CATIE, Turrialba
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"Quantitative "risk smart" indicators to support management decisions of Portuguese forests on mitigating fire-hazard"

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SUMMARY:

INTRODUCTION

- Reviewing the evidence
- Objectives

MODELS & APPROACHES

- #1. Biomass accumulation under forest cover
- #2. Fire risk modeling
- #3. Fire damage modeling
- #4. Fire behaviour modeling
- #5. Optimizing time-scaling fuel treatments

TAKE HOME MESSAGES

ACKNOWLEGMENT

ForChange Forest Ecosystem Management under Global Change

CATIE
Solutions for environment and development
Soluciones para el ambiente y desarrollo

Introduction

I. Reviewing the evidence

I. BACKGROUND

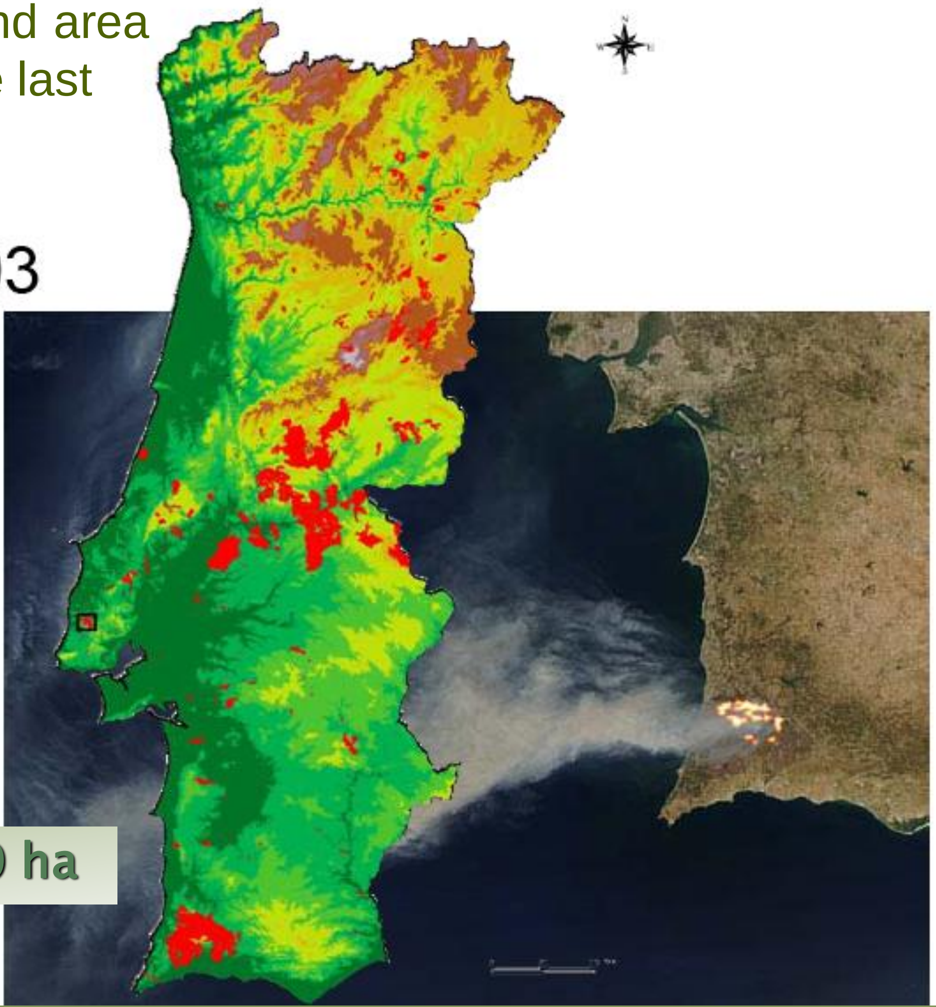
- Wilfires have a substantial impact on forest landscape composition and constrain the economic viability

- Understanding wildfire behavior first at stand-level and landscape-level is critical to address wildfire impacts in Portuguese forest management planning

I. BACKGROUND

- ☐ Increase in the no. and area fo forest fires over the last three decades

- Portugal 2003



425,000 ha

- ☐ Over 3.8 x 10^6 ha (40% of the country's territory was burned by wildfires)

Year 2016 = 155,000 ha

I. EVIDENCE

Five types of Fire regimes ("pyromes") at International level (1997-2010)

Current Issue > vol. 110 no. 16 > Sally Archibald, 6442–6447

Defining pyromes and global syndromes of fire regimes

Sally Archibald[a,b,1], Caroline E. R. Lehmann[c], Jose L. Gómez-Dans[d], and Ross A. Bradstock[e]

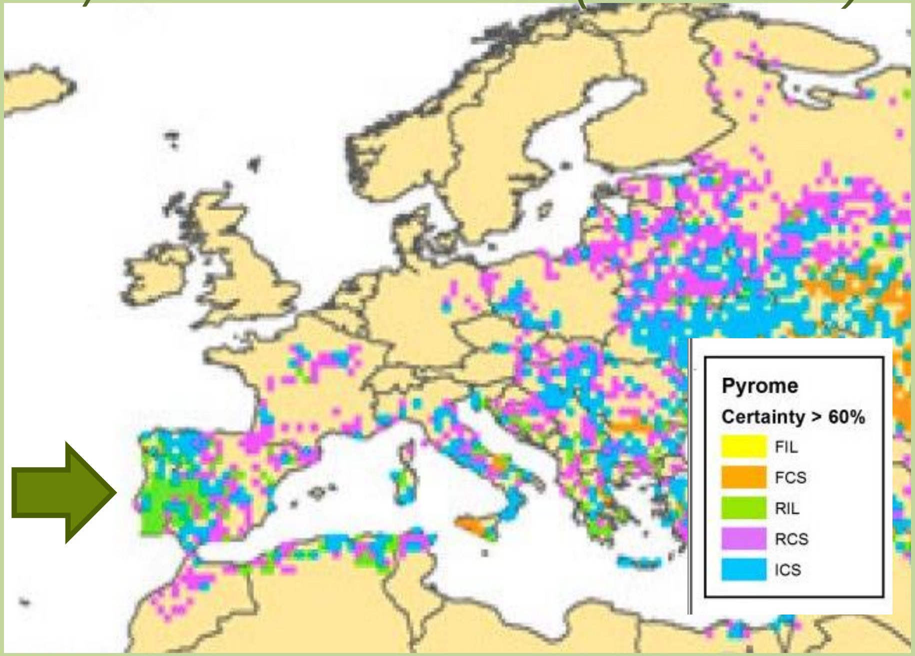
Author Affiliations

Edited by James T. Randerson, University of California, Irvine, CA, and accepted by the Editorial Board March 7, 2013 (received for review July 17, 2012)

