rotation and 0.2 (20%) for the change to third rotation (personal communication Dr. Paula Soares, 2015), as there is a percentage of stools that do not survive in the transition between cycles.

[12] http://home.isa.utl.pt/~joaopalma/modelos/globulus30/

-Number of shoot per stump to maintain is set generally between 1 and 2 (Soares & Tomé, 2001). In this case 1.6 was employed for change from first rotation to the second rotation and 1.8 from the second rotation to the third rotation (personal communication Dr. Paula Soares, 2015).

-Site Index from inventory data (including assumption when missing data based in some cases on proximity or fuel model, age and rotation, implemented in the web).

Results were useful for two purposes. On one hand, biometric variables (i.e. dominant height, quadratic mean diameter and basal area) are required and prepared for further analyzes at stand level in order to estimate canopy characteristic for simulating fire behavior characteristics over time with special consideration to the crown fire activity. On the other hand, wood volume and total biomass (converted to carbon storage value by multiplying by standard value) of each eucalyptus stand work as objectives function in the optimization process over time.

Stand growth was estimated using the simulators Web Globulus 3.0 developed by Tomé et al., (2006) and understory growth was only consider in terms of fuel type change when applicable, however, in most cases, shrublands and agricultural fields were supposed not to experiment any radical land use change during the temporal study in the area.

Forest canopy characteristics: Canopy Bulk Density (CBD), Canopy Base Height (CBH) and canopy cover (CC)

Obtaining reliable estimates of forest canopy attributes is critical for simulating both surface and crown fire behavior in fire behavior modeling systems, such as in FlamMap software. On one hand, canopy characteristics alter surface fire behavior by protecting the surface fuelbed from wind and sun, reducing wind speed and affecting dead fuel moisture content. On the other hand, canopy characteristics directly affect crown fire occurrence and behavior when determining the environmental conditions that lead to crown fire initiation and spread. Some forest canopy characteristics are analyzed for directly or indirectly influencing simulations of surface and crown fire patterns: canopy base height (CBH),canopy bulk density (CBD) and percentage of canopy cover (CC) (Scott, 2012).

The Canopy Bulk Density (CBD) characterizes the available canopy mass per canopy volume unit (kg/m3), that is, the available canopy fuel density in a stand. CBD supplies information for fire behavior models, to determine the initiation and spread of crown fires[13]. The Canopy Base Height (CBH) expresses the average height between the ground and the bottom of the forest stand canopy. CBH provides fire behavior information when determining the probability of vertical fire propagation into the canopy, that is, where a surface fire is likely to transition to a crown fire (torching). CBH unit measurements are meters.

Crown fuel characteristics (canopy cover, crown base height, and crown bulk density) were derived from published literatures as further supported by expert knowledge. CBH and CBD data in the present study are provided only for forested areas, i.e, the case of eucalyptus plantations. Canopy base height (CBH, m) and canopy bulk density (CBD, kg/m^3) were estimated from equations in Soares & Tomé (2001) modified by Tania Oliveira and Cruz & Viegas (1998) for the case of eucalyptus in Portugal. Results are supported by field data in Cruz & Viegas (1998, graphical information) and expert knowledge (personal communication Dr. Paula Soares, 2015).
For the case of CBH, crown length (CL) (modified by Tania Oliveira from Soares & Tomé, 2001) was extracted from dominant stand height (hdom):

$$CL = H\ (1/(1 + e^{(-2.3813+8.875766(1/t) - 0.57464\ (N/1000) - 0.32621\ hdom + 0.213794\ dbh)})^{1/6})\ \text{(meters)};$$

$$CBH = Hdom - CL\ \text{(meters)}$$

Where N is the number of trees (trees/ha), dbh is the diameter at breast height (cm), t is age, hdom is dominant height (m) and H is average height (m).
Results from growth and yield modeling Globulus 3.0 provided with quadratic mean diameter (dbh, meters), which was converted to mean diameter to be introduced in the CBH equation following equation of conversion in Mateus (2011). Mean diameter was modeled using the function:

$$d = dg - (1/1 + \exp^{(-0.2508\ hdom + 0.0829\ S + 0.000746\ N + 0.4058\ dg)})\ dg$$

Where d is quadratic diameter (cm^2), hdom is dominant height (m), S is Site Index and N is number of trees (trees/ha).

[13] http://www.landfire.gov/fuel.php

Considering that mean diameter data was not significantly improving compared to the estimated quadratic mean diameter and for simplicity, Mateus´ equation was not finally included in this study and it was decided to continue with the given quadratic mean diameter as a surrogate of diameter at breast height.

In the case of equation in Soares & Tomé 2001 for CBH, greater values for age, number of trees or dominant height resulted in smaller crown ratio values, reflecting more advanced stand development stages or more competition for the resources. However, at a particular age, an increase in diameter resulted in higher crown ratio values, expressing tree dominance relationships (Soares & Tomé, 2001).

For the case of the calculation of CBD, equation in Cruz & Viegas (1998), based on basal area (G) and diameter, was followed:

$$CA = e^{(1.444+(-7.613/dbh))} \ (m^2)$$

$$CBD = 0.649-0.001BA-0.486CA^{0.089} \ (kg/m^3)$$

Where C is Crown Area (m^2), BA is basal area (m^2/ha).

The higher the CBD, the smaller the diameter and basal area are, and thus milder conditions (lower wind speeds, higher fuel moistures) can lead to an active crown fire spread through the forest canopy (Scott, 2012).

These equations were defined for a tree level, however, these details of data were not available and supported by expert knowledge, the procedure was calculating CBH and CBD assuming the mean values at stand level.

Finally, canopy cover was expressed in five categories of percentage (84%, 60%, 44%, 22%) as explain in previous sections (2.3.1. Analyzing current land use state, Status of the eucalyptus stands).

Collecting, analyzing and grouping the data turned to be a very consuming task for the necessity of coordinating and validating data with different protocols and finally create new data bases. Plus, the calculations and assumptions performed included research and validation of the data (Cruz & Viegas, 1998).

Dynamic fuel population in eucalyptus stands and surface fuel

The surface fuel and canopy cover was modified and assigned over time due to planting operations, harvesting, and vegetation re-growth and thus correspondingly altered. Fuel categories changed over time followed fuel model descriptions (Identification fuel model key in Portuguese, Fernandes et al., 2009, see Annex 3), fuel load characterization (Forest fuel model for Portugal[14], see Annex 2) and expert knowledge of fire and forest managers from the mill´s pulp and paper company (Table 3). In the case of canopy cover normally augmented to the next canopy cover percentage category every period until the final cut, at 12 years old (Table 3).

Table 2. Dynamic fuel model type and canopy cover percentage in Eucalyptus stands considering fuel characterization over time.

Age 2015	Fuel % canopy	Fuel load (t/ha)	Age 2018	Fuel % canopy	Fuel load (t/ha)	Age 2021	Fuel % canopy	Fuel load (t/ha)	Age 2024	Fuel % canopy	Fuel load (t/ha)
1	224/44	1-8	**4**	223/60	9-18	**7**	211/60	4-6	**10**	211/84	4-6
2	224/60	1-8	**5**	223/60	9-18	**8**	211/60	4-6	**11**	211/84	4-6
9	211/60	4-6	**12**	211/84	4-6	**3**	224/44	1-4	**6**	223/60	9-18
	223/84	9-18		211/84	4-6		224/44	1-4		223/60	9-18
10	211/44	4-6	**1**	224/22	1-4	**5**	223/60	9-18	**8**	211/84	4-6
	211/60	4-6		224/22	1-4		223/60	9-18		211/84	4-6
	211/84	4-6		224/22	1-4		223/60	9-18		211/84	4-6
12	211/44	4-6	**3**	224/44	1-4	**6**	226/60	2-5	**9**	211/60	4-6
	211/84	4-6		224/44	1-4		223/60	9-18		211/84	4-6
13	211/44	4-6	**3**	224/60	1-4	**6**	226/60	9-18	**9**	211/84	4-6
	211/84	4-6		224/60	1-4		226/60	9-18		211/84	4-6

In surface fuel model, model type maintained the same and canopy cover was set to zero where previously 0%, that is, urban areas, agricultural lands or shrublands. Other shrublands areas with isolated trees and pine stands were set to 22% of canopy cover for the whole set of time scenarios as considered to be dispersed trees in the stand and not enough to jump to the following class of 44% over time.

2.3.2.2. Wildfire simulation

Spatial fire growth and behavior modeling facilitates land management planning at spatial scale and, thus, help supporting future forest management decisions. In this study, FlamMap is chosen as a tool to explore fire behavior characteristics and fire spread across a landscape. FlamMap assume constant wind speed, direction and fuel

[14] http://www.icnf.pt/portal/florestas/dfci/Resource/doc/cartografia-dfci/ModeloCombustivelPT.pdf

moisture (Pausas 2004). FlamMap is a spatial fire behavior that calls for an landscape file (LCP), fuel moisture and weather data as input data for growth and fire behavior simulation. FlamMap outputs lend itself well to landscape comparisons (for example, pre- and post- fuel treatment effectiveness). Besides that, FlamMap works fine when mapping and helping to recognize risky areas, hazardous fuel types, ignition and burning patterns. That is important information for identifying priority areas to perform fuel treatments thus aiding in management prioritizations and fire risk assessments (Stratton 2004).

New version of FlamMap 5.0 also allows end-users to create burn probabilities, fire perimeters, flame length probabilities and fire size list from multiple random ignition or ignitions based on historic fire ignitions information for a further quantitative wildland fire risk evaluation. One limitation is that FlamMap does not allow for temporal analyzes so that itself can not reflect how the effectiveness of treatments changes over time with vegetative growth. In the present study for addressing the temporal limitation, four unique landscape files input data with regards of the fuel type, canopy characteristis and biometric characteristis, previously designed and calculated for every time period, were created. For characterizing the fuel optimization in Landscape Treatment Designer (LTD) along the time line of 9 years, different scenarios are represented as explained before: t_0 (current situation), t_1 (situation in 3 years, in 2018), t_2 (situation in 6 years,2021) and t_3 (situation in 9 years, 2024). For each scenario (t_0, t_1, t_2, t_4) the procedure defined in the following sections is performed.

FlamMap fire behavior simulator

Landscape file

The landscape file (LCP) is the basic input in the fire and behavior simulation process and is composed by three types of information: i) spatial raster data for elevation (meters), aspect (degrees) and slope (degrees) from a digital terrain model data (DTM), ii) fuel model, and canopy cover from data base of the study area and iii) optional canopy and biometric data such as Crown Base Height (CBH), Crown Base Density (CBD) and dominant height (Hdom) calculated by canopy characteristics equations developed for eucalyptus (Cruz & Viegas, 1998; Soares & Tomé, 2001). The optional data is no required for a surface simulation, however, it is important when aiming to determine and explore crown fire features that might be important in the study. Canopy base height (CBH), dominant height (Hdom), canopy bulk density

(CBD), canopy cover (CC) and fuel model type variables in ASCII format (Table 4.) together with environmental data allow for characterizing the area in terms of fire behavior potentials (Flame Length (FL,m), Rate of Spread (ROS, m/min), Fire line Intensity (FLI, kW/m), Crown Fire Activity (CFA) and Burn Probability (BP, %)) at stand level. The above mentioned eight layers were arranged at a 30 meter pixel scale (Table 4.)

Table 3. Description of variables used to create landscape file (LPC) for baseline current conditions (t_0, 2015 year) . In italics optional information.

Variable	Data range	Units	Scale/resolution (meters)
Elevation	51-389	Meters	30
Slope	0-67	Degrees	30
Aspect	1-359	Degrees	30
Fuel model type	0-235	Custom	30
Canopy cover	0-84	Percentage	30
Dominant Height	20-251	Meters*10	30
Canopy Base Height	0-180	Meters*10	30
Canopy Bulk Density	8-25	Meters*100	30

LCP files should be critiqued and limitations understood to ensure proper use and to produce realistic results (Stratton, 2006).

Fuel custom type, fuel moisture and wind data

For simulation purposes, the weather and fuel scenario is required, especially in terms of fuel custom type, fuel moisture and wind data.

Custom fire behavior fuel models

Vegetation characterization is usually accomplished through fuel models, consisting of a set measurable properties used in fire behavior models. Although the availability of the standard fire behavior fuel models covers a wide variety of surface fuelbeds, certain situations may still require the use of custom fuel models. Besides that, standard fuel model should not be expected to match fire behavior observations perfectly because it has been designed for general application[15].

In this study case, each model type was defined by a custom fuel model from the set of 18 customized fuel models developed for Portugal conditions, with the exception of eucalypt slash for which fuel model of Cruz (2005) as described in previous sections

[15]http://www.wfmrda.nwcg.gov/docs/NIFTT/Reference%20Materials/Intro_to_Fire_Behavior_Modeling_Guide_2012.06.25.pdf

(2.3.1. Analyzing current land use state). A Custom Fuel Model File (.fmd) was created in the wildfire simulator for characterizing the fuel model types.

Fuel moisture

A fixed set of weather conditions and fuel moistures contents were derived for 90th and 97th percentile for the cases of average weather scenario and severe weather scenario with values of 7 % and 9.3%, respectively (9% as fuel moisture content applied) for the 1 hour dead fuel at every fuel type in the landscape. Values at 10 and 100 hour dead fuel size classes were computed adding 1% and 2% to the 1 hour dead fuel size, respectively.

Particularly noticeable were the high values in fuel moisture for the case of Serra do Socorro in comparison with other regions in Portugal. This is given by the Atlantic influence which allows for fresh summer with frequent foggy days[16]. For dead fine fuel moisture content the weather information was compiled from the nearest weather station (Dois Portos weather station, 1200 observations). Data considered high fire risk season ranging from May to October, as large fires can occur a bit outside summer, and twelve years as collection observation years (2001-2012) (Dr. Paulo Fernandes, Universidade de Trás-os-Montes e Alto Douro).Then, for the live fuel moisture content the following data are employed: 0,85,95 % respectively for grass, shrubs and canopy fuelbeds. The method employed was according to the FWI methodology when using "Fine Fuel Moisture Code (FFMC)". Two Fuel Moisture File (.fms), one per each weather scenario, were created in order to introduce the weather moisture information in the wildfire simulator according to the weather conditions in the study area.

It was considered that the irrelevant differences in terms of area affected by one specific data of fire potentials were influenced by the high fuel moisture in the area in both percentiles, 90th and 97th. Finally, only one weather scenario was considered under the 97th percentile since results through the fire simulation process showed no significant differences between the two original scenarios studied (severe scenario, 97th percentile; and average scenario, 90th percentile).

Wind data

The wind scenario was developed with inputs from expert local fire managers to build a likely extreme wind scenario that called for 32 km/h under a severe situation, reflecting

[16] http://www.cm-tvedras.pt/ficheiros/urbanismo-pp/pmdfci/PMDFCI_2008_2012_TorresVedras.pdf

those months where typically most of the ignitions are produced. Predominant winds blow from north[17], and the degrees clockwise from north is set at 320 degrees. Wind information is held constant along the area. The most important concern in the simulation procedure was presenting as closer as possible to the reality the wind and fuel moisture inputs of extreme fire conditions since under these circumstances the fires are responsible for the most damage (Ager et al., 2006).

Burn probability data

Burn probability (BP) is the spatially explicit likelihood that a pixel on a raster landscape will burn. BP models consider ignition locations, topography, weather conditions, and the rate and direction of fire spread on a landscape (Miller et al. 2010). BPs help to identify areas of the landscape where fire is more likely to occur given random ignitions or predefined ignitions scheme within that landscape. Moreover, the information provided by the burn probability module can be used to support decisions regarding strategic fire and fuels management planning activities[18], including conducting wildland fire risk assessments, optimizing fuel treatments, and prevention planning (Miller et al, 2010).

The inputs for the BP calculations (0-1 fraction) are: 200 random ignitions (Ager et al. 2006) and 300 minutes (5 hours) (Kalabokidis, et al 2013). Spotting, critical contributor process to the growth of the fire, was considered at a low frequency (1 %) (Ellis 2000; Stratton 2006). The importance in describing and quantifying the probability of spotting is that, although "*spotting is a chance event*", it complicates, in most of the cases, the fire fighter brigades extinction work (Albini, 1979). Embers lofted during passive crowning might initiate new fires downwind, which turns fire control a much more complicated task and increases fire growth (Scott & Reinhardt, 2001). Meteorological conditions (i.e. fuel moisture content) influence ignition likelihood by firebrands (Ellis, 2015). In Albini 1979, fuel moisture content between 7-12 % is related to high to medium ignition hazard and spotting favoured by gusts. Besides, topography, i.e slope, directly influences passive crown fire by facilitating the radiant energy transfer heat to the crowns (Rothermel, 1983) (see Annex 1.).