Abstract

Fire is a ubiquitous component of the Earth system that is poorly understood. To date, a global-scale understanding of fire is largely limited to the annual extent of burning as detected by satellites. This is problematic because fire is multidimensional, and focus on a single metric belies its complexity and importance within the Earth system. To address this, we identified five key characteristics of fire regimes—size, frequency, intensity, season, and extent—and combined new and existing global datasets to represent each. We assessed how these global fire regime characteristics are related to patterns of climate, vegetation (biomes), and human activity. Cross-correlations demonstrate that only certain combinations of fire characteristics are possible, reflecting fundamental constraints in the types of fire regimes that can exist. A Bayesian clustering algorithm identified five global syndromes of fire regimes, or pyromes. Four pyromes represent distinctions between crown, litter, and grass-fueled fires, and the relationship of these to biomes and climate are not deterministic. Pyromes were partially discriminated on the basis of available moisture and rainfall seasonality. Human impacts also affected pyromes and are globally apparent as the driver of a fifth and unique pyrome that represents human-engineered modifications to fire characteristics. Differing biomes and climates may be represented within the same pyrome, implying that pathways of change in future fire regimes in response to changes in climate and human activity may be difficult to predict.

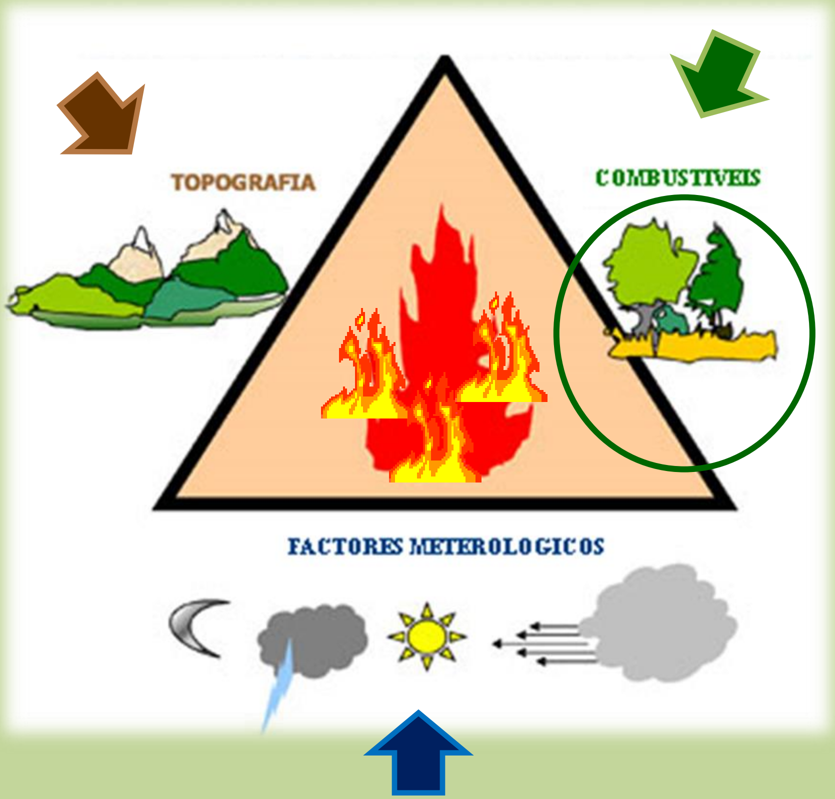
fire-climate-vegetation feedbacks | energetic constraints | fire intensity | fire return period | fire size



(http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3631631/)

- **RIL type [rare–intense–large]:** high-intensity, larger fires = Portugal **(Green)**

I. EVIDENCE



Three factors comprise the fire behavior triangle :

- the area’s topography
- weather conditions
- the amount of fuel

We can lower fire risk and wildfire damage by removing or reducing fuels in strategic locations…

I. MOTIVATION : AIMS ?

Advance of the state- of- the- art

Pro

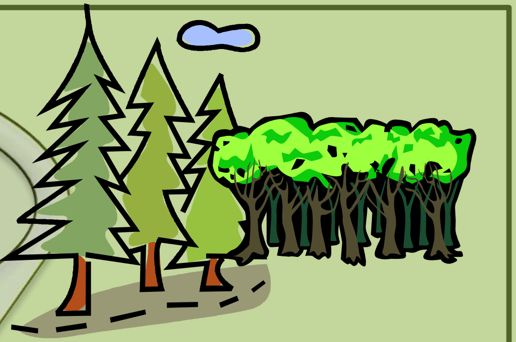
es

Fire Occurence

Stand structure

Fire effects

Fire behavior



Provide forest managers, policy makers with tools to support their decisions, and more effectively align management policies, plans, and practices across fire-prone landscapes

II. Objectives

I. A model of shrub biomass accumulation as a tool to support management of Portuguese forests

II. Developing wildfire risk probability models for *Eucalyptus globulus* stands in Portugal

III. Modelling post-fire damage and tree mortality in forest stands in Portugal. A forest planning-oriented model

Phase I | Portugal mainland

II. Objectives

IV. Coupling fire behaviour modelling and stand characteristics to assess and mitigate fire hazard in Portuguese Forest

V. Optimizing time-scaling fuel treatments in eucalyptus plantation in Portugal

Phase II: specific case studies

Biomass accumulation

I. A model of shrub biomass accumulation under tree cover

2.1| Shrub biomass accumulation under forest cover

Research Article - doi: 10.3832/ifor0931-008 ©iForest - Biogeosciences and Forestry

A model of shrub biomass accumulation as a tool to support management of Portuguese forests

Brigite Botequim (1), Ane Zubizarreta-Gerendiain (1-2), Jordi Garcia-Gonzalo (1), Andreia Silva (1), Susete Marques (1), Paulo M Fernandes (3), José MC Pereira (1), Margarida Tomé (1)

Assessment of forest fuel loading is a prerequisite for most fire management activities. However, the inclusion of shrub biomass in forest planning has been hindered by the inability to predict its growth and accumulation. The main objective of this study was to model shrub biomass over time under a tree canopy with the aim of including shrub management in fire risk mitigation plans. To this purpose, data was obtained from the 4th and 5th Portuguese National Forest Inventories. Five biologically realistic models were built to describe shrub biomass accumulation in Portuguese forests. The selected model indicates that maximum biomass is affected by stand basal area and the percentage of re-sprouting shrub species in the stand. Biomass growth rate was clearly affected by the regeneration strategies of shrubs in combination with climatic conditions (mean annual temperature). The model can be used in the accumulation form for initialization purposes or in one of the two alternative difference forms to project observed shrub biomass. The model proposed in this study facilitates the inclusion of shrub biomass in forest growth simulations, and will contribute to more accurate estimates of fire behavior characteristics and stored carbon. This is essential to improve decision-making in forest management plans that integrate fire risk, namely to schedule understory fuel treatments.

Keywords: Shrub Growth, Understory Vegetation, Wildfire Risk, Fire Management, Forest Planning, Decision Making

describe fuel and shrub dynamics by time-dependent models of forest fire hazard (Gould et al. 2011). However, shrub biomass accumulation information for Mediterranean areas is very limited. Few studies addressed the temporal dynamics of shrub structure and/or biomass in shrublands (Baeza et al. 2006), which are expected to be different under a forest canopy, due to competition for resources (*i.e.*, light, water). Hence, little attention has been given to understory vegetation, likely due to its limited economic importance. Nonetheless, the ecological significance of the understory is high, since it plays an important role on nutrient cycles, carbon storage and fire hazard.

Currently available carbon models still lack details on biomass dynamics, which in turn affect the calculation of these processes. A recent study by Rosa et al. (2011) to estimate pyrogenic emissions of greenhouse gases, aerosols and other trace gases from wildfires in Portugal identified shrub biomass as the variable with the greatest impact on the uncertainty inherent in such estimates. Therefore, it is essential to improve the assessment of forest biomass, including its spatial and temporal variation.

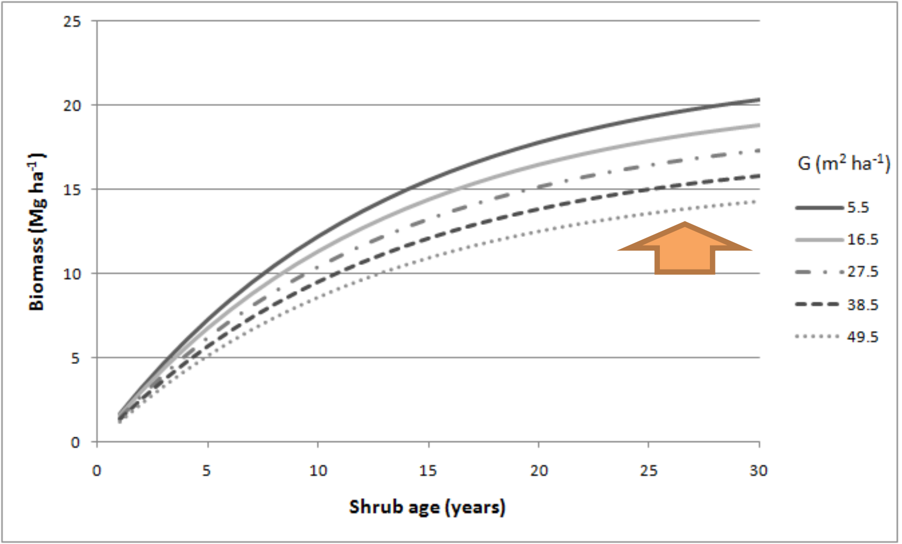
In the Mediterranean region, fire is one of the most important factors affecting forest ecosystems, both ecologically and economically (Pereira & Santos 2003). Higher shrub loading implies higher flammability, likelihood of crowning fire, and difficulty in fire control (Schmidt et al. 2002, Fernandes 2009a). Fernandes et al. (2004) observed dif-

1995-1998 NFI :102 stands
2005-2006 NFI : 319 stands

Espécies arbustivas	**4th NFI (%)**	**5th NFI (%)**
Arbutus unedo	**2**	**4.4**
Cistus ladanifer	**4.9**	**18.2**
Cistus salvifolius	**3.9**	**7.2**
Cytisus spp.	**15.7**	**16**
Dittrichia viscosa	**-**	**0.3**
Erica spp.	**26.5**	**21.4**
Lavandula spp.	**1.9**	**0.9**
Pistacia lentiscus	**-**	**0.3**
Others	**10.8**	**2.2**
Pterospartum tridentatum	**9.8**	**9.1**
Pyrus spp.	**-**	**0.3**
Rubus spp.	**2**	**4.7**
Ulex spp.	**22.5**	**15**

2.2| Shrub biomass accumulation under forest cover

$$W =(32.72 - 0.239 * resp-0.1528 * G) * (1-\exp^{(-(0.00108 * resp+0.00249 * T)*t)})$$



- higher values of G and percentage of resprouters, the total amount of shrub biomass decreased