[17] http://www.cm-tvedras.pt/ficheiros/urbanismo-pp/pmdfci/PMDFCI_2008_2012_TorresVedras.pdf
[18] http://iftdss.sonomatech.com/iftdss/documentation/Content/ExternalResources/IFT-RANDIG.pdf

Fire behavior : processing data

FlamMap assumes that every pixel on the raster landscape burns and makes fire behavior calculations (e.g., fire line intensity, flame length) for each location (cell), independent of one another. FlamMap is a fire behavior mapping and analysis program that computes potential fire behavior characteristics. Here, fire behavior refers to the gross characteristics of fire, e.g., fire length (m), fireline intensity (kW/m), rate of spread (m/min), burn probability (fraction) or whether the fire is a surface or crown fire. These magnitudes are key to managing wildland fire fighting operations, to estimating ecological effects of fires, and to allocating fuel treatments in order to alter fire behavior potentials[19]. Prediction in the fire behavior is product of analyzing the fire environment, that is, a combination of fuels, weather, and topography data input.

Outputs in FlamMap are generated in ASCII files having a major detailed mapping outputs however this outputs were not applicable to the management units in this case study. For characterization purposes the ASCII raw data from FlamMap is used in terms of defining the area under certain characteristics. However, for mapping usefulness and simplicity, outputs data are displayed at stand level as generally fuel treatments are performed at stand scale (following sections).

For the next stage of the optimization processes the fire behavior characteristics from FlamMap were prepared to obtain the LTD shapefile input required. For this operation and in order to minimize the lost of information “Zonal Statistic as Table” tool and “Join field” in ArcGIS 10 were employed. “Zonal Statistic as Table” tool works summarizing the values of a raster within the limits of another dataset and reports the results to a table. In this case, the mean of the raster values within the polygon was chosen as representative value of the stand. Then, “Join field” connects the contents of a table (the mean value of fire characteristics per stand) to another dataset based on a common attribute field (shapefile with information of the limits of the polygons).

2.3.2.3 Landscape Treatment Designer (LTD)

Landscape spatial simulation and time scheduling planning combine in order to optimally examine likely effects of spatial fuel treatment programs on wildland fire behaviors and effects at the landscape scale (Finney, 2004) over time. Fuel treatments have been widely used as a tool to reduce fire likelihood, reduce hazardous fuel loads and catastrophic effects in many forests around the globe. However, prioritizing where, when and how efficiently implement fuel treatments across a forest landscape arise as

[19] http://www.firescience.gov/projects/01-1-3-21/project/01-1-3-21_01-1-3-21_finney_pnw_gtr610.pdf

the most challenging task for forest and fire managers. Landscape Treatment Designer (LTD) (Ager et al 2012; Ager et al submitted) works optimizing locations of fuel treatments, while might consider fire behavior characteristics, highly valuable resources, operational feasibility and economic, social and ecological constraints over space.

LTD can address multiple objective and treatment constraints at landscape level. Forest and fire managers should consider implementing the array of fuel treatments that best achieve their objectives within economic constraints and acceptable levels of risk (Stephens et al., 2009). The model addresses only spatial distribution of fuel treatments in a certain situation in time. However, in practice, treatment effects are ephemeral; vegetation recovers and starts growing after treatments. Therefore, a multi-period schedule that gives continuity and maintenance to prescriptions performed in the previous period is elemental when aiming to reach a certain fuel arrangement as a fire preventive measure. Spatially explicit multiperiod fuel treatment scheduling is a complex problem and most of the modeling efforts to date have either employed heuristic approaches or considered very small landscapes (Minas et al., 2014).

LTD is presented as a decision support model to prioritize project areas regarding a wide range of options as objectives (Ager et al., 2013). In this work, the aim is set at comparing economic outputs (potential timber volume) with ecological (carbon storage) and fire protection. For achieving this objective at time-scale, LTD is firstly tested in t_0, and then in the corresponding t_1, t_2 and t_3 scenarios.

LTD uses a polygon layer attributed with landscape conditions and a wide variety of variables for addressing the optimization problem in each period t_0, t_1, t_2 and $t_{3.}$ Three main data have been included and utilized in the LTD decision support model:

-Merchantable timber volume (kg/m^3) and total biomass (carbon storage, Mg/ha) both objectives with the same direction, i.e. maximization.

Timber volume and total biomass, as mentioned above in section 2.3.2.1 “Temporal analyzes: eucalyptus growth model“, were obtained from the Growth and Yield simulation model for Eucalyptus in Portugal (Tomé et al., 2006). Further, total biomass to carbon stocks conversion is obtained by multiplying the volume of total biomass by a factor of 0.5 (Kyoto protocol). The carbon fraction of biomass has a standard value of

0.5, although others methods may allow for variation with different species, different components of a tree or a stand and age of the stand[20].

-Potential fire outputs thresholds.

Fuel treatments were prioritized based on fire potentials conditions, i.e. flame length (m) and rate of spread (m/min). Then, treatments projects are triggered when a stand exceeded a spread rate of 10 meters per minute and a flame length higher than 1.5 meters. Flame height is an important measure, related to fireline intensity, and hence severity, both in terms of suppression difficulty and impact on flora and fauna (Burrows, 1999).

-Area-budget constraint policies.

The fuel optimization process for reducing fuels over extensive areas must consider limited budget, policies constraints and regulations, management objectives, treatment effects and public opinion. This will not only restrict treatment location, but also type, and total area treated, and thus can significantly degrade the performance of these strategies (Ager et al , 2007). Due to economic constraints just a certain percentage of the area receives fuel treatments (intensity fuel treatment level). The user specifies a maximum allowable treatment area which is considered as area constraint. Maximum area treated reflects the seasonal and annual budget constraints mentioned above displayed by the gPS for prevention activities in Serra do Socorro. Considering seasonal budget and maximum area under eucalyptus and other cover types, area limitation was considered firstly at 70 hectares and then 100 hectares with a buffer of 10 hectares extra (“slack variable”).

The LTD has two options; it can strategically place project areas in an aggregated approach (coordination of treatment to build large patches) or dispersed treatment plans. The program can build a single treatment plan or be run iteratively creating a treatment priority map with a maximum of number of projects which in this case study was set at 4. In each iteration, the same scenario is used to find the optimal project area, generating the first, second, third and the fourth best options.

[20] http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp3/Chp3_2_Forest_Land.pdf

3. Results & Discussion

In this chapter the results of the data analysis are presented regarding the objectives. In section 3.1, a characterization of the fire metrics regarding fire behavior at landscape level in Serra do Socorro (i.e flame length, rate of spread, fire line intensity, crown fire activity and burn probability). In section 3.2 figures are representing the strategic for optimizing fuel treatment arrangement over space and time for Serra do Socorro case study. The results are analyzed and organized in order to outline the findings of this research to support planning decisions forestry activities in Portugal.

3.1 Assessing fire behavior over time

Eucalypts forests managed as short-rotation coppices require fuel biomass accumulation treatments in order to reduce fire hazard by limiting fire spread, fire intensity and fire crowning, decreasing the ecological allowing opportunities for the wildfire suppression. Fire behavior models (e.g FlamMap fire simulator) are basics tools in the fire prevention management. For the case of Serra do Socorro tables and figures have been developed from calculated field data under a severe weather scenario (7% of humidity) in order to predict fire characteristics in eucalypt forest over time.

The fire metrics were criticized in order to confirm that fire behavior calculations are reasonable and that they appropriately represent expected fire behavior on the planning units under the conditions set. Besides that, the evaluation of the outputs of FlamMap has been fundamental for the adequate functioning of the Landscape Treatment Designer. Worthy to mention that final fire potentials characteristics to enter in the optimization software are corresponding to average value at stand level (polygon defined for land use land cover). This is due to the format conversion from FlamMap outputs (ASCII format) to LTD inputs (Shapefile format) and the aim of maintaining the same polygon structures defined for land use land cover information database. Although some differences in upper limit values occurred after the transformation the general pattern maintains, as these maximum values are within a very restricted area and turned to be not very representative of the area.

3.1.1 FL and FLI patterns over time (2015-2024)

Flame length (FL) is the distance from the flame base to the tip of continuous flaming (Scott, 2012). FL and fire line intensity (FLI) are two variables closely tied and positively correlated. Two mathematical relationships are commonly used to estimate FL from FLI; Byram's equation is used to predict surface fire flame length whereas Thomas' (1963) equation is commonly used to estimate FL for passive and active crown fire (Scott, 2012). FLI is defined as the rate of heat release per unit length of fire front (Forestry Canada Fire Danger Group 1992 in Scott & Reinhardt 2001) and it is measured in kilowatts per meter (kW/m). FLI and FL are related to the suppression difficulty of a wildfire and effectiveness in the extinction (Cheney et al., 2012; Palheiro, Fernandes & Cruz, 2006).

It is often presented as a very practical measure of the difficulty of suppression and it is positively linked with the spotting mechanism (Ellis, 2000). Flame length is offered as a interesting fire behavior characteristic because it is more handy to personnel on the ground, whereas fire line intensity is not (Scott, 2012).

Maximum flame length over time present at the beginning an increase from t_0 to t_1 of approximately 6 meters (Table 5 and Table 6), and then in t_3 (Table 8) decreases up to approximately previous values in t_0 (Table 5). However the severity in first phase t_0 is higher as more area occupies medium fire length values (e.g. 13 meters; 14 hectares vs. 1.5 hectares) while higher fire lengths are found in t_3 but are located into a few spots (Table 8, Figure 7).

Most of the zero meters flame length belongs to non forested areas. Areas with fuel model 211 are eucalyptus forest (fuel load defined from 4 to 6 tons per hectare) and present lower FL than fuel model 224, eucalyptus young plantations where fuel load is reduced up to 1-4 tons per hectare. This might be one of the reasons why fire metrics are extreme in situation t_2 where most plantations are between 3 and 5 years old. Cheney et al. 2012 explored the relationships between flame height, fuel attributes and other fire metrics (correlated reasonably well with surface head fire rate of spread).

In following tables (Tables 5 to 8), FL results from FlamMap simulator over time are expressed in terms of area and percentage cover in the landscape.

Analyzing the change in area cover for the different FL some patterns are recorded for the sixth class, more than 10 meters, and it ranks as follows $t_2 > t_0 > t_1 > t_3$ (Table 7, Table 5, Table 6, Table 8). This pattern exemplifies the general pattern for the distribution of FL, especially for t_1 and t_3 which follows opposite directions. When FL is classified with high values (>3 meters) t_1 present the higher area under these values, presumably given the fuel models fire hazard, while t_4 present the smaller area. When on the contrary, FL is classified with low values (<3 meters), t_4 present the higher area.

Table 4. Flame Length classification and corresponding area for t_0 (2015).

Flame Length(m)	Area (hectares) proportion of area (%)
0	86.8 (6)
0-0.5	986.85 (68)
0.5-1.5	78.21 (5.4)
1.5-3	34.29 (2)
3-10	231.57 (15)
>10	31.95 (2.2)

Table 5. Flame Length classification and corresponding area for t_1 (2018).

Flame Length (m)	Area (hectares) proportion of area (%)
0	86.8 (6)
0-0.5	986.22 (68)
0.5-1.5	58.05 (4)
1.5-3	14.13 (0.9)
3-10	223.47 (15)
>10	81 (5.6)

Table 6. Flame Length classification and corresponding area for t_2 (2021).

Flame Length (m)	Area (hectares) proportion of area (%)
0	86.8 (6)
0-0.5	986.31 (68)
0.5-1.5	131.85 (9)
1.5-3	29.43 (2)
3-10	186.75 (12.8)
>10	28.53 (1.9)

Table 7. Flame Length classification and corresponding area for t_3 (2024).

Flame Length (m)	Area (hectares) proportion of area (%)
0	86.8 (6)
0-0.5	986.22 (68)
0.5-1.5	120.96 (8.3)
1.5-3	53.01 (3.6)
3-10	187.74 (12.95)
>10	14.94 (1)

Results from FlamMap simulator over time are shown in Figure 7. Note that values in Tables are referring to the raw data from FlamMap (ascii) before obtaining estimators through format conversion (shapefile) in order to optimize fuel treatments locations in LTD. The following figures presented in this chapter to visualize the changes over time are the inputs in LTD optimization process.

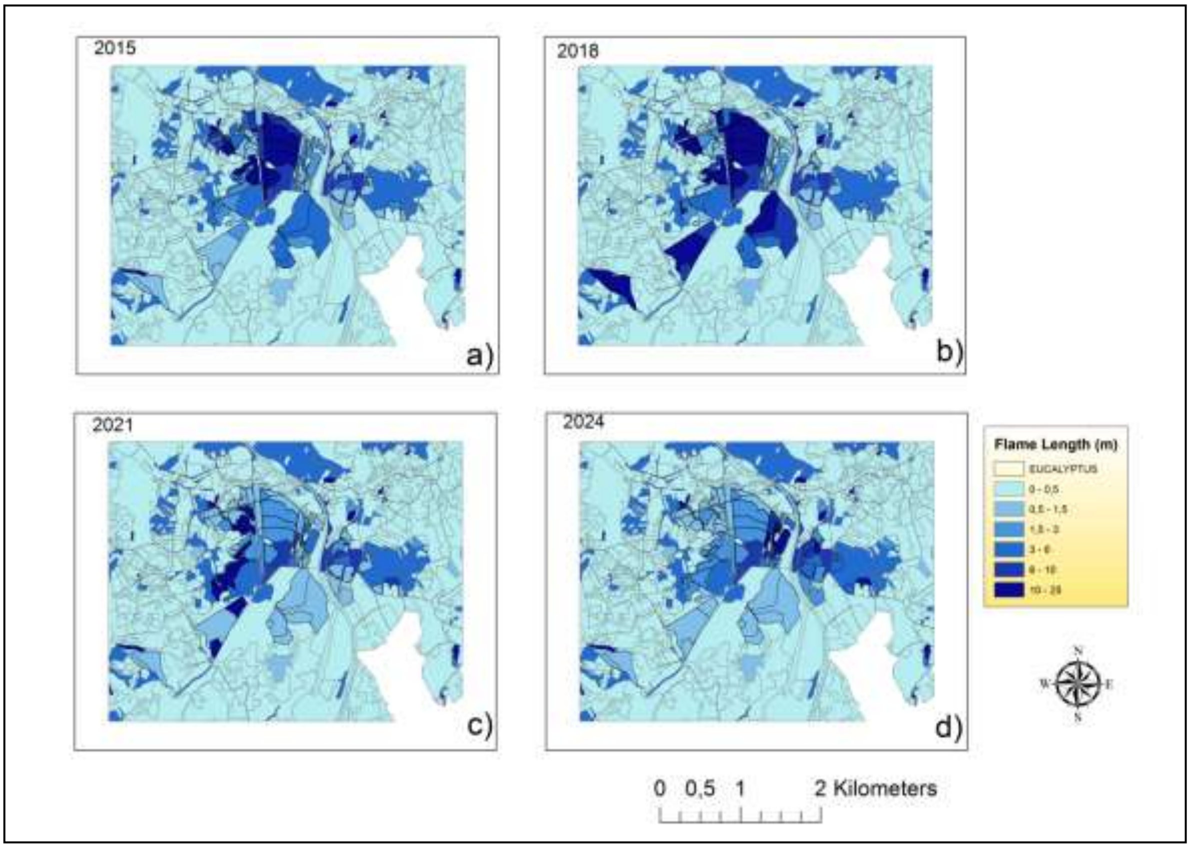

Figure 7. Characterization of Flame Length over time a) 2015, b) 2018, c) 2021, d) 2024.

Fireline Intensity (FLI) follows the same pattern as Flame Length (FL), increasing from t_0 to t_1 (Table 9 and Table 10), reaching maximum values (39825 KW/m), and then decreasing up to meet estimates in t_3 (Table 12) similar to the ones in t_0 (about 28100 Kw/m). The areas presenting higher FLI meet spots where young eucalypt are located (fuel model 224), but also shrublands (fuel model 235, 234). Fire intensities seldom exceed 50000 kW/m and most crown fires fall within the range of 10000 - 30000 kW/m (Alexander, 1982). In Serra do Socorro, most active crown fire is associated over time to young plantations and reach maximum values of fire line intensity.

Alexander & Lanoville 1989 presented suggestions for evaluating FLI in black spruce-lichen woodland fuel type including a control rating or fire suppression interpretation from Muraro 1975 and B.C. Ministry of Forests (1983). The fireline intensity classes used for the case of the eucalyptus plantations in Serra do Socorro are those suggested by Alexander and Lanoville (1989) adapted from Muraro 1975 and B.C. Ministry of Forests (1983) grouped into categories classified and expressed in terms of area and percentage cover from the landscape. Results from FlamMap simulator over time are shown in Figure 8a, b,c and d.

Table 8. Fire line Intensity description and corresponding area at t_0 (2015) (Alexander and Lanoville, 1989).