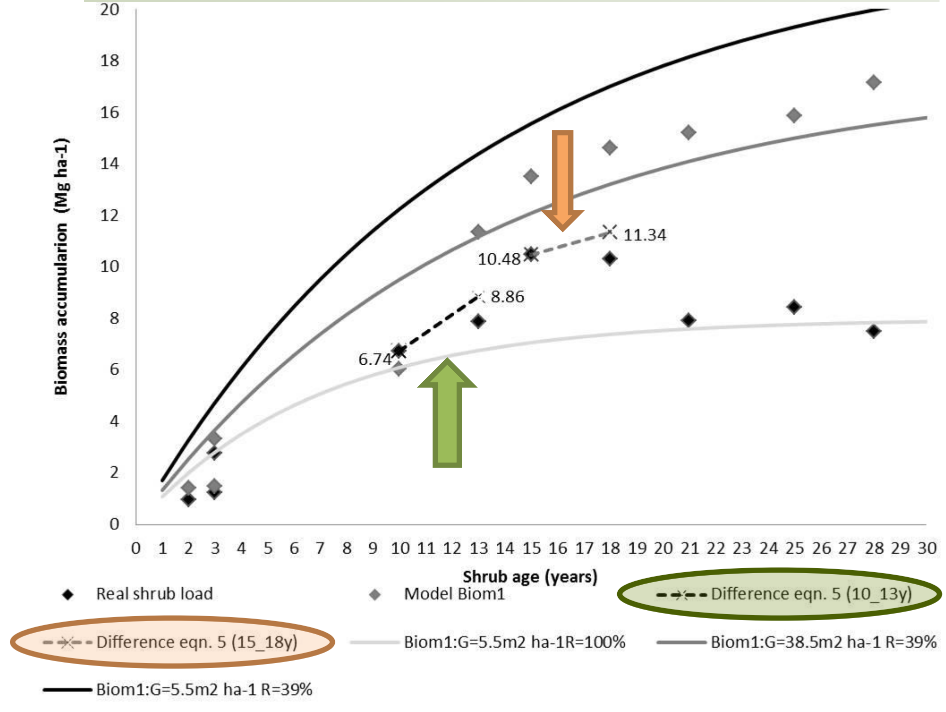
Variables descriptions

- ***W*** : shrub biomass (Mg ha^{-1});
- ***Resp*** : resprout percentage (%);
- ***G*** : stand basal area (m^2 ha^{-1});
- ***T***: annual mean temperature (ºC);
- ***t***: shrub age
  - *numbers of years between the occurrence of the last fire or the plantation of stand and the inventory measurement*

2.3| Shrub biomass accumulation under forest cover

$$\mathrm{Bio}_2 = \mathrm{Bio}_1 \frac{(32.72 - 0.239\,\mathrm{resp} - 0.1528\,G_2)\left(1 - \mathrm{e}^{(-(0.00108\,\mathrm{resp}+0.00249\,\mathrm{T})\,t_2}\right)}{(32.72 - 0.239\,\mathrm{resp} - 0.1528\,G_1)\left(1 - \mathrm{e}^{(-(0.00108\,\mathrm{resp}+0.00249\,\mathrm{T})\,t_1}\right)}$$

Difference equation form: Application

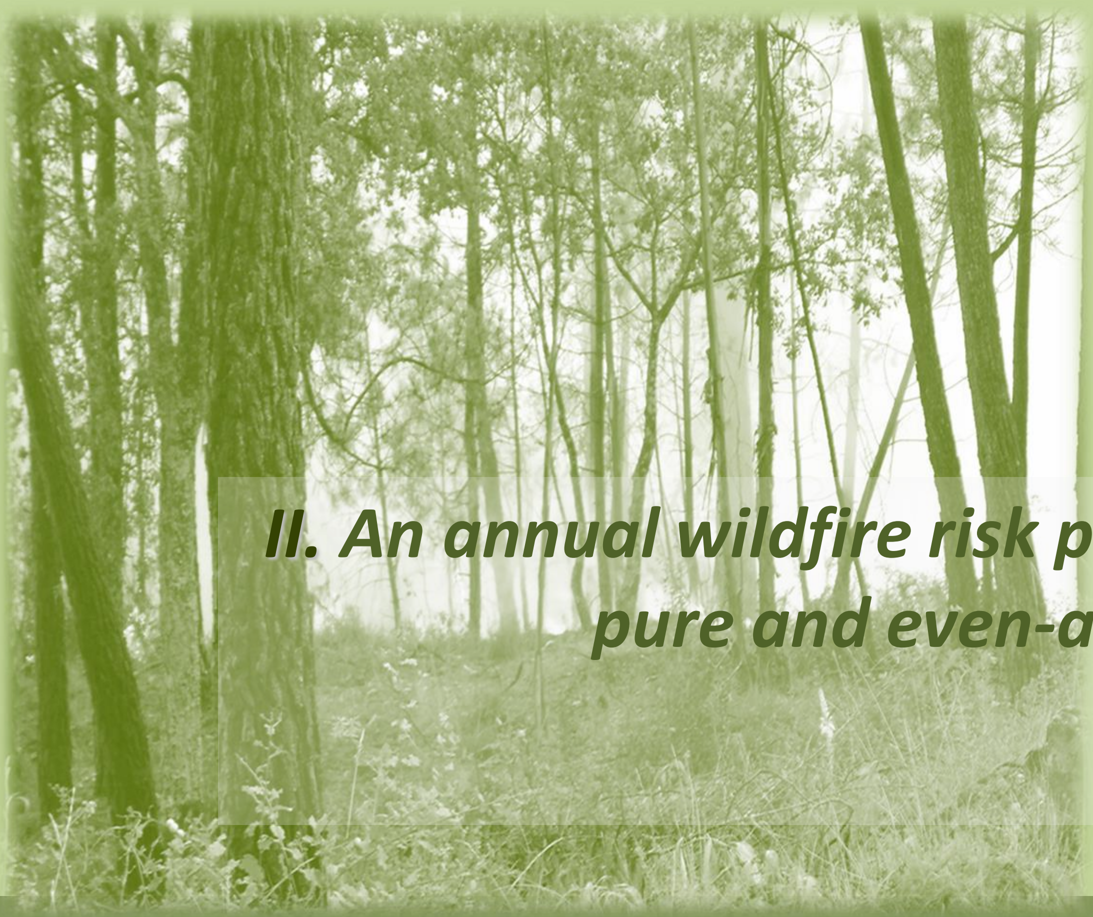


when age at time t_1 is known

Variables descriptions

- ***Bio_1, Bio_2*** : shrub biomass at times t_1 and t_2(Mg ha^{-1});
- ***Resp*** : resprout percentage (%);
- ***G_1, G_2*** : stand basal area (m^2 ha^{-1}) at t_1 and t_2(Mg ha^{-1});
- ***slope*** (%);
- ***T***: mean annual temperature (ºC);

Fire Risk

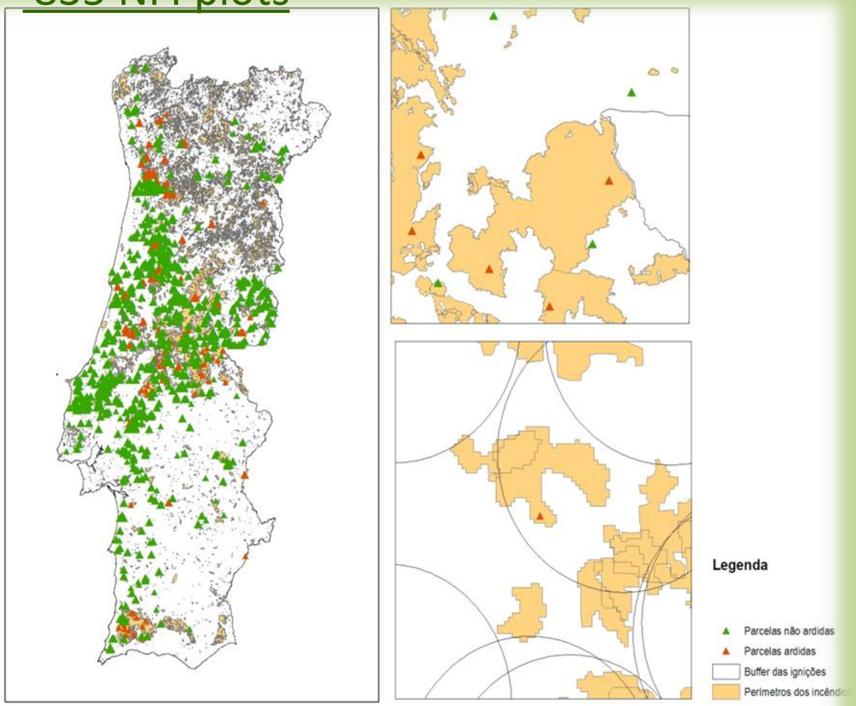


II. An annual wildfire risk probability model for pure and even-aged eucalypt stands

3.1| Probability of wildfire risk occurence

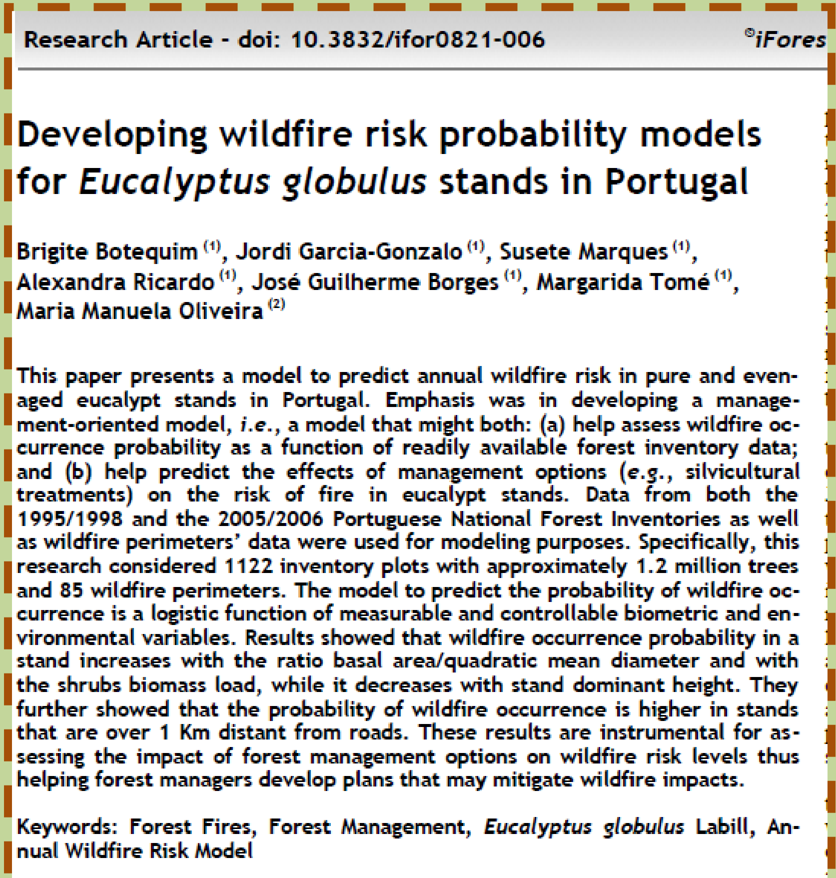
Pure and even–aged eucalypt stands

835 NFI plots



Sub-set Burnt Plots (red): 107

Stand-scale level information


Research Article - doi: 10.3832/ifor0821-006 ©iFores

Developing wildfire risk probability models for *Eucalyptus globulus* stands in Portugal

Brigite Botequim (1), Jordi Garcia-Gonzalo (1), Susete Marques (1), Alexandra Ricardo (1), José Guilherme Borges (1), Margarida Tomé (1), Maria Manuela Oliveira (2)