Fireline Intensity (kW/m)	Control description	Area (hectares) proportion of area (%)
0	-	86.81 (6)
500 (>0)	Fairly easy	1040.85 (71.8)
500-2000	Moderately difficult	60.57 (4.2)
2000-4000	Very difficult	10.26 (0.7)
4000-10000	Extremely difficult	122.85 (8.5)
>10000	Virtually impossible	128.34 (8.85)

Table 9. Fire line Intensity description and corresponding at t_1 (2018). (Alexander and Lanoville, 1989).

Fireline Intensity (kW/m)	Control description	Area (hectares) proportion of area (%)
0	-	86.81 (6)
<500 (>0)	Fairly easy	1040.76 (71.8)
500-2000	Moderately difficult	20.52 (1.4)
2000-4000	Very difficult	20.79 (1.4)
4000-10000	Extremely difficult	96.84 (6.68)
>10000	Virtually impossible	183.96 (12.68)

Table 10. Fire line Intensity description and corresponding areaat t_2 (2021). (Alexander and Lanoville, 1989).

Fireline Intensity (kW/m)	Control description	Area (hectares) proportion of area (%)
0	-	86.81 (6)
<500 (>0)	Fairly easy	1098.36 (75.76)
500-2000	Moderately difficult	47.34 (3.26)
2000-4000	Very difficult	5.58 (0.38)
4000-10000	Extremely difficult	73.44 (5)
10000-30000	Virtually impossible	138.15 (9.5)

Table 11. Fire line Intensity description and corresponding area at t_3 (2024) (Alexander and Lanoville, 1989).

Fireline Intensity (kW/m)	Control description	Area (hectares) proportion of area (%)
0	-	86.81 (6)
<500 (>0)	Fairly easy	1077.4 (74.3)
500-2000	Moderately difficult	67.6 (4.6)
2000-4000	Very difficult	19.35 (1.33)
4000-10000	Extremely difficult	69.3 (4.78)
10000-30000	Virtually impossible	129.24 (8.9)

As seen in Figure 8, the vast majority of the landscape is classified with a FLI less than 500 kW/m, while a small percentage (between 8.85 and 12.68 % in the cases of t_1 and t_2) of the total area beloning to a very critical category ("*extremely difficult and virtually impossible*"), where "*suppression action must be restricted to fire back and flanks*", "*direct fire control is likely to fail*", "*escaped fire is likely to happened*" and "*suppresion curtailed until burning conditions ameliorate*" (Alexander & Lanoville, 1989).

Fire line Intensity is characterized in a scale from 0 to 30000 Kw/m (Figure 8). Values are in concordance with the fuel model types and the fuel load of those models. For example, while pasturelands and herbs type models present very low FLI; shrublands and other forest stands present higher values over the whole area. Both land uses appear to be constant over time when the model is not alter. However, the case of eucalyptus plantations is different, as model is constantly changing and thus fuel load, structure and burn vulnerability. First scenario, t_0 (2015), present two major areas with young plantations (1 and 2 years old) which poses a risk in term of wildfire, this is represented for high values of FLI (as occurred with FL before) (Figure 8a). As those young plantations growth, fuel loads augment and develop into a new model (model 223, 9-18 ton/ha) and thus explaining the maximum values reach at this stage (Figure 8b). Figure 8c represents the scenario in t_2 (2021), characterized for plantations at ages from 3 to 8 years old, FIL is reduced as the inclusion of less heavier fuel load models are presented in the area (226, 2-5 ton/ha; 224, 1-4 ton/ha and 211, 4-6 ton/ha).

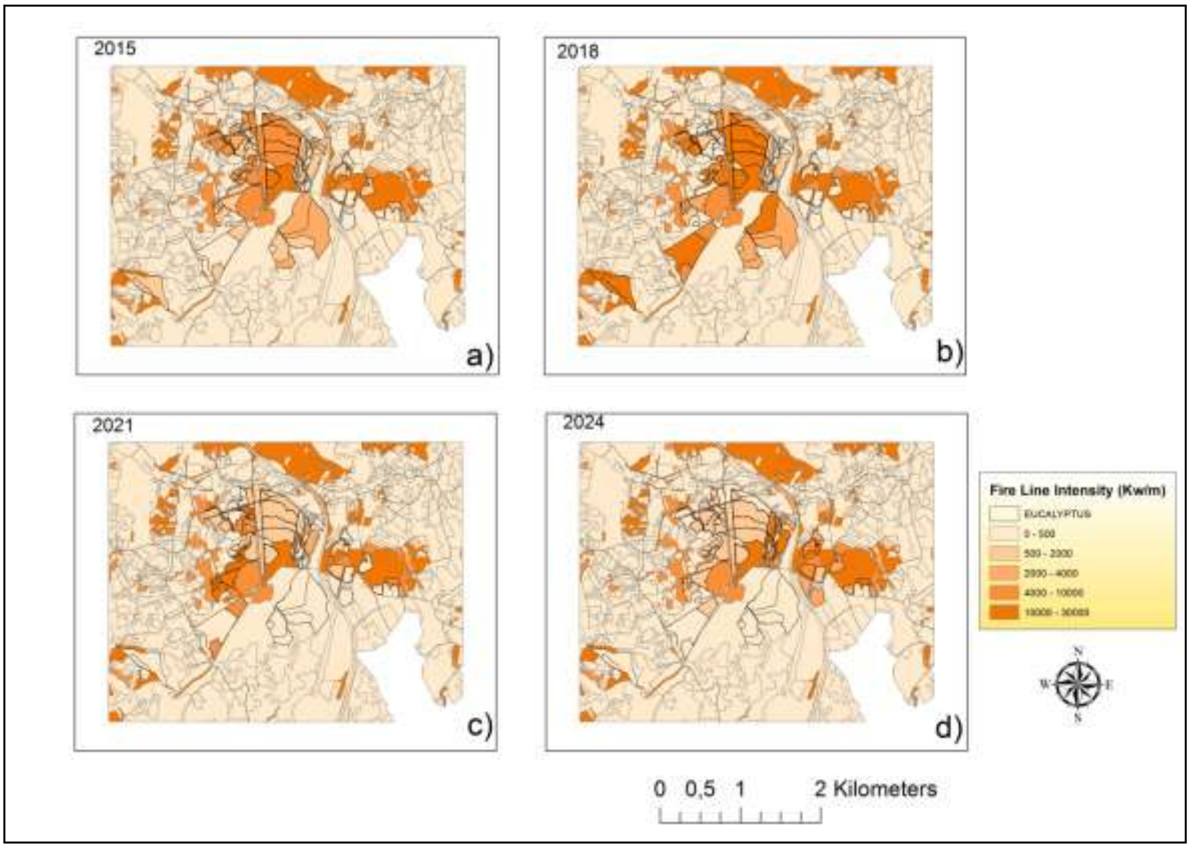

Figure 8.Characterization of Fire Intensity Line over time a) 2015, b) 2018, c) 2021, d) 2024.

3.1.2 ROS patterns over time (2015-2024)

Rate of Spread (ROS) refers to the fire velocity through the surface fuels (in case of surface fire) or the overall speed a fire travels through both surface and aerial fuels (when surface fire plus crown fire is expected)[21]. Rate of spread influences the likely maximum scope of wildfire, especially important if there are values at risk or areas of concern within the landscape. Moreover, ROS is a significant factor affecting Fire line Intensity (FLI) and Flame Length (FL) which are important for determining fire effects (Scott, 2012). For supporting FLI and ROS categorization, Alexander & Lanoville 1989 classification is followed.

If available fuel types within the area present excessive canopy cover values, ROS will be reduced due to the sheltering effect of the tree canopy. According to this, in the present study those areas presenting 60% of canopy cover are giving, in most of the cases, reduced values of ROS. For example, ROS value generally ranges from 0.2 to 5 meters per minute when 60% of canopy cover.

Alexander & Lanoville 1989 relate FLI and ROS in black spruce-lichen forests including a descriptive term from Muraro 1975 and B.C. Ministry of Forests (1983) and arrange into three main categories classified as *surface fire*, *intermittent fire* and *crown fire*. Intermittent crown fire is described as crown fire that alternates in space and time between surface fire and active crown fire (Scott & Reinhardt, 2001), that is discontinuous torching (Merrill and Alexander 1987 in Alexander & Lanoville 1989). In most of the time scale analyses the active crown activity pattern follows a relationship with ROS between 17 and 52 m/min.

Supported by Alexander & Lanoville 1989, the following classification for the case of the eucalyptus plantations in Serra do Socorro is shown in Table 13, Table 14, Table 15 and Table 16.

[21]http://warnercnr.colostate.edu/docs/frs/starfire/STARFireReference/Supporting/GEARHEAD_FireBehaviorAndFlamMap.pdf

Table 12. Characterization of Rate of Spread and corresponding area t_0 (Alexander & Lanoville 1989).

Rate of Spread(m/min)	Descriptive term	Fire Activity Class	Area (hectares) percentage (%)
0	-	-	86.8 (6)
> 0 – 2.8	Extremely slow-moderately slow	Surface fire	1069.83 (73.7)
2.8-5.5	Moderately slow	Surface fire	27.36 (1.8)
5.5-9.2	Moderately fast	Intermittent fire	18.18 (1.25)
9.2-14	Moderately fast-fast	Intermittent fire	88.65 (6.1)
14-20	Fast	Intermittent fire	133.47 (9.2)
20-52	Very fast-extremely fast	Crown fire	25.38 (1.75)

Table 13. Characterization of Rate of Spread and corresponding area for t_1 (Alexander & Lanoville 1989).

Rate of Spread(m/min)	Descriptive term	Fire Activity Class	Area (hectares) percentage (%)
0	-	-	86.8 (6)
> 0 – 2.8	Extremely slow-moderately slow	Surface fire	1047.6 (72.2)
2.8-5.5	Moderately slow	Surface fire	26.37(1.81)
5.5-9.2	Moderately fast	Intermittent fire	23.22 (1.6)
9.2-14	Moderately fast-fast	Intermittent fire	103.41 (7.1)
14-20	Fast	Intermittent fire	43.91 (9.9)
20-52	Very fast-extremely fast	Crown fire	18.36 (1.26)

Table 14. Characterization of Rate of Spread and corresponding area involved for t_2 (Alexander & Lanoville 1989).

Rate of Spread(m/min)	Descriptive term	Fire Activity Class	Area (hectares) percentage (%)
0	-	-	86.8 (6)
> 0 – 2.8	Extremely slow-moderately slow	Surface fire	1124.46 (77.6)
2.8-5.5	Moderately slow	Surface fire	22.14 (1.52)
5.5-9.2	Moderately fast	Intermittent fire	10.53 (0.72)
9.2-14	Moderately fast-fast	Intermittent fire	92.79 (6.4)
14-20	Fast	Intermittent fire	102.33 (7)
20-52	Very fast-extremely fast	Crown fire	10.66 (0.7)

Table 15. Characterization of Rate of Spread and corresponding area for t_3 (Alexander & Lanoville 1989).

Rate of Spread(m/min)	Descriptive term	Fire Activity Class	Area (hectares) percentage (%)
0	-	-	86.8 (6)
> 0 – 2.8	Extremely slow-moderately slow	Surface fire	1115.55 (77)
2.8-5.5	Moderately slow	Surface fire	43.92 (3)
5.5-9.2	Moderately fast	Intermittent fire	11.25 (0.7)
9.2-14	Moderately fast-fast	Intermittent fire	91.26 (6.3)
14-20	Fast	Intermittent fire	95.04 (6.5)
20-52	Very fast-extremely fast	Crown fire	5.85 (0.4)

The most critical classes of ROS, classified as fast, very fast and extremely fast account for about 11%, 11.2%, 7.2% and 6.9% of the total area of the landscape over time (Table 13, Table 14, Table 15 and Table 16), mainly distributed in the young eucalypt plantations (224 fuel model type), and in shrublands areas (234 and 233 fuel model type). On the contrary, as older is the stand, smaller is ROS. Decreasing ROS values appear when forest stands growth over time since t_0. Lower ROS values are also related to herbs fuel models (231 and 232 fuel model type) distribution.

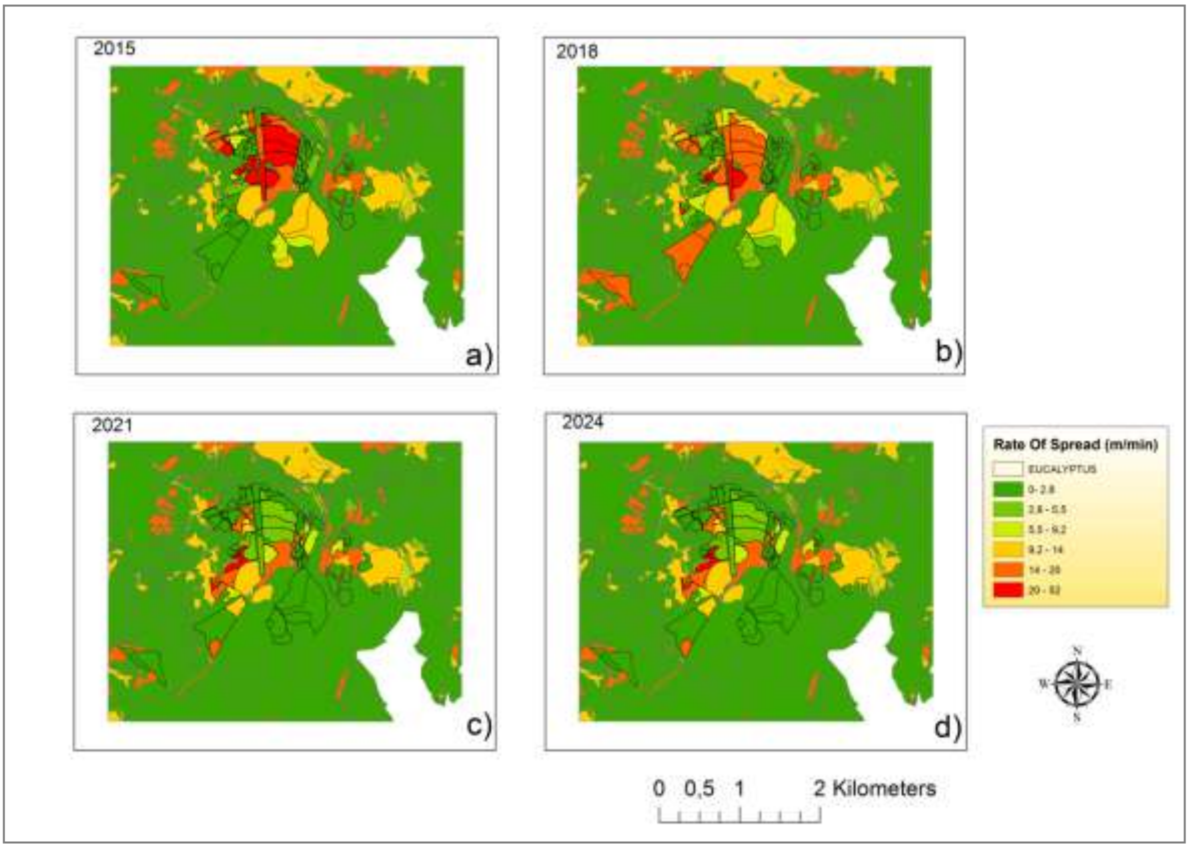

Figure 9. Characterization of Rate of Spread over time. a) 2015, b) 2018, c) 2021, d) 2024.

Rate of spread might also be enhanced with an increasing slope because the flames are brought into closer contact with the fuel as slope rises (Cheney et al., 2012). In Serra do Socorro, two peaks (see Annex 1) might be correlated to the higher values of ROS.

3.1.3 CFA patterns over time (2015-2024)

There are two stages in the crown fire process: the initiation of crown fire activity, known as ‘‘torching’’, and the process of active crown fire spread, where fire moves from tree crown to tree (Agee & Skinner, 2005). Crown fire initiation depend on surface fire intensities, canopy foliar moisture, and Crown Base Height. While Canopy Base

Height (CBH) is used to determine if torching occurs, Canopy Bulk Density (CBD) affects transition to an active crown fire (Stratton, 2006). Undoubtedly, from all the types of wildfires, fire characteristics are extreme when active crowning fire occurs and present a major threat to the extinction crews, being direct attack impossible. High heat intensity, fast spread, long spotting distances and large flame lengths are some of the characteristics of active crown fire (Scott and Reinhardt, 2001). Thus, prediction of the conditions under which crown fires start and propagate turn to be critical for fire managers (Piqué et al. 2014). As expected those areas with low CBH (see Figure 10 and Annex 6) presented more torching activity. CBH was found to be the most important variable when predicting fire severity and crown fire expectation (Botequim et al., 2013). In Serra do Socorro, these areas where assigned with eucalyptus young fuel models (224). Besides, fire crowning is presented when FLI ranges from 4000-28000 Kw/m. Following the same pattern as with the others fire characteristics, the regions in risk belong to young plantations stands, particularly plantations of two years old located in the north of the area presenting higher values in FLI (presumably due to topography characteristics) and CFA, while minimum values in CBH (See Annex 6).