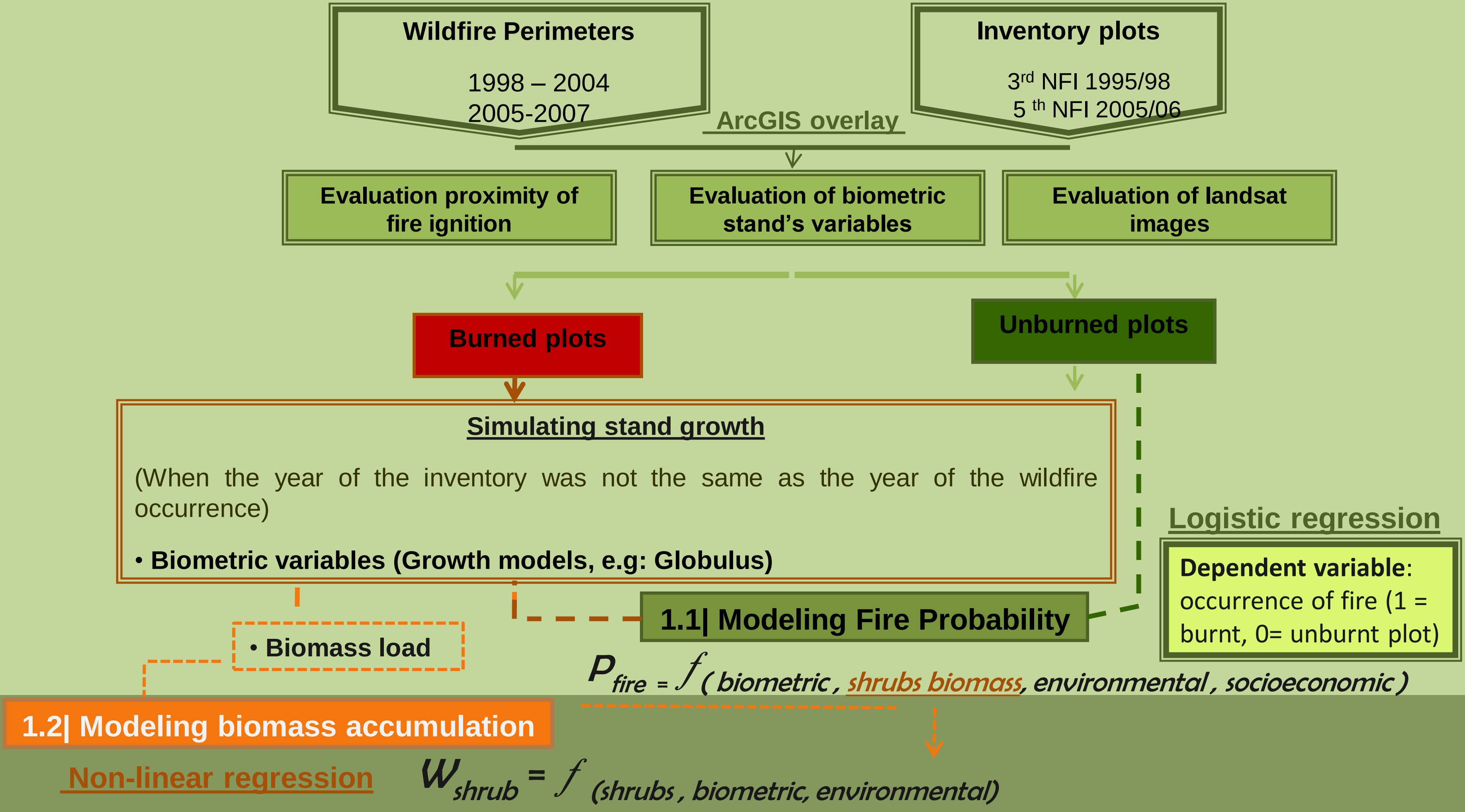
This paper presents a model to predict annual wildfire risk in pure and even-aged eucalypt stands in Portugal. Emphasis was in developing a management-oriented model, *i.e.*, a model that might both: (a) help assess wildfire occurrence probability as a function of readily available forest inventory data; and (b) help predict the effects of management options (*e.g.*, silvicultural treatments) on the risk of fire in eucalypt stands. Data from both the 1995/1998 and the 2005/2006 Portuguese National Forest Inventories as well as wildfire perimeters' data were used for modeling purposes. Specifically, this research considered 1122 inventory plots with approximately 1.2 million trees and 85 wildfire perimeters. The model to predict the probability of wildfire occurrence is a logistic function of measurable and controllable biometric and environmental variables. Results showed that wildfire occurrence probability in a stand increases with the ratio basal area/quadratic mean diameter and with the shrubs biomass load, while it decreases with stand dominant height. They further showed that the probability of wildfire occurrence is higher in stands that are over 1 Km distant from roads. These results are instrumental for assessing the impact of forest management options on wildfire risk levels thus helping forest managers develop plans that may mitigate wildfire impacts.

Keywords: Forest Fires, Forest Management, *Eucalyptus globulus* Labill, Annual Wildfire Risk Model

Fire perimeters > 5 ha during two periods (1997 – 2004 and 2005 – 2007)

3.2| Probability of wildfire risk occurence

Stand-scale level information



Wildfire Perimeters

1998 – 2004
2005-2007

Inventory plots

3rd NFI 1995/98
5 th NFI 2005/06

ArcGIS overlay

Evaluation proximity of fire ignition

Evaluation of biometric stand's variables

Evaluation of landsat images

Burned plots

Unburned plots

Simulating stand growth

(When the year of the inventory was not the same as the year of the wildfire occurrence)

- **Biometric variables (Growth models, e.g: Globulus)**

- **Biomass load**

1.1| Modeling Fire Probability

Logistic regression

Dependent variable: occurrence of fire (1 = burnt, 0= unburnt plot)

$$P_{fire} = f(\text{biometric}, \underline{\text{shrubs biomass}}, \text{environmental}, \text{socioeconomic})$$

1.2| Modeling biomass accumulation

Non-linear regression

$$W_{shrub} = f(\text{shrubs}, \text{biometric}, \text{environmental})$$

3.3| Probability of wildfire risk occurence

Annual Probability of wilfire occurency

(PROC Logistic, SAS 9.1)

Botequim et al. 2013

$$PburnEc = \frac{1}{1+e^{-(-5.4005-0.0540Hdom+0.3166G/dg+0.3959Biomass+0.5372RoadDist)}}$$

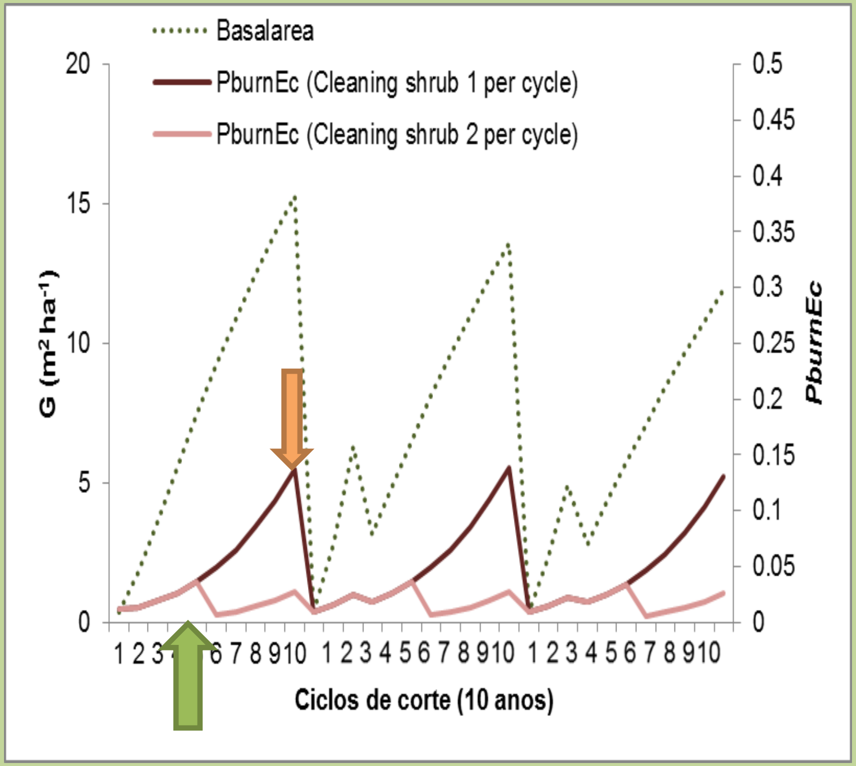
$$\begin{cases} RoadDist = 0 & If \quad \text{RoadDistance} < 1km \\ RoadDist = 1 & If \quad \text{RoadDistance} > 1km \end{cases}$$