The crown fire activity output by FlamMap indicates whether (1) a surface fire, (2) a passive crown fire or (3) active crown fire is expected[22]. In Serra do Socorro, about 84% of the area is classified into surface fire, whereas about 5% belongs to crown fire (both passive and active crown fire) (Table 17, Table 18, Table 19 and Table 20).

Crowning potential in dense eucalypt stands is only moderate (Fernandes, 2009), and specifically in *E. globulus* that compared to other eucalypts species is less prone to crown fire (Luke and McArthur 1978 in Fernandes et al. 2011).

[22]http://warnercnr.colostate.edu/docs/frs/starfire/STARFireReference/Supporting/GEARHEAD_FireBehaviorAndFlamMap.pdf

Table 16. Crown Fire Activity Class and corresponding area for t_0.

Type of Fire - Class	Descriptive term	Area (hectares) proportion of area (%)
0	None	86.81 (6)
1	Surface fire	1268.01 (87.5)
2	Passive crown fire	24.48 (1.68)
3	Active crown fire	70.38 (4.8)

Table 17. Crown Fire Activity Class and corresponding area for t_1

Type of Fire - Class	Descriptive term	Area (hectares) proportion of area (%)
0	None	86.81 (6)
1	Surface fire	1238.22 (85.41)
2	Passive crown fire	74.97 (5.2)
3	Active crown fire	49.68 (3.4)

Table 18. Crown Fire Activity Class and corresponding area for t_2

Type of Fire - Class	Descriptive term	Area (hectares) proportion of area (%)
0	None	86.81 (6)
1	Surface fire	1327.23 (91.5)
2	Passive crown fire	24.21 (1.6)
3	Active crown fire	11.52 (0.8)

Table 19. Crown Fire Activity Class and corresponding area for t_3

Type of Fire - Class	Descriptive term	Area (hectares) proportion of area (%)
0	None	86.81 (6)
1	Surface fire	1340.01 (92.4)
2	Passive crown fire	14.22 (0.95)
3	Active crown fire	8.64 (0.6)

Similar to the other fire potentials for Serra do Socorro, active crown fire, one of the most critical wildfire characteristics, decreases over time (Tables 17 to 20; Figure 10).

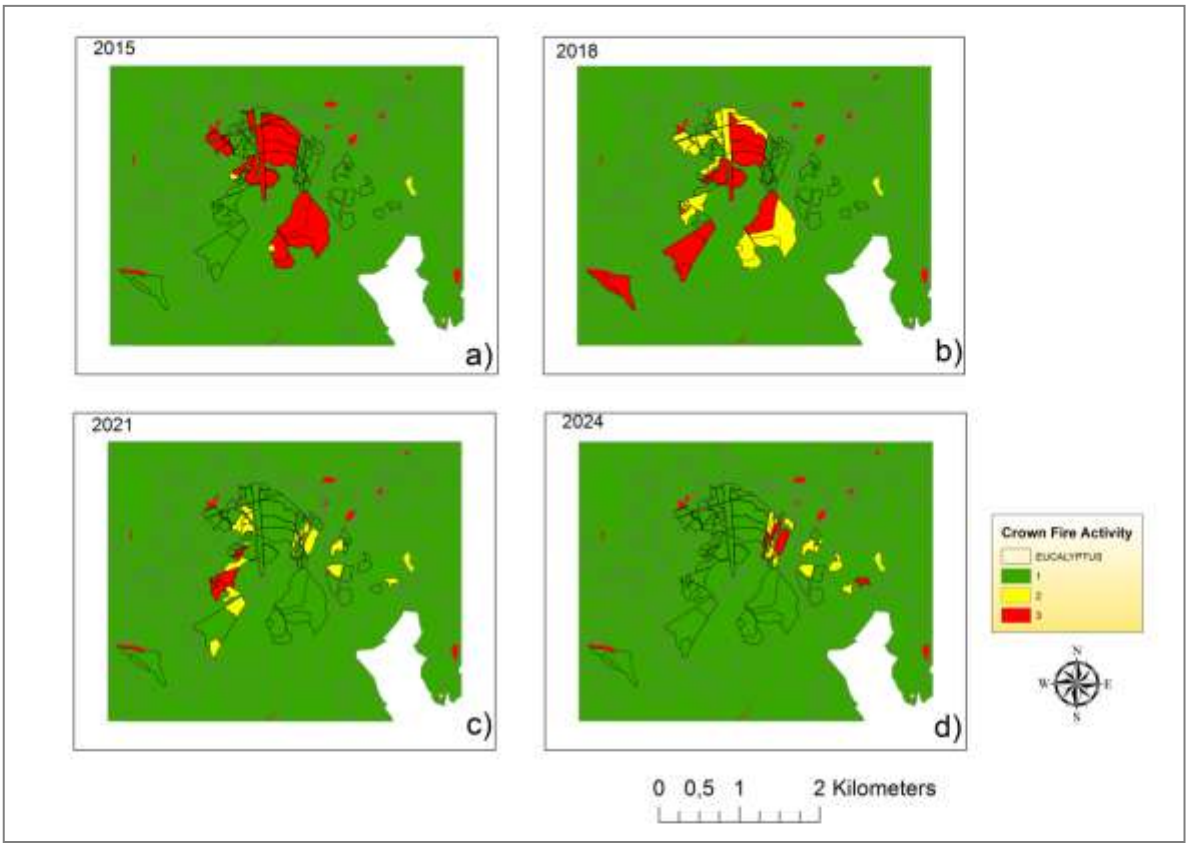

Figure 10. Characterization of Crown Fire Activity over time a) 2015, b) 2018, c) 2021, d) 2024.

In general, fire crown occurrence probability rises from t_0 to t_1 by the incorporation of new young trees at the beginning of the planning period. Canopy characteristics calculated, i.e low CBH (crowns of young stands may still be low to the ground or present low branches) and high CBD, are consistent with these patterns (see Annex 5), as both plays a major role in fire crowning.

3.1.4 BP patterns over time (2015-2024)

Burn probability (BP) is the spatially explicit likelihood that a pixel on a raster landscape will burn. BP models consider ignition locations, topography, weather conditions, and the rate and direction of fire spread on a landscape (Miller et al. 2010). BP help to identify where and when wildfire occurrence is more likely to occur given random ignitions or predefined ignitions scheme within that landscape. Moreover, the information provided by the burn probability metric can be used to support decisions regarding strategic fire and fuels management planning activities [23], including conducting wildland fire risk assessments, optimizing fuel treatments, and prevention planning (Miller et al., 2010). BP can also be applied to quantify the influences of alternative fuel treatments (Ager et al., 2007).

Burn probabilities represent in this work likelihood estimation of burn probabilities of each pixel given random ignitions. This work address the temporal (from t_0 to t_3) variability in fire likelihood, which may be much greater than the spatial variability in BP within a landscape (Miller et al., 2010; Wu et al., 2013). As seen in the following tables (Table 22, Table 23, Table 24 and Table 25), BP vary greatly over time, probably due to the forest succession and change in forest fuel load. Thus burn probabilities indicate these dynamic (time-dependent) changes in fuels across a time length (Wu et al., 2013).

[23] http://iftdss.sonomatech.com/iftdss/documentation/Content/ExternalResources/IFT-RANDIG.pdf

Table 20. Burn probability and corresponding area for t_0.

Burn Probability -Class	Area (hectares) proportion of area (%)
0	1194.17 (82.4)
0.2	104.94 (7.24)
0.4	56.08(4)
0.6	40.59 (2.8)
0.8	27.37 (1.8)
0.12	26.55 (0.018)

Table 21. Burn probability and corresponding area for t_1.

Burn Probability -Class	Area (hectares) proportion of area (%)
0	1289.7 (86)
0.2	78.39 (5.2)
0.4	50.84 (3.3)
0.6	30.42 (2)
0.8	0.18 (0.01)
0.12	-

Table 22. Burn probability and corresponding area for t_2.

Burn Probability -Class	Area (hectares) proportion of area (%)
0	1254.2 (83.6)
0.2	102.96 (6.8)
0.4	66.33 (4.4)
0.6	21.42 (1.4)
0.8	4.77 (0.2)
0.12	-

Table 23. Burn probability and corresponding area for t_3.

Burn Probability -Class	Area (hectares) proportion of area (%)
0	1253.12
0.2	133.65 (8.9)
0.4	62.82 (4.1)
0.6	0.09 (≈ 0)
0.8	-
0.12	-

When random ignitions are selected in FlamMap-MTT, then the only output will be a burn probability map (fraction ranges from 0 to 1). These probabilities are properly interpreted as conditional probabilities, since they are conditional upon large fires occurring (Finney, 2006). In Serra do Socorro, burn probabilities (BP) from random ignitions range from a fraction of 0.0047 to 0.1350, averaging 0.0287 for the whole area. The BP map is categorized into six risk classes, representing the different probabilities corresponding to a wildfire ignition: 0–0.20; 0.20-0.40; 0.40–0.60; 0.60–0.80, 0.80–0.1 and >0.1 (Table 22 to 25). BPs are concentrated in the southeast and central sector and were associated with areas having fuel models characterized by young plantations with high spread rates (from 12000 to 28000 KW/m). Besides, in those patches along the landscape with higher values of BP altitude factors might be suggested as affecting spatial patterns of BP and also fire behavior (See Annex 1, DTM). Despite the values are generally low Figure 11. shows an increase rise by the incorporation of new young trees at the beginning of the planning period (González-Olabarria & Pukkala, 2011) with a maximum value in Serra do Socorro of 13% burn probability (t_1) (Figure 11a).

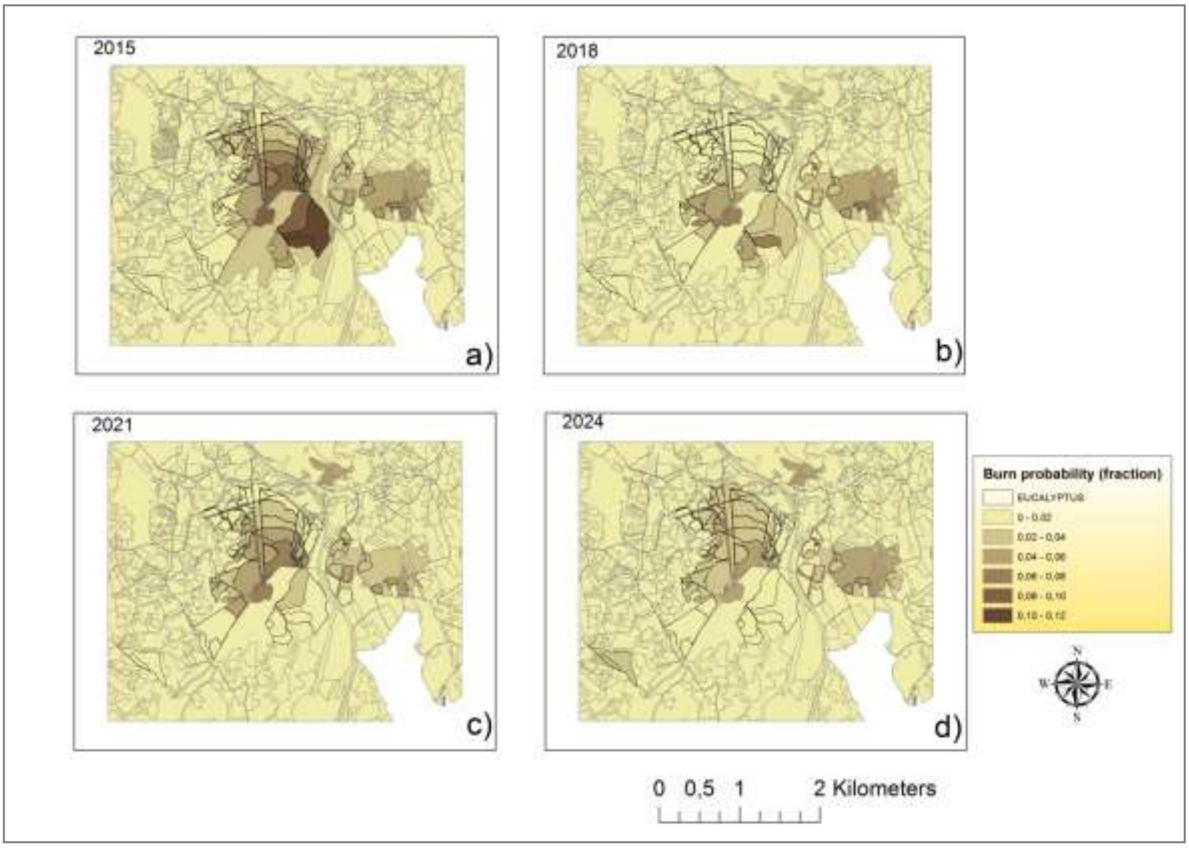

Figure 11. Characterization of Burn probabilities over time. a) 2015, b) 2018, c) 2021, d) 2024.

Botequim et al. 2013 highlight higher wildfire occurrence probability in stands with prevailing smaller trees and indicate that higher shrub biomass, typically accompanying young plantations, increases burn probability.

3.2 Optimizing fuel treatments at landscape level

Objectives, thresholds and constraints inputs into the LTD generated a map of project areas and a priority sequence of four project areas and stands to treat.

Objectives values were given by the Growth and Yield simulator. The objective was set at maximizing timber volume and carbon storage. Both objectives are weighted the same, although may be the option of different weighting for each objective. FlamMap simulator provided with the thresholds in LTD, that is Flame Length >1.5 meters and Rate of Spread >10 m/min. Stands with FLs and ROS values exceeding thresholds hold a major risk in the area.
Highest FL and ROS metrics from simulated wildfire was observed mainly where young eucalypts plantations are located over time (t_0, t_1). Modeled fire behavior indicated that if untreated, some stands would burn with fast - very fast - extremely fast behavior ROS (t_0=11%, t_1=11.2%, t_2=7.1% and t_3= 6.9%). Regarding FL, between 14 and 21% of the area is burning at values superior to 3 meters over time (t_0=17%, t_1=21%, t_2=15% and t_3= 14%). These values are expected to decrease for each of the periods as those stands with the higher metric in FL and ROS are to be attained first.

As constraint, a surrogate of the budget policy was set at 70 hectares (5% of the total landscape, 40% of the EU plantations area), and at 100 hectares (7% of the total landscape, 58% of the EU plantations area) for the planning area, expressed in percentage of total area treated (intensities). This fuel treatment intensity was based on the local stakeholders and forest manager information and field data. However, testing 70 ha (5% of the total landscape) seems to be a more realistic data as intensity of area treated in the landscape of Serra do Socorro (personal communication Tiago Oliveira, 2015).

The planning area optimization presents both approaches. LTD can be used to develop aggregated (coordination of treatment to build large patches) (Figure 12 and 15) or dispersed treatment plans (individual and independent treatments) (Figure 13 and 14). The program runs treatment iteratively creating a treatment priority map. In this case, four project planning priority areas were selected for recursively perform the optimization model, resulting in a sequence of project areas and respective priorities (ranking in priority planning). The project labeled “1” represents the highest priority

planning area for the given objective, the project labeled “2” represents the second highest priority planning area for the given objective, the project labeled “3”represents the third highest priority planning area for the given objective and the project labeled “4” represents the fourth highest priority planning area for the given objective.
In the case of Serra do Socorro both approaches might be of great relevance, however, this is in intimately link to the ownership of the land units. Pulp industry would focus on aggregate fuel treatments, as it might imply saving cost of machinery or human resources. For the side of forest owners non aggregate might be more adequate.

There is a pattern over time that also decreases the number of projects available (from t_0 to t_4, (Figure 12 a, b, c, d and Figure 13 a, b, c , d for 70 hectares case; and Figure 14 a, b, c,d and Figure 15 a, b, c, d for 100 hectares case) as fire metrics decreases over time and thresholds are not overpass to trigger fuel treatments operations. Maps of the rankings show spatial variation in the location of optimal planning area over time. The greatest opportunities to achieve reduction in wildfire hazard (potential flame length and rate of spread) while maximizing timber volume and carbon storage value can be found mainly where eucalyptus plantations and shrublands areas are located (central zone). The higher fire risk levels of the periods t_0 and t_1 (Figure 12a,12b;13a,13b;14a,14b;15a,15b) prompted most of the spatial fuel treatments within plantations in a juvenile stage. This is consistent with the previous fire behavior outputs by FlamMap in terms of FL and ROS, when situated maximum values at northern young eucalyptus stands (central zone). In t_2 and t_3 (Figure 12c, 12d; Figure 13c,13d; Figure 14c, 14d and Figure 15c, 15d) spatial fuel treatments are placed, mostly, within eucalyptus plantations but also outside plantations, in shrublands areas (FL>1.5 m and ROS>10 m/min). This is even more noticeable when moving into the ranking to the other less priority projects (Project 2, Project 3 and Project 4).
Young eucalypts plantations present relatively thin stems and bark. The crowns are low and closer to the ground, and shrubs mixture around them generating a continuos fuel layer so that the probability of being burned is almost double (González Olabarria, 2006). Mature individuals provide more landscape fire resistant than young aged plantations. Some works indicate that large trees (mature stands) pose a lowest risk, especially when higher mean tree diameter, no presence of ground vegetation and low vertical irregularity are present at forest stand level (González Olabarria, 2006). Others researches related mature fire resistant and taller forests stands with less fire vulnerability (Agee & Skinner 2005), decreasing fire line intensity and lowering wildfire occurrence probability (Agee & Skinner, 2005; Botequim et al., 2013). Besides, young

plantations stands are often presented in high densities (especially before stool selection in eucalypt plantations, that is approximately before 3 years old) and thus high levels of biomass are available on the ground (fuel model 239, 224). Denser stands comprising smaller trees are more prone to high-intensity crown fire due to high vertical and horizontal continuity (Cruz et al. 2004 in Botequim et al. 2013). Following this line Ager et al 2010 aimed to identify stands that are heavily stocked and thereby fire-prone to optimize sites for fuel reduction treatment.
Wildfire prevention prescriptions are made effective by treating characterized hazardous fuels stands in eucalypt plantations, even under extreme weather conditions (Fernandes et al., 2011)

For the case of non aggregate perspective and 70 hectares of intensity treatment level, the spatial distributions of fuel treatment units are mapped in Figure 12.

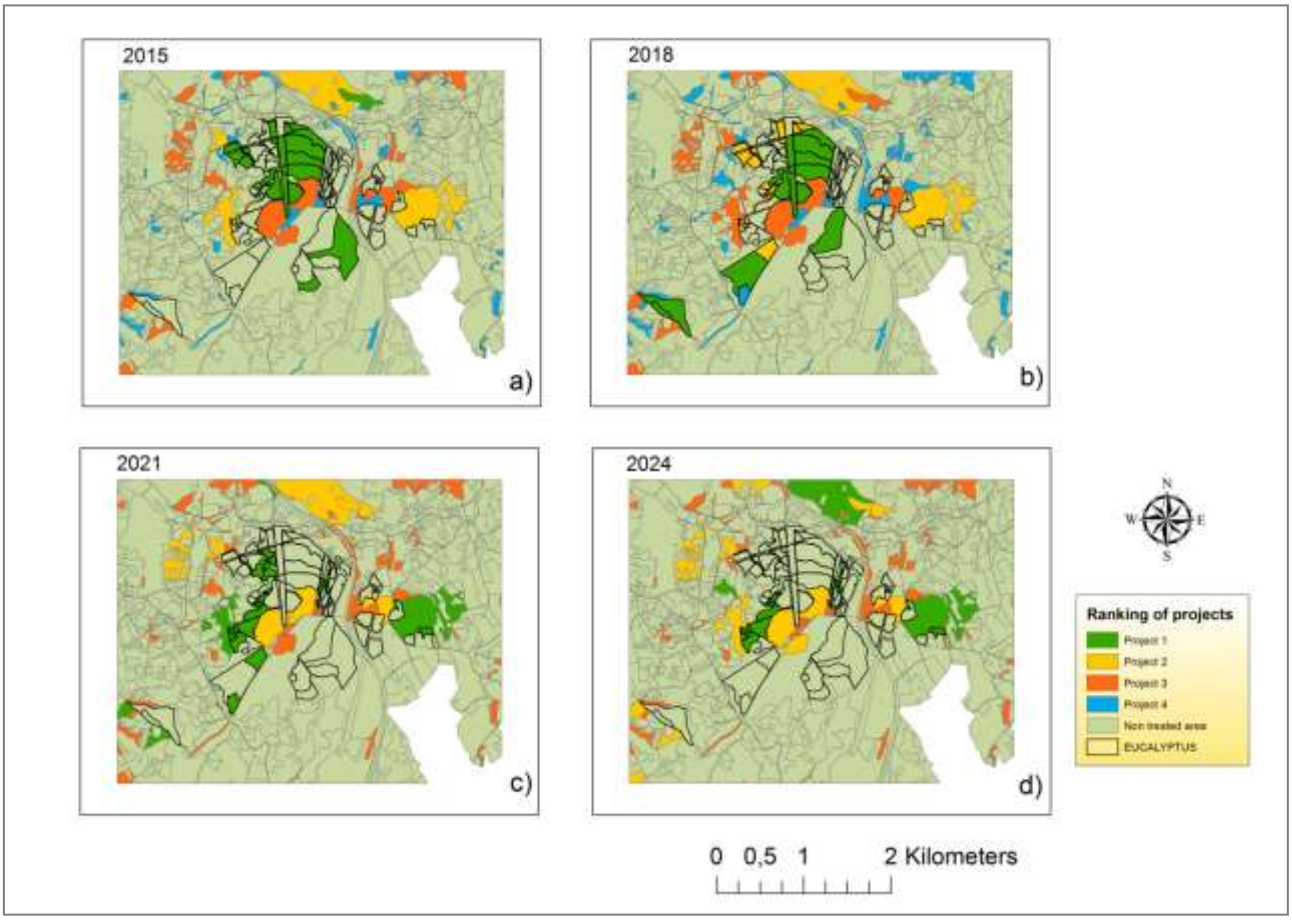

Figure 12. Ranking of projects in term of maximizing objectives subject to treatment area constraints and ROS and FL thresholds (non aggregate option). Area 70 hectares.

A baseline scenario representing from the current status (t_0) to final time-scaled period (t_3) is displayed in maps for aggregation fuel planning strategy and 70 hectares area constraint (Figure 13.).

The two strategic fuel treatment planning (aggregated / non aggregated) on reducing wildfire size and intensity differed greatly.

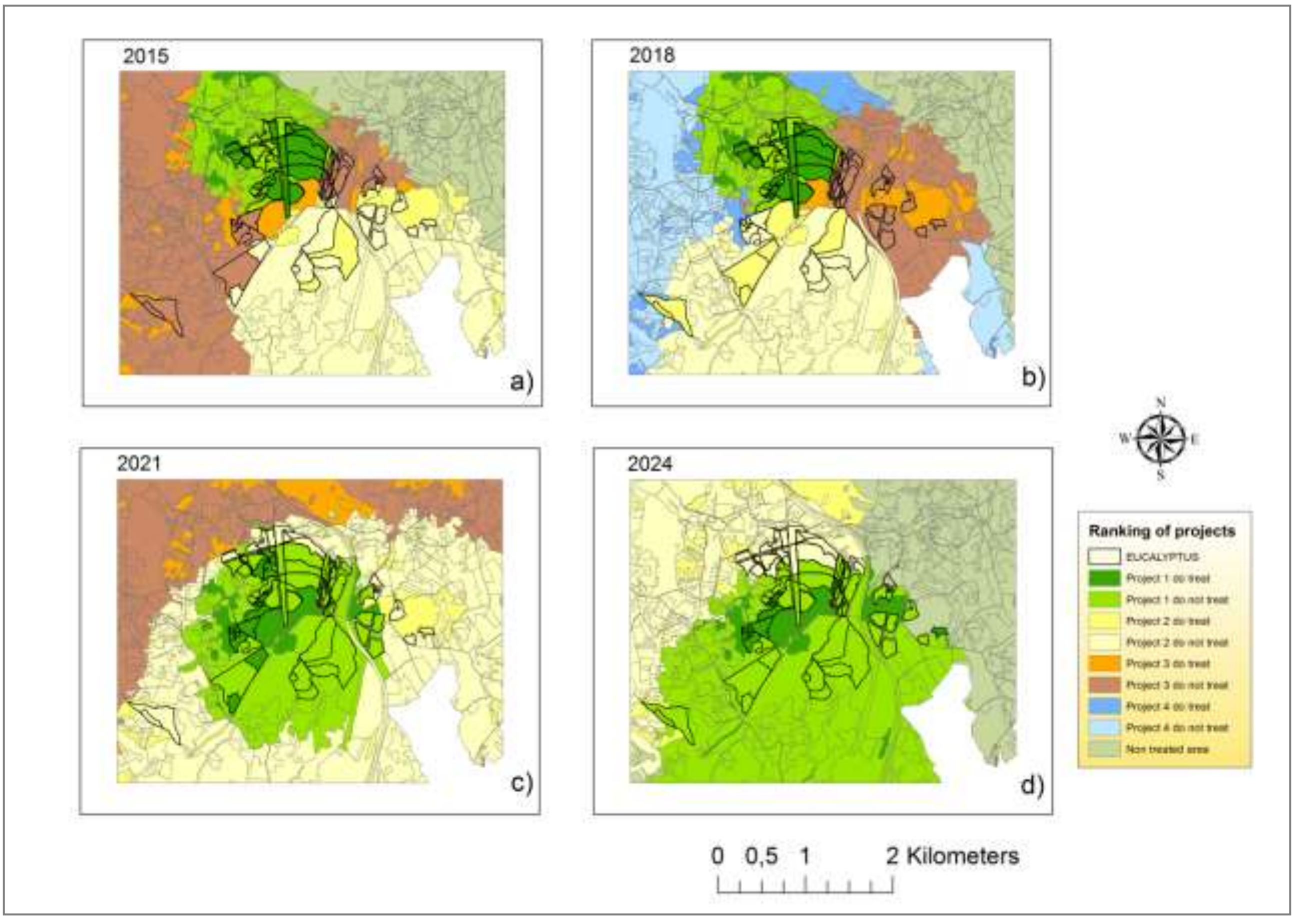

Figure 13. Ranking of projects in term of maximizing objectives subject to treatment area constraint and ROS and FL thresholds (aggregate option). Area 70 hectares.

As the treatment area constraint was increased, from 70 hectares to 100 hectares, stands with maximum values of ROS and FL became scarce, thus requiring more stands to be treated as the project expanded. In this work, LTD cannot always maximize all the four projects because it runs out of area, so it can only address 2 or 3 projects (Figure 14 and 15).

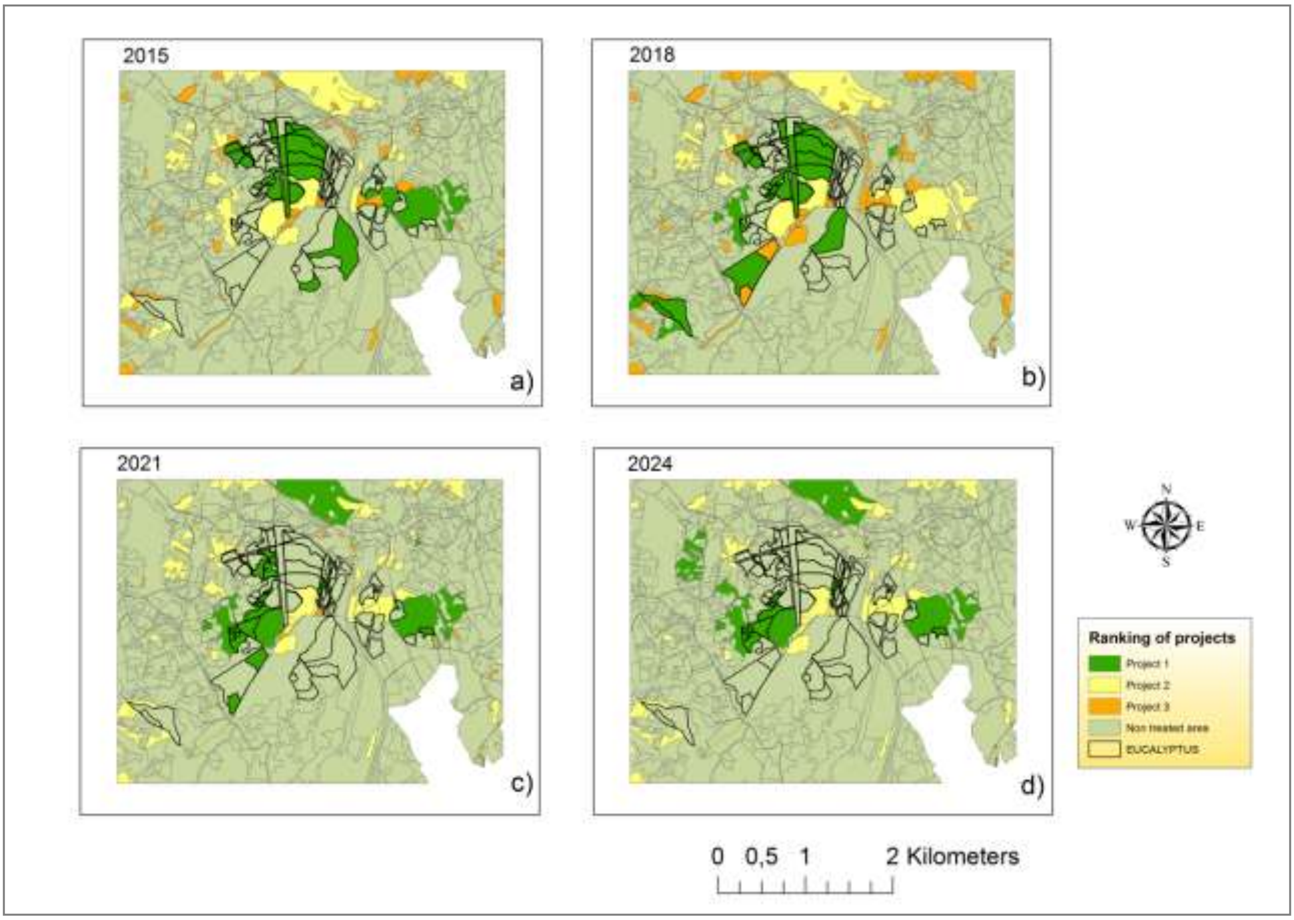

Figure 14. Ranking of projects in term of maximizing objectives subject to treatment area constraint and ROS and FL thresholds (non aggregate option). Area 100 hectares.

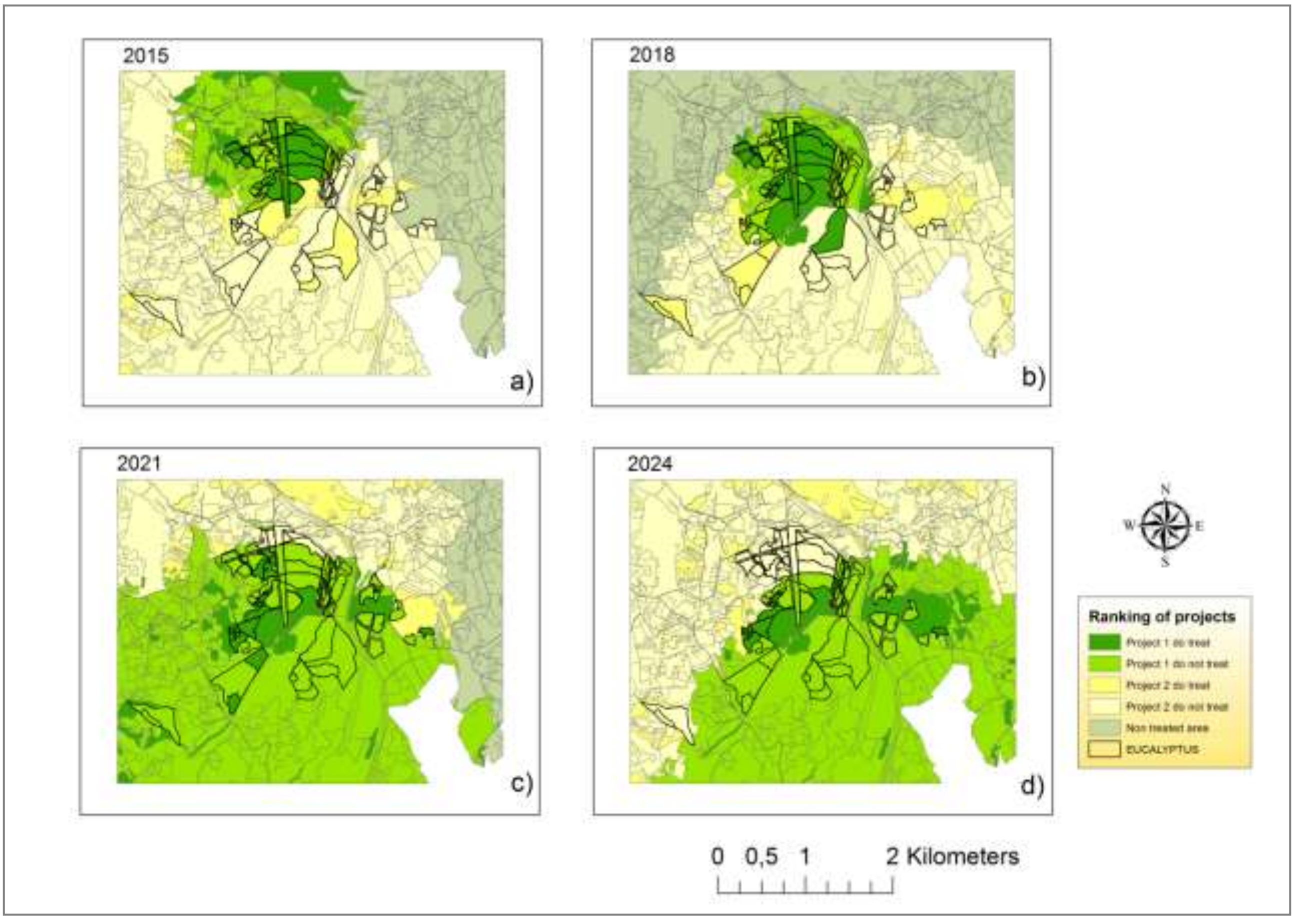

Figure 15. Ranking of projects in term of maximizing objectives subject to treatment area constraints and ROS and FL thresholds (aggregate option). Area 100 hectares

The fire simulation and the optimization of fuel treatment work were in line with local manager experiences and knowledge since field prevention operations performed, at current state, are coincident to those stands that LTD optimizes (personal communication Tiago Oliveira, 2015).