- **easily obtainable by forest inventories or forest simulators**

- stands with **higher density (*G/dg*) especially in stands with low quadratic mean diameter (i.e. higher G/dg)** are in general more prone to burn. Yet this further depends on the tree sizes;
- **shrub biomass *(Biomass)*** was the most important variable affecting the probability of wildfire occurrence ($p<0.0001$);
- **larger distances to the road *(RoadDist)*** network lead to an increase of the probability of fire occurrence;
- the **increase of stand dominant height *(hdom)*** decreases this probability

3.4| Probability of wildfire risk occurence

Eucalypt stands: Application



- Altitude: 217 m
- Slope: 11.5º
- Annual precipitation: 650mm
- Shrubs biomass: 50% resprouters
- 1250 trees
- Cutting cycles: 10 years
- Rotation (n): 3
- Cleanning : 1 or 2 per rotation

The annual fire occurence probability in a pure even-aged eucalypt stand ranged from:

➢**0% e 0.2%** if cleaned once in every cutting cycle

➢**0 % a 0.04%** if fuel treatments are prescribed to occur twice every cutting cycle

Fire effects

III. A post-fire model at stand level and the individual tree survival probability to mitigate damage in any forest stand structure

4.1 | Fire damage models

- **Management-oriented post-fire mortality stand-level models**

sustainability

MDPI

Article

Modelling post-fire damage and tree mortality in pure and mixed forest stands in Portugal - A forest planning-oriented model.

Brigite Botequim [1*], Jordi Garcia-Gonzalo [1,2], Andreia Silva [1], Susete Marques [1], José G. Borges [1], Maria Manuela Oliveira [3], and Margarida Tomé [1]

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Academic Editor: name
Received: date; Accepted: date; Published: date

Abstract: Assessing the impacts of management strategies may allow designing less risky forests to wildfires. This is the first attempt to develop a planning-oriented model to predict the effect of stand structure and forest composition on the expected mortality for supporting fire-smart management decisions in Portugal. Post-fire mortality was modeled as a function of measurable forest inventory data and/or projections over time (165 pure and 76 mixed forest stands, 2520 individual trees, 16 species), collected by the 5th National Forest Inventory plots (NFI) plus other sample plots from ForFireS project, and intercepted within 2006–2008 wildfire perimeters' data.

Post fire inventory considered

ForFireS Ficha da parcela

ForFireS Ficha das árvores

FICHA DAS ÁRVORES

Campo da ficha das árvores: 5

Código	Espécie ou grupo de espécies
100	*Quercus* de folhas caducas
200	*Quercus ilex*
300	*Quercus suber*
400	*Fagus sylvatica*
500	*Castanea sativa*
600	*Betula sp.*
700	*Fraxinus sp.*
800	*Populus sp.*
900	*Eucalyptus sp.*
1000	Outras folhosas (susceptíveis de atingir uma altura de 5 m)
1100	*Pinus pinaster*
1200	*Pinus sylvestris*
1300	*Pinus nigra*
1400	*Pinus pinea*
1500	*Pinus halepensis*
1550	*Pinus radiata*
1600	*Abies sp.*
1700	*Picea sp.*
1800	*Cedrus sp.*
1900	Outras coníferas (susceptíveis de atingir uma altura de 5 m)

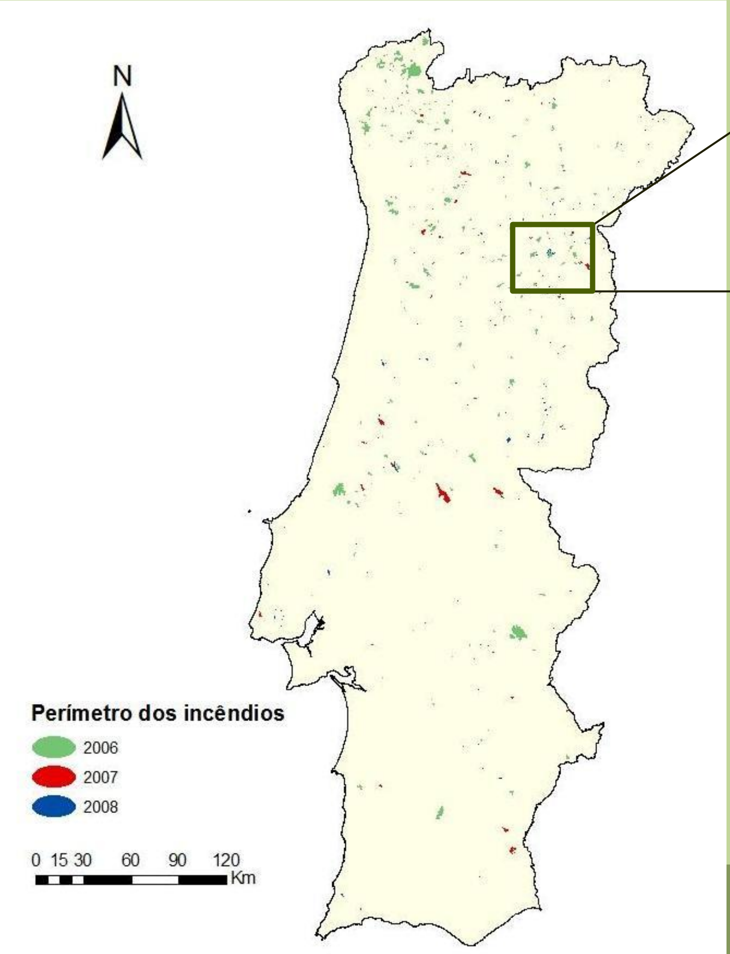
- measurement of biometric variables
- Measureme[illegible] of fire effe[illegible] characteristics
  - degree [illegible] [illegible]uction
  - burne[illegible] [illegible]
  - burned canopy height