Following in this chapter will be presented future recommendations and improvements as the contribution of this research.

4. Contribution for fire management strategies

4.1 Original contributions

This work is focus on fuel management (fuel load and biometric variables), and not in treating probabilities. However, as spatial process, wildfires are a not only related to forest fuel load accumulation but also to a wide range of spatial controls, such as human activity, weather, and topography (Aldersley et al., 2011). A detailed understanding of wildfire regime, social and economical aspects and might be required to be considered as the interacting effects of spatial controls (Wu et al., 2013).

Given the high risk and cost of performing forest and shrublands fuel treatments across a whole real landscape, effective allocation of resources is critical. The planning methodology might help and connect forest owners and other stakeholders to solve conflicts creating collaborative opportunities for accomplishing objectives. Where and when should group Portucel Soporcel (gPS) invest on prevention? Which stands should be assumed for fire prevention treatment management? The time-investing strategies provided in this work present an innovation and highlight the effectiveness of a methodology for a optimal fuel prevention management. This work intends to support fire and forest management of gPS eucalyptus farms, selecting priority intervention areas and designing successful strategies to increasing operational effectiveness in Serra do Socorro.

4.2 Future challenges

This work should be considered as work in progress, since future challenges are to be addressed. Further steps to be tackled are presented next.

The aim is to perform sensitivity analyzes for testing different scenarios regarding different values of area treated or annual budget schemes. In the same way, objective value and thresholds might present “step” values in such a way that the information of changes in fuel treatments when increasing 1 unit in the objective, threshold or constraint value would be available. Understanding the importance of the inputs will positively improve results in the optimization model. When different objectives and thresholds or constraints are selected in the optimization software, results would have varied somewhat, and most probably varied the location where to treat. Contrasting scenarios help exploring the future most probable consequences of taking one or other decision.

It is key aspect for managers to consider the landscape context when planning fuel management strategies (Schmidt et al. 2008). In this line, some studies (Ager et al., 2015) make used of the simulation modeling to quantify wildfire transmission and approach the concept of transmission network among and within land owners and communities within the study area. Wildfire transmission of risk to and from the wildland interface, agricultural fields, and shrublands areas. One of the reasons that made to include agricultural fields, shrublands and other land uses in the study area is the importance of the surrounding vegetation when planning fuel management strategies and the risk it might poses this surrounding area. For instance, burning after harvesting is a very common practice in September in Serra do Socorro. This might entail a serious risk for wildfire in the rest of the area and in the eucalypt plantations. Fire risk transmission from and to agricultural fields might be address in future studies in Serra do Socorro.

Despite that it is widely recognized among fire managers the spatial interactions among land uses in terms of fire spread and intensity, quantifying risk and exposure transmission have been not yet well understood (Ager et al 2015). Some questions that might be addressed are "*how a forest-wide fuel management program change the transmission network and associated metrics*" or "*how wildfire transmission affects fire adapted communities, biodiversity conservation and ecosystem services demands*" (Ager et al., 2014).

The new LTD version, still no available online (personal communication, Alan Ager, July 2015, Ager et al, submitted) allows for different options than compared to the old version. Specifically those new options that were not tested in this project are the ones that might be further explored in future researches. For example, the adjacency preference that takes into consideration the spatial arrangement of fuel attributes and treatments modifying wildfire spread at the landscape level (Wu et al., 2013). Adjacency is based on distances between contiguous polygon centroids so that a data file will provide with information about what stand is next to another one. LTD uses this information to group together the stands in the optimization problem. Another approach calls for different weighting of objectives, prior required rescale of the data. For instance, in case different weights aim to be tested in LTD, the objectives values must be converted to percentage in such a way that all objectives are in the same scale (unless the data are similar). Finally, the inclusion of economic (maximize volume timber value) and ecological (fire protection) objectives in the LTD using the inverse of fire behavior potentials, as both must be minimize or maximizes in the priority project planning in LTD.

5. Conclusions

This work aimed at highlighting that appropriate forest management planning might accomplish with incomes from commercial eucalyptus plantation management and ecological values while including fire prevention strategy (multiple objectives). Forest and fire management need to be adapted to the forest dynamic (every stage is characterized by a wildfire risk, for example) and to the site conditions, especially considering both structure and composition to encourage fire resilience. The novelty in this study arise in addressing the limitation of the fire behavior simulator FlamMap and LTD software when identifying optimal project locations at only one snapshot at time. This restriction was overtaken using a series of tools to characterize the area over period of 9 years (i.e. growth and yield modeling, canopy characteristics equations and dynamic fuel population processes).This is indeed an insight into real-life problems met in forest planning.

The strategic location of fuel treatment projects provided by Landscape Treatment Designer was in line with current field prevention operations performed (personal communication Tiago Oliveira, 2015). However, results are not always expected to be perfect given model assumptions and limitations of input data but to guide the fuel treatment design under the problematic of the wildfire in the Mediterranean region.

An extensive work on preparing the inputs for the fire simulations and optimization process were carried out as they are critical on having representative predictions is the estimates for a local weather (winds and fuel moistures) and fuel models. However, some assumptions had to be made in the study and the impacts of these assumptions on optimal fuel arrangement both spatially and temporally need to be further analyzed in the future. Investments in acquiring, developing and improving data need to be prioritized in wildfire risk studies and strategic location of resources to be closer as possible to the reality of the problem. Besides data input uncertainties over time (wildfire ignitions patterns, weather conditions, fuels accumulation, land uses changes), wildfire simulations itself might present many sources of uncertainty and the results

should be regarded as general indicators of wildfire exposure and fuel management planning for prioritizing fire protection efforts (Salis et al., 2013).
Final results provides with maps and tables as an clear approach to present and communicate wildfire risk to landowners in Serra do Socorro and other areas in Central Portugal, helping the understanding of the necessity of targeting specific areas for additional fuel management and protection efforts under the desired objectives (Salis et al., 2013).

As LTD maximize the objective value set in this work, that is timber volume and carbon storage, optimization strategy looks for maintaining old eucalyptus plantations (more timber volume and more carbon storage) unless exceed the thresholds. Strategic fuel treatment location in LTD is not very complex; it is fast and a very practical instrument for forest stakeholders and decision makers. However, as outputs general guidelines are provided that enhance fire management planning and quantifying the impact of fuel prescriptions on a fire prone landscape. Finally, this methodology can be easily implemented in operational planning decision making and helps efficient forest management when answering spatial and temporal question such as where and when fuel treatments are required.

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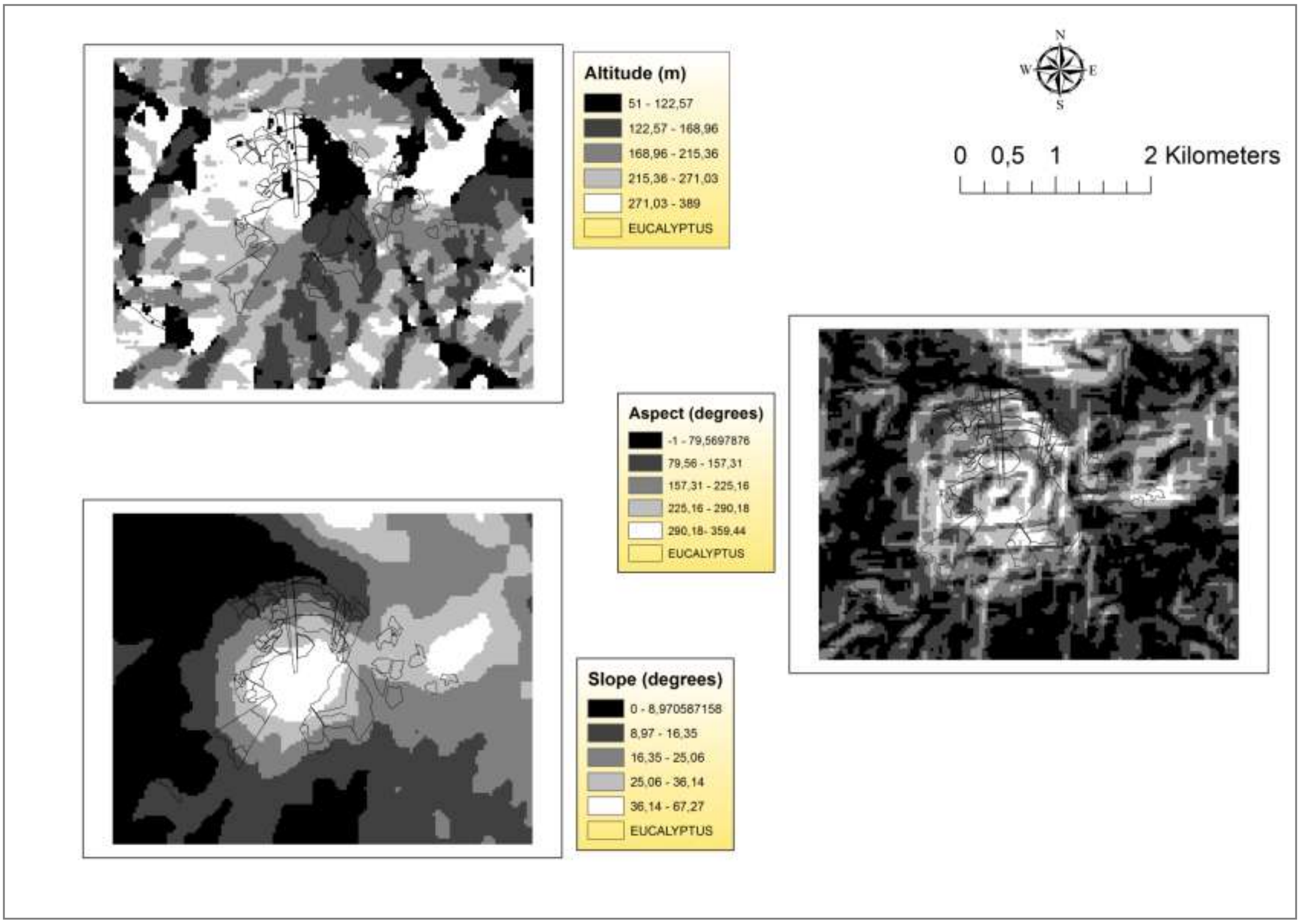
http://www.firelab.org/project/flammap
http://www.fs.fed.us/wwetac/ltd/

Annexes

Annex 1 – Digital Model Terrain (DTM) Serra do Socorro.



Annex 2 – Fuel model descriptions [In Portuguese].

Modelos de combustível florestal para Portugal

Grupo	Modelo	Nº Farsite	Descrição do complexo combustível	Aplicação
Folhada (F)	F-RAC	214	Folhada muito compacta de coníferas com agulha curta. Carga de combustível fino: 4-6 (t/ha)	Povoamentos de *Pseudotsuga*, *Cedrus*, *Cupressus*, *Chamaecyparis*, *Pinus sylvestris*, *P. nigra*. Formações maduras de *Acacia dealbata*.
	F-FOL	212	Folhada compacta de folhosas com folha caduca ou perene. Carga de combustível fino: 2-5 (t/ha)	Povoamentos de carvalho, castanheiro, vidoeiro e faia. Sobreiral e azinhal densos, medronhal e acacial (excepto *A. dealbata*).
	F-PIN	213	Folhada de pinhais de agulha média a longa. Carga de combustível fino: 4-7 (t/ha)	Pinhais de *P. pinaster, P. pinea, P. halepensis, P. radiata*.
	F-EUC	211	Folhada de eucalipto. Carga de combustível fino: 4-6 (t/ha)	Eucaliptal.
Folhada e vegetação (M)	M-CAD	221	Folhada de folhosas caducifólias com sub-bosque arbustivo, usualmente com bastante combustível vivo. Carga de combustível fino: 8-17 (t/ha)	Povoamentos de carvalho, castanheiro, vidoeiro e faia.
	M-ESC	222	Folhada de folhosas esclerófilas com sub-bosque arbustivo. Carga de combustível fino: 7-17 (t/ha)	Sobreiral e azinhal.
	M-PIN	227	Folhada de pinheiro de agulha média a longa com sub-bosque arbustivo. Carga de combustível fino: 8-18 (t/ha)	Pinhais de *P. pinaster, P. pinea, P. halepensis, P. radiata*.
	M-EUC	223	Folhada de eucalipto com sub-bosque arbustivo. Carga de combustível fino: 9-18 (t/ha)	Eucaliptal.
	M-	224	Folhada descontínua de eucalipto com ou sem sub-bosque arbustivo nas linhas de	Eucaliptal jovem ou recentemente gradado.

	EUCd		plantação. Carga de combustível fino: 1-4 (t/ha)	
	M-H	226	Folhada com sub-bosque herbáceo. Carga de combustível fino: 2-5 (t/ha)	Povoamentos florestais, independentemente da espécie.
	M-F	225	Folhada com sub-bosque de fetos. Carga de combustível fino: 6-9 (t/ha)	Povoamentos florestais, independentemente da espécie.
Vegetação (V)	V-MAb	234	Mato baixo (<1 m) com bastante combustível morto e/ou fino. Carga de combustível fino: 7-14 (t/ha)	Matos e charnecas de urze, tojo, carqueja, zimbro. Povoamentos abertos ou jovens, independentemente da espécie, com estrato arbustivo constituído por aquelas espécies.
	V-MAa	233	Mato alto (>1 m) com bastante combustível morto e/ou fino. Carga de combustível fino: 12-27 (t/ha)	Matos de urze, tojo ou carqueja, ou giestal velho. Povoamentos abertos ou jovens, independentemente da espécie, com estrato arbustivo constituído por aquelas espécies. Regeneração natural densa de pinhal.
	V-MMb	237	Mato baixo (<1 m), com pouco combustível morto e/ou com folhagem relativamente grosseira. Carga de combustível fino: 4-8 (t/ha)	Matos de giesta, piorno. Matos de esteva, carrasco, zambujeiro, medronheiro, lentiscos e outras espécies mediterrânicas. Silvados. Povoamentos abertos ou jovens, independentemente da espécie, com estrato arbustivo constituído por aquelas espécies.

Annex 3 – Identification key for fuel models in Portugal [In Portuguese].

Critérios de selecção dos modelos de combustível

1. Identificar o grupo no qual o modelo de combustível se insere. O grupo é definido pelo estrato (ou combinação de estratos) que dominam a propagação do fogo. A identificação dos estratos é baseada na respectiva espessura/altura e grau de revestimento do solo, de acordo com a tabela seguinte.

Matriz de classificação do grupo de modelos de combustível. C = coberto, h = altura. d – combustível descontínuo, F – grupo folhada; M – grupo misto; V – grupo vegetação.

Folhada	Sub-bosque			
	C < 1/3	1/3 < C < 2/3	C > 2/3, h < 1 m	C > 2/3, h > 1 m
C < 3/4	d	d	V	V
C > ¾, h < 2 cm	F	M	M	V
C > ¾, h > 2 cm	F	M	M	M

2. Dentro do grupo, seleccionar o modelo de combustível atendendo aos seguintes critérios: composição do estrato arbóreo, natureza e altura da vegetação dos outros estratos, importância relativa do combustível morto e/ou dos elementos bastante finos nos arbustos.

Chave de identificação dos modelos de combustível

A. Povoamentos florestais em que o comportamento do fogo é dominado pela folhada. …………………………………………………………………………..…….. **Grupo F**.

1. Povoamentos de coníferas de agulha curta (*Pseudotsuga*, *Cedrus*, *Cupressus*, *Chamaecyparis*, *Pinus sylvestris*, *P. nigra*), cuja folhada é muito compacta e constituída por agulhas curtas, ou formações maduras de *Acacia dealbata*. A quantidade de detritos lenhosos sobre a folhada pode ser substancial. …... **F-RAC**.

2. Formações de folhosas, caducifólias (*Quercus*, *Castanea*, *Betula*) ou esclerófilas (*Quercus*, *Arbutus*, *Acacia* sp., excepto *A. dealbata*), caracterizadas por folhada de compactação moderada a elevada …... **F-FOL**.

3. Pinhais de espécies de agulha média-longa (*P. pinaster, P. pinea, P. halepensis, P. radiata*) formando caruma pouco compacta. …... **F-PIN**.

4. Eucaliptal, de folhada pouco compacta. ….. **F-EUC**.

B. Povoamentos florestais em que o comportamento do fogo resulta do efeito combinado da folhada e da vegetação do sub-bosque, usualmente baixa (<1 m). …...... **Grupo M**.

1. Formações de folhosas caducifólias e de resinosas de agulha curta. ……………………………………………………………………..……...... **M-CAD**.

2. Formações de folhosas esclerófilas (sobreiro, azinheira). ……..……….…..... **M-ESC**

3. Pinhal de agulha média-longa (*P. pinaster, P. pinea, P. halepensis, P. radiata*). ………………………………………………………………………...… **M-PIN**

4. Eucaliptal. ……………………………………………………………..... **M-EUC**

5. Eucaliptal jovem ou recentemente gradado, com folhada descontínua. Se existente, o sub-bosque está limitado às linhas de plantação. ……………..…....... **M-EUCd**

6. Povoamentos florestais com sub-bosque herbáceo …………………………....... **M-H**

7. Povoamentos florestais com sub-bosque de fetos ………………….…….…..... **M-F**

C. Formações, com ou sem estrato arbóreo, em que o comportamento do fogo é determinado pela vegetação arbustiva ou herbácea. ………………………………………………………………..…..…….. **Grupo V**.

1. Matos ou povoamentos com vegetação arbustiva constituída por espécies com retenção significativa de combustível morto na copa e/ou com folhagem fina (urzes, tojos, carqueja).

1.1. Os arbustos são baixos (<1 m) ……………..…………………….…... **V-MAb**

1.2. Os arbustos são altos (>1 m) ……………..………………………...... **V-MAa**

2. Matos ou povoamentos com vegetação arbustiva constituída por espécies sem retenção significativa de combustível morto na copa e/ou com folhagem relativamente grosseira (giestas, esteva, carrasco e outras espécies mediterrânicas).

2.1. Os arbustos são baixos (<1 m) ……………..…………………….…... **V-MMb**

2.2. Os arbustos são altos (>1 m) …………….……………………….…... **V-MMa**

3. Mato jovem (até 3 anos desde o último fogo) independentemente das espécies dominantes, frequentemente com vegetação herbácea. ……......................... **V-MH**

4. Formações herbáceas, com ou sem estrato arbóreo.

4.1. As ervas são baixas (<0,5 m) …………..……………………............ **V-Hb**

4.2. As ervas são altas (>0,5 m) ……………..…………………………....... **V-Ha**

Annex 4 – Canopy Bulk Density (kg/m3*100) and Canopy Base Height (m*10)

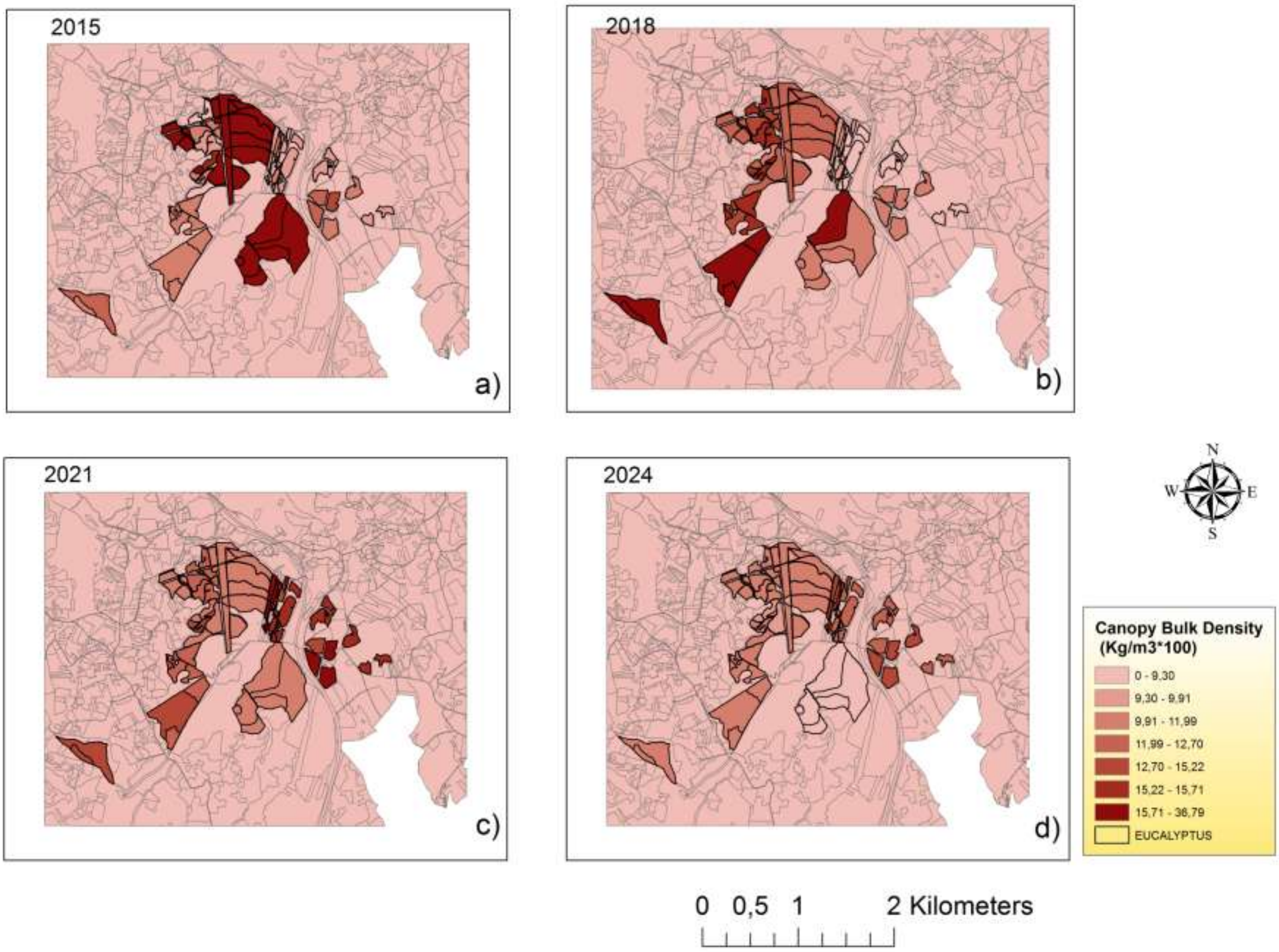
ID	CBD_15	CBH_15	CDB_18	CBH_18	CBD_21	CBH_21	CBD_24	CBH_24
1000,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1001,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1002,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1003,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1004,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1005,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1006,00	18,05	25,65	12,71	76,18	11,27	124,19	10,41	153,78
1007,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1008,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1009,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1010,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1011,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1012,00	11,65	97,87	36,79	0,01	12,05	7,47	10,45	131,48
1013,00	11,98	88,91	35,01	0,01	12,05	7,47	11,27	141,04
1014,00	11,42	133,04	36,79	0,01	12,86	68,71	11,54	106,71
1015,00	12,49	113,21	36,79	0,01	12,84	68,95	11,55	107,21
1016,00	11,13	120,13	36,79	0,01	12,92	70,82	11,54	109,13
1017,00	25,32	0,01	35,01	0,01	10,08	79,72	9,12	105,92
1018,00	25,32	0,01	11,71	32,45	10,08	79,72	9,12	105,92
1019,00	25,32	0,01	11,71	32,45	10,08	79,72	9,12	105,92
1020,00	9,63	152,18	8,95	169,52	15,52	15,82	12,71	65,42
1021,00	9,63	152,18	8,95	169,52	15,52	15,82	12,71	65,42
1022,00	9,63	152,18	8,95	169,52	15,52	15,82	12,71	65,42
1023,00	9,63	152,18	8,95	169,52	15,52	15,82	12,71	65,42
1024,00	11,58	43,71	10,80	62,87	15,61	15,99	12,76	66,43
1025,00	12,67	44,27	11,81	52,10	14,86	13,17	12,37	59,53
1026,00	14,08	42,51	11,13	98,06	16,02	18,34	12,86	69,60

1027,00	12,05	81,06	11,13	98,06	15,90	18,17	12,86	69,60
1028,00	9,63	152,18	8,95	169,52	15,52	15,82	12,71	65,42
1029,00	9,63	152,18	8,95	169,52	15,52	15,82	12,71	65,42
1030,00	11,76	86,10	10,92	100,49	15,81	17,17	12,80	67,68
1031,00	25,32	0,01	11,71	32,45	10,08	79,72	9,12	105,92
1032,00	25,32	0,01	11,71	32,45	10,08	79,72	9,12	105,92
1033,00	25,32	0,01	11,71	32,45	10,08	79,72	9,12	105,92
1034,00	9,88	107,91	9,66	94,88	15,81	17,08	12,81	67,56
1035,00	9,88	107,91	9,66	94,88	15,81	17,08	12,81	67,56
1036,00	11,10	118,95	9,91	130,33	15,81	17,08	12,81	67,56
1037,00	10,51	121,61	9,40	169,52	15,61	16,27	12,76	66,35
1038,00	11,10	118,95	9,90	130,30	15,81	17,08	12,81	67,56
1039,00	9,63	152,18	9,31	178,38	15,52	15,82	12,71	65,42
1040,00	10,51	121,61	9,66	135,13	15,61	16,27	12,76	66,35
1041,00	9,70	171,88	9,12	181,81	14,85	13,22	12,39	59,89
1042,00	10,51	121,61	9,66	135,13	15,61	16,27	12,76	66,35
1043,00	9,70	171,88	9,12	181,81	14,85	13,22	12,39	59,89
1044,00	9,63	152,18	9,31	178,38	15,52	15,82	12,71	65,42
1045,00	9,88	107,91	9,66	94,88	15,81	17,08	12,81	67,56
1046,00	9,70	171,88	9,12	181,81	14,85	13,22	12,39	59,89
1047,00	9,88	107,91	9,66	94,88	15,81	17,08	12,81	67,56
1048,00	9,88	107,91	9,66	94,88	15,81	17,08	12,81	67,56
1049,00	10,91	101,66	9,48	104,60	15,52	15,84	12,71	65,46
1050,00	10,91	101,66	9,48	104,60	15,52	15,84	12,71	65,46
1051,00	9,70	171,88	9,12	181,81	14,85	13,22	12,39	59,89
1052,00	10,91	101,66	9,48	104,60	15,52	15,84	12,71	65,46
1053,00	9,70	171,88	9,12	181,81	14,85	13,22	12,39	59,89
1054,00	9,70	171,88	9,12	181,81	14,85	13,22	12,39	59,89
1055,00	9,63	152,18	9,31	178,38	15,52	15,82	12,71	65,42
1056,00	9,88	107,91	9,66	94,88	15,81	17,08	12,81	67,56

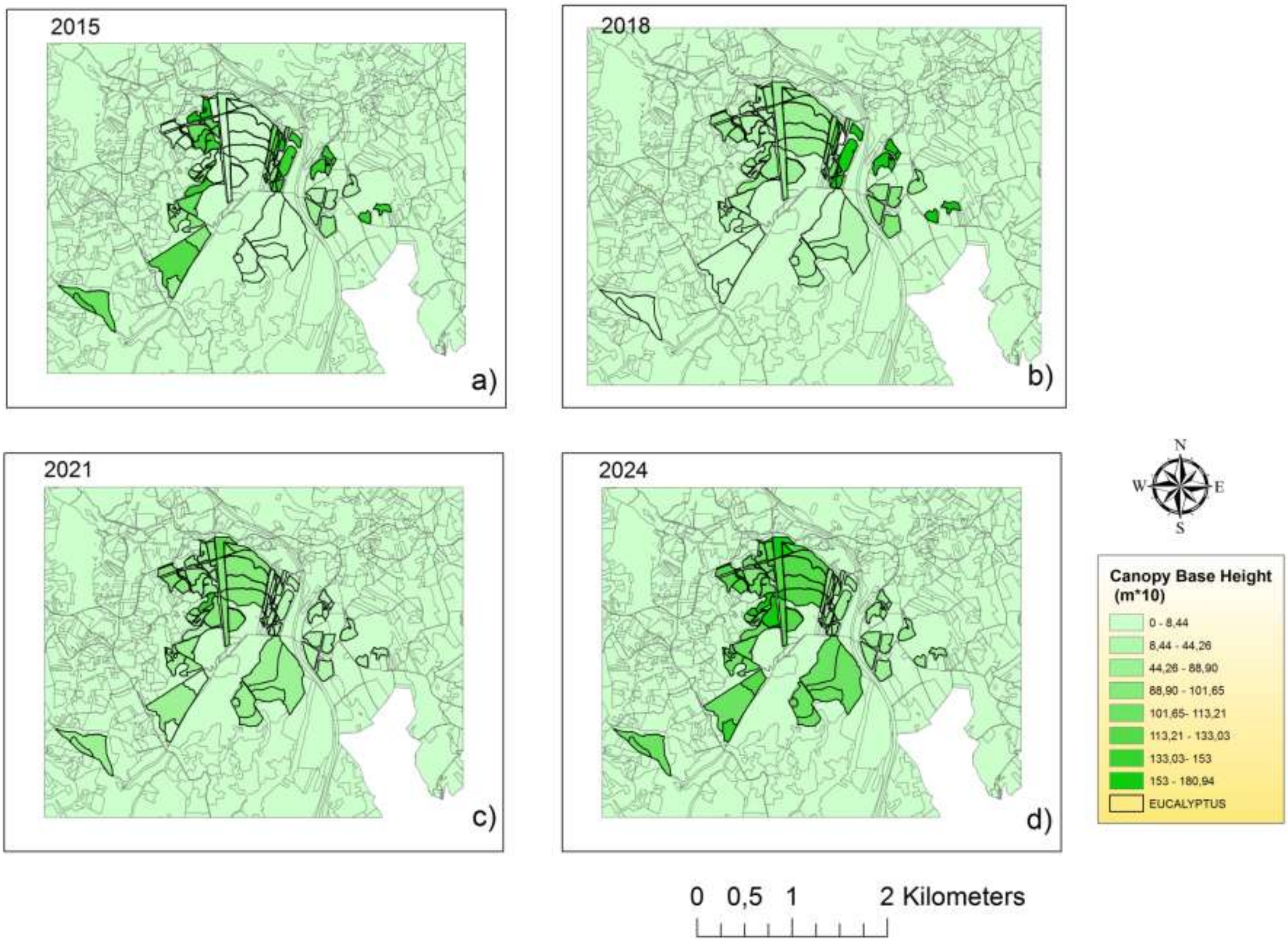
1057,00	9,88	107,91	9,66	94,88	15,81	17,08	12,81	67,56
1058,00	9,88	107,91	9,66	94,88	15,81	17,08	12,81	67,56
1059,00	9,88	107,91	9,66	94,88	15,81	17,08	12,81	67,56
1060,00	9,63	152,18	9,31	178,38	15,52	15,82	12,71	65,42
1061,00	9,88	107,91	9,66	94,88	15,81	17,08	12,81	67,56
1062,00	9,63	152,18	9,31	178,38	15,52	15,82	12,71	65,42
1063,00	9,88	107,91	9,66	94,88	15,81	17,08	12,81	67,56
1064,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1065,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1066,00	9,18	180,95	15,49	16,13	12,65	63,55	11,41	103,50
1067,00	9,03	171,16	15,52	15,86	12,65	63,55	11,49	103,09
1068,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1069,00	10,52	112,03	14,80	13,14	12,33	59,73	11,41	103,03
1070,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1071,00	9,96	80,81	15,62	15,57	12,74	65,06	11,55	102,94
1072,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1073,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1074,00	10,52	106,44	15,23	14,93	12,53	63,51	11,38	100,75
1075,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1076,00	10,52	112,03	14,80	13,14	12,33	59,73	11,41	103,03
1077,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1078,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1079,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1080,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1081,00	9,38	153,00	15,49	16,06	12,61	65,54	11,42	103,41
1082,00	9,33	138,01	15,49	33,89	12,61	65,50	11,42	103,37
1083,00	18,05	3,52	12,71	51,50	11,27	93,25	10,41	124,08
1084,00	9,96	80,81	15,62	15,57	12,74	65,06	11,55	102,94
1085,00	15,24	8,44	12,00	85,61	10,68	135,26	9,85	169,94
1086,00	18,05	3,52	12,71	51,50	11,27	93,25	9,85	169,94

1087,00	9,81	125,71	15,40	15,83	12,62	65,42	11,41	103,16
1088,00	18,05	3,52	12,71	51,50	11,27	93,25	9,85	169,94
1089,00	10,27	96,23	15,69	16,63	12,74	66,90	11,48	104,83
1090,00	10,27	96,23	15,69	16,63	12,74	66,90	11,48	104,83
1091,00	8,94	145,90	12,57	45,05	10,68	35,69	11,41	102,00
1092,00	18,05	3,52	12,71	51,50	11,27	93,25	9,85	169,94
1093,00	10,52	112,03	15,40	15,83	12,33	59,73	11,41	103,03
1094,00	11,18	80,97	15,18	16,09	12,50	65,80	11,31	103,39
1095,00	11,18	80,97	15,18	16,09	12,50	65,80	11,31	103,39
1096,00	11,05	96,39	15,71	15,56	12,80	65,03	11,57	102,66
1097,00	11,05	96,39	15,40	15,84	12,62	65,43	11,46	103,57
1098,00	18,05	3,52	12,71	51,50	11,27	93,25	9,85	169,94
1099,00	18,05	3,52	12,71	51,50	11,27	93,25	9,85	169,94
1100,00	18,05	3,52	12,71	51,50	11,27	93,25	9,85	169,94
1101,00	18,05	3,52	12,71	51,50	11,27	93,25	9,85	169,94
1102,00	18,05	3,52	12,71	51,50	11,27	93,25	9,85	169,94
1103,00	18,05	3,52	12,71	51,50	11,27	93,25	9,85	169,94
1104,00	18,05	3,52	12,71	51,50	11,27	93,25	9,85	169,94
1105,00	18,05	3,52	12,71	51,50	11,27	93,25	9,85	169,94
1106,00	18,05	3,52	12,71	51,50	11,27	93,25	9,85	169,94
1107,00	11,65	97,87	36,79	0,01	12,05	7,47	10,45	131,48
1108,00	11,65	97,87	36,79	0,01	12,05	7,47	10,45	131,48
1109,00	11,98	88,91	36,79	0,01	12,05	7,47	11,27	141,04
1110,00	11,98	88,91	35,01	0,01	12,05	7,47	11,27	141,04

Annex 5-CBD over time



Annex 6-CBH over time



Annex 7– Growth Yield modelling for Eucalypt plantation: Merchantable volume (Vmc, m^3ha-1), total biomass (Wt, Mg ha-1) and carbon storage (C, Mg ha-1)

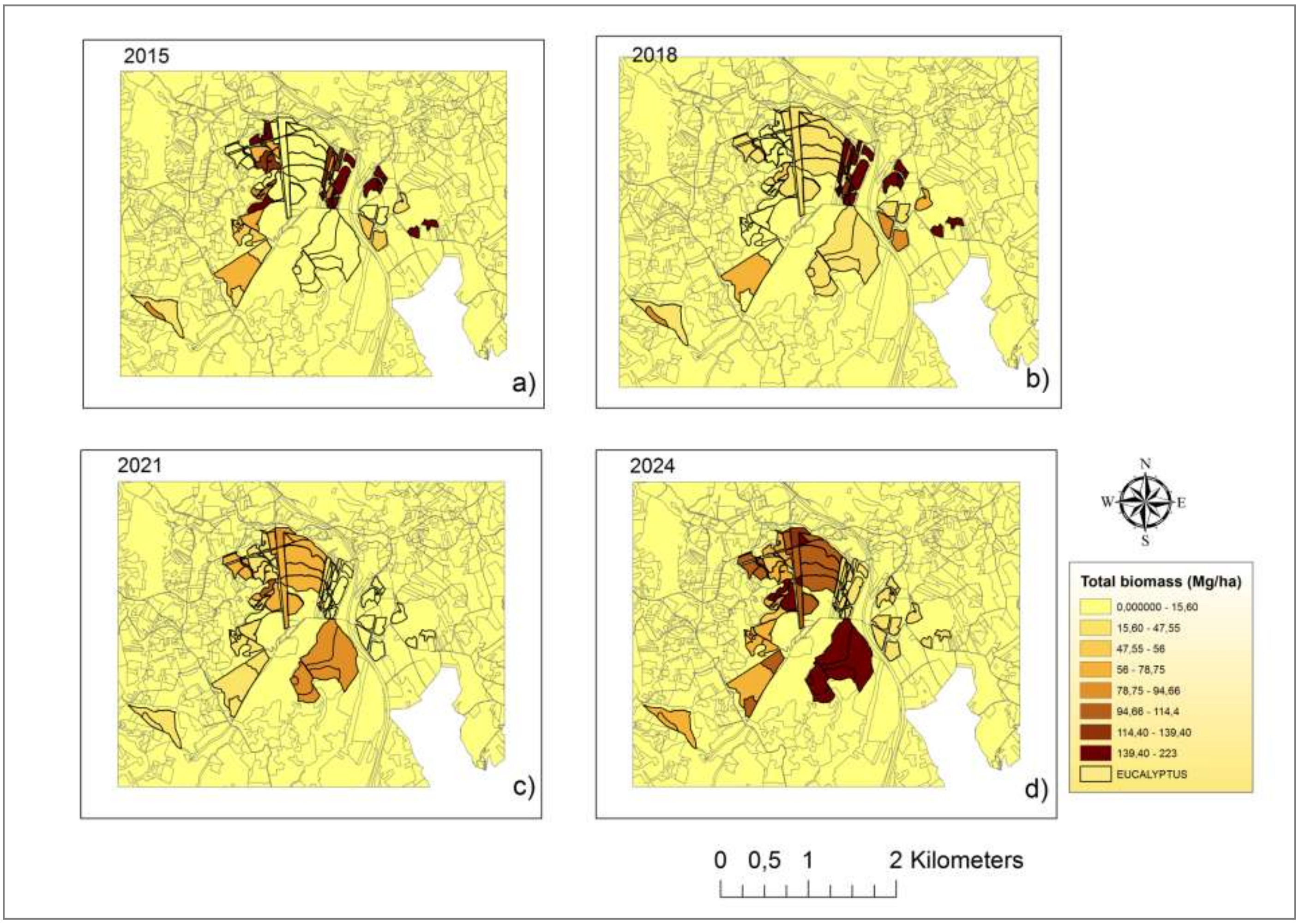
ID	Vmc15	Wt15	C_15	Vmc18	Wt18	C_18	Vmc21	Wt21	C_21	Vmc24	Wt24	C_24
1000	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1001	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1002	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1003	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1004	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1005	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1006	1,68	4,60	2,30	38,62	38,94	19,47	87,51	83,36	41,68	135,44	127,52	63,76
1007	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1008	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1009	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1010	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1011	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1012	56,86	44,71	22,36	0,00	0,53	0,27	59,54	45,72	22,86	138,83	102,12	51,06
1013	45,33	36,32	18,16	0,00	0,53	0,27	59,60	45,72	22,86	138,65	102,11	51,05
1014	84,13	78,76	39,38	84,13	78,75	39,38	39,11	31,96	15,98	80,20	61,17	30,59
1015	49,83	47,55	23,78	49,83	47,55	23,78	39,64	32,43	16,22	81,34	62,00	31,00
1016	94,36	88,00	44,00	94,36	88,00	44,00	42,38	34,85	17,43	86,90	66,27	33,14
1017	0,01	2,80	1,40	46,76	41,70	20,85	113,61	92,90	46,45	176,52	140,90	70,45
1018	0,01	2,80	1,40	46,76	41,70	20,85	113,61	92,90	46,45	176,52	140,90	70,45
1019	0,01	2,80	1,40	46,76	41,70	20,85	113,61	92,90	46,45	176,52	140,90	70,45
1020	164,56	154,56	77,28	223,70	207,42	103,71	5,65	6,98	3,49	35,11	28,29	14,15
1021	164,56	154,56	77,28	223,70	207,42	103,71	5,65	6,98	3,49	35,11	28,29	14,15
1022	164,56	154,56	77,28	223,70	207,42	103,71	5,65	6,98	3,49	35,11	28,29	14,15
1023	164,56	154,56	77,28	223,70	207,42	103,71	5,65	6,98	3,49	35,11	28,29	14,15
1024	41,03	42,28	21,14	68,49	65,49	32,75	5,71	7,25	3,63	36,26	29,36	14,68
1025	15,11	15,61	7,80	27,65	26,66	13,33	5,29	5,66	2,83	29,65	23,14	11,57

1026	10,05	11,02	5,51	19,80	19,55	9,78	5,51	6,43	3,21	32,77	26,10	13,05
1027	53,04	51,98	25,99	85,27	80,19	40,10	11,00	8,22	4,11	40,53	33,23	16,62
1028	164,56	154,56	77,28	223,70	207,42	103,71	5,65	6,98	3,49	35,11	28,29	14,15
1029	164,56	154,56	77,28	223,70	207,42	103,71	5,65	6,98	3,49	35,11	28,29	14,15
1030	55,50	53,60	26,80	87,40	81,50	40,75	5,81	7,63	3,82	37,93	30,89	15,45
1031	0,01	2,80	1,40	46,76	41,70	20,85	113,61	92,90	46,45	176,52	140,90	70,45
1032	0,01	2,80	1,40	46,76	41,70	20,85	113,61	92,90	46,45	176,52	140,90	70,45
1033	0,01	2,80	1,40	46,76	41,70	20,85	113,61	92,90	46,45	176,52	140,90	70,45
1034	135,86	127,19	63,60	189,84	175,31	87,66	5,80	37,65	18,83	7,57	30,64	15,32
1035	135,86	127,19	63,60	189,84	175,31	87,66	5,80	37,65	18,83	7,57	30,64	15,32
1036	100,97	75,72	37,86	146,50	108,26	54,13	5,80	7,57	3,79	37,65	30,64	15,32
1037	110,73	103,43	51,72	158,11		0,00	5,70	7,20	3,60	36,07	29,00	14,50
1038	100,97	75,72	37,86	146,50	108,26	54,13	5,80	7,57	3,79	37,65	30,64	15,32
1039	165,40	153,50	76,75	223,70	207,42	103,71	5,65	6,98	3,49	35,11	28,29	14,15
1040	110,73	103,43	51,72	158,11	146,13	73,06	5,70	7,20	3,60	36,07	29,00	14,50
1041	147,66	137,26	68,63	200,00	186,82	93,41	5,31	5,72	2,86	29,89	23,36	11,68
1042	110,73	103,43	51,72	158,11	146,13	73,06	5,70	7,20	3,60	36,07	29,00	14,50
1043	147,66	137,26	68,63	200,00	186,82	93,41	5,31	5,72	2,86	29,89	23,36	11,68
1044	165,40	153,50	76,75	223,70	207,42	103,71	5,65	6,98	3,49	35,11	28,29	14,15
1045	135,86	127,19	63,60	189,84	175,31	87,66	5,80	37,65	18,83	7,57	30,64	15,32
1046	147,66	137,26	68,63	200,00	186,82	93,41	5,31	5,72	2,86	29,89	23,36	11,68
1047	135,86	127,19	63,60	189,84	175,31	87,66	5,80	37,65	18,83	7,57	30,64	15,32
1048	135,86	127,19	63,60	189,84	175,31	87,66	5,80	37,65	18,83	7,57	30,64	15,32
1049	100,16	94,66	47,33	144,75	134,38	67,19	5,65	7,00	3,50	35,19	28,36	14,18
1050	100,16	94,66	47,33	144,75	134,38	67,19	5,65	7,00	3,50	35,19	28,36	14,18
1051	147,66	137,26	68,63	200,00	186,82	93,41	5,31	5,72	2,86	29,89	23,36	11,68
1052	100,16	94,66	47,33	144,75	134,38	67,19	5,65	7,00	3,50	35,19	28,36	14,18
1053	147,66	137,26	68,63	200,00	186,82	93,41	5,31	5,72	2,86	29,89	23,36	11,68
1054	147,66	137,26	68,63	200,00	186,82	93,41	5,31	5,72	2,86	29,89	23,36	11,68
1055	165,40	153,50	76,75	223,70	207,42	103,71	5,65	6,98	3,49	35,11	28,29	14,15

1056	135,86	127,19	63,60	189,84	175,31	87,66	5,80	37,65	18,83	7,57	30,64	15,32
1057	135,86	127,19	63,60	189,84	175,31	87,66	5,80	37,65	18,83	7,57	30,64	15,32
1058	135,86	127,19	63,60	189,84	175,31	87,66	5,80	37,65	18,83	7,57	30,64	15,32
1059	135,86	127,19	63,60	189,84	175,31	87,66	5,80	37,65	18,83	7,57	30,64	15,32
1060	165,40	153,50	76,75	223,70	207,42	103,71	5,65	6,98	3,49	35,11	28,29	14,15
1061	135,86	127,19	63,60	189,84	175,31	87,66	5,80	37,65	18,83	7,57	30,64	15,32
1062	165,40	153,50	76,75	223,70	207,42	103,71	5,65	6,98	3,49	35,11	28,29	14,15
1063	135,86	127,19	63,60	189,84	175,31	87,66	5,80	37,65	18,83	7,57	30,64	15,32
1064	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1065	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1066	217,93	160,18	80,09	6,22	7,64	3,82	37,72	30,46	15,23	76,58	58,22	29,11
1067	237,31	223,00	111,50	5,89	7,90	3,95	37,72	30,46	15,23	80,26	61,17	30,59
1068	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1069	92,49	69,46	34,73	5,67	6,09	3,05	31,29	24,54	12,27	75,57	57,42	28,71
1070	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1071	114,13	87,52	43,76	5,54	6,98	3,49	35,18	28,46	14,23	72,34	54,90	27,45
1072	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1073	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1074	95,14	72,05	36,03	6,00	7,00	3,50	35,00	27,90	13,95	71,10	53,84	26,92
1075	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1076	92,49	69,46	34,73	5,67	6,09	3,05	31,29	24,54	12,27	75,57	57,42	28,71
1077	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1078	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1079	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1080	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1081	188,49	139,40	69,70	6,20	7,50	3,75	37,48	30,25	15,13	76,11	57,85	28,93
1082	184,11	136,34	68,17	6,19	7,56	3,78	37,30	30,16	15,08	72,92	57,70	28,85
1083	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	118,53	111,02	55,51
1084	114,13	87,52	43,76	5,54	6,98	3,49	35,18	28,46	14,23	72,34	54,90	27,45
1085	5,53	8,78	4,39	59,68	54,97	27,49	117,54	110,38	55,19	174,18	162,77	81,39

1086	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	174,18	162,77	81,39
1087	153,17	114,40	57,20	6,17	7,50	3,75	37,20	30,00	15,00	75,54	57,40	28,70
1088	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	174,18	162,77	81,39
1089	110,52	84,25	42,13	6,00	7,78	3,89	38,44	31,23	15,62	78,46	59,73	29,87
1090	110,52	84,25	42,13	6,00	7,78	3,89	38,44	31,23	15,62	78,46	59,73	29,87
1091	199,30	146,90	73,45	6,08	7,20	3,60	6,08	7,50	3,75	73,20	55,53	27,77
1092	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	174,18	162,77	81,39
1093	92,49	69,46	34,73	6,17	7,52	3,76	31,29	24,54	12,27	75,57	57,42	28,71
1094	69,22	54,53	27,27	6,85	8,00	4,00	39,11	31,45	15,73	79,47	59,66	29,83
1095	69,22	54,53	27,27	6,85	8,00	4,00	39,11	31,45	15,73	79,47	59,66	29,83
1096	72,83	56,00	28,00	5,82	6,80	3,40	35,50	27,90	13,95	71,27	54,00	27,00
1097	72,83	56,00	28,00	6,20	7,53	3,77	37,22	30,00	15,00	75,53	57,39	28,70
1098	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	174,18	162,77	81,39
1099	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	174,18	162,77	81,39
1100	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	174,18	162,77	81,39
1101	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	174,18	162,77	81,39
1102	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	174,18	162,77	81,39
1103	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	174,18	162,77	81,39
1104	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	174,18	162,77	81,39
1105	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	174,18	162,77	81,39
1106	1,68	4,60	2,30	31,68	32,78	16,39	74,78	71,46	35,73	174,18	162,77	81,39
1107	56,86	44,71	22,36	0,00	0,53	0,27	59,54	45,72	22,86	138,83	102,12	51,06
1108	56,86	44,71	22,36	0,00	0,53	0,27	59,54	45,72	22,86	138,83	102,12	51,06
1109	45,33	36,32	18,16	0,00	0,53	0,27	59,60	45,72	22,86	138,65	102,11	51,05
1110	45,33	36,32	18,16	0,00	0,53	0,27	59,60	45,72	22,86	138,65	102,11	51,05

Annex 5– Total Biomass (Mg/ha)



Annex 8–Merchantable Timber volume (m^3/ha)