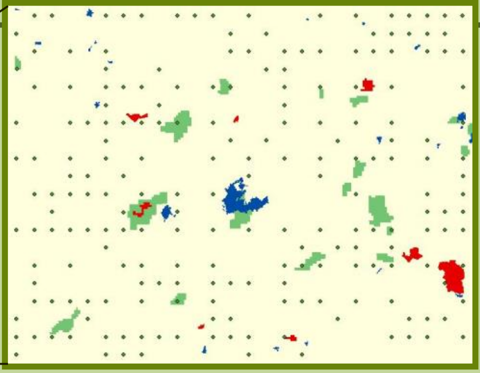
Burnt plots: burnt stump ***(a)****; burnt Pinus pinaster stands (***b***)*

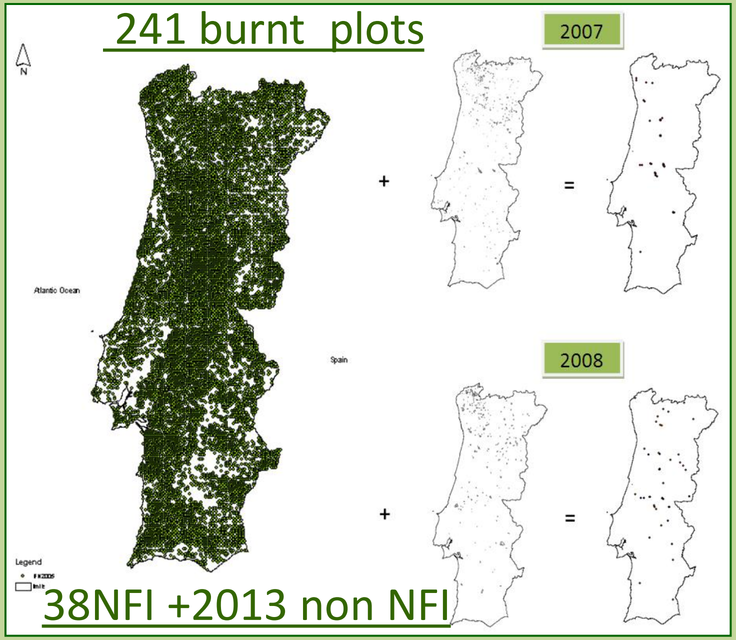
Burnt plots: pine stand burnt with low severity ***(c)****; high severity damage in a pinus stand* ***(d)****.*

4.2|Fire damage models

Fire perimeters >5ha in the period 2006-2008





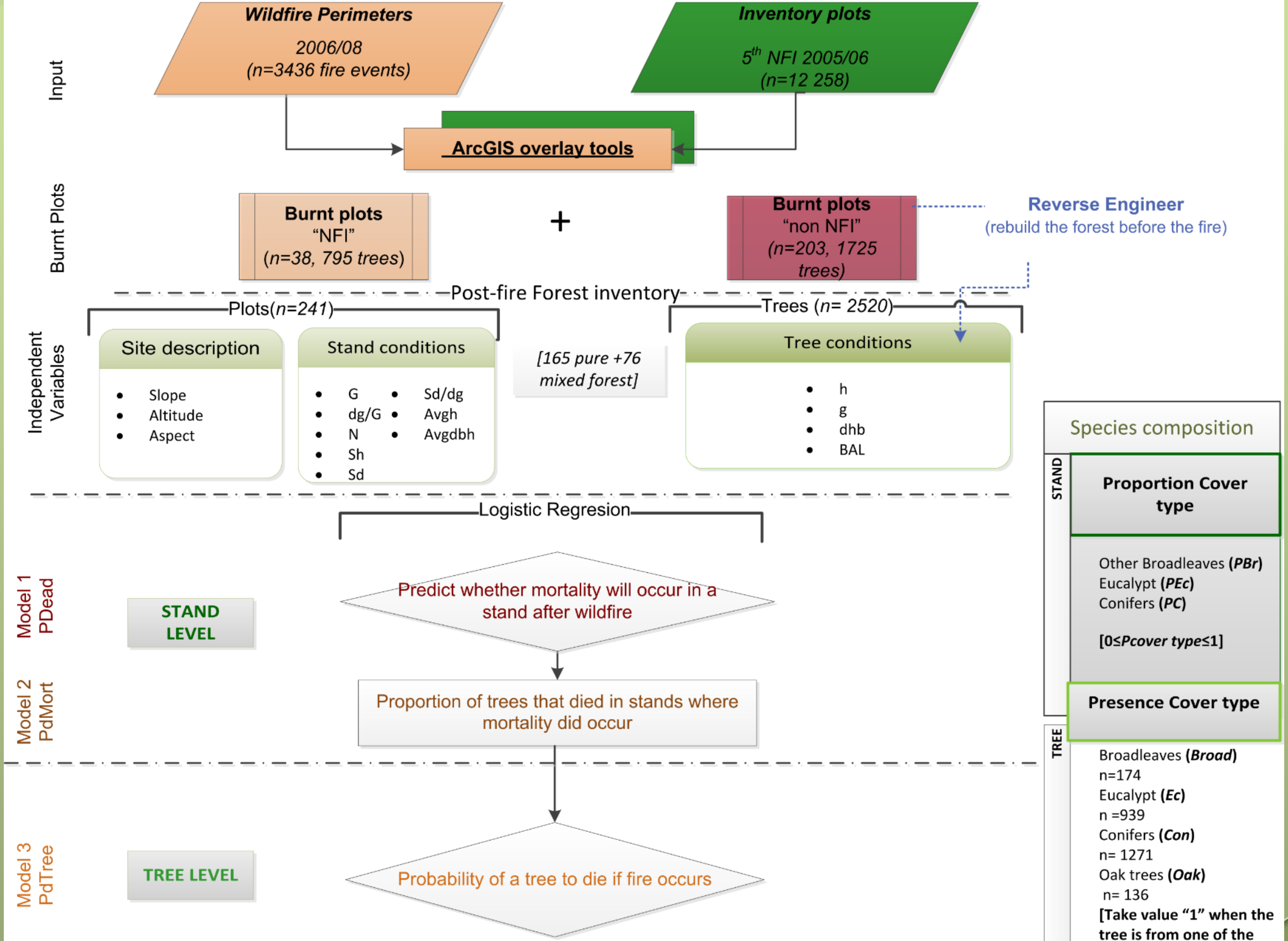


241 burnt plots

38NFI +2013 non NFI

Inventoried trees = 2520 (1905 dead trees)

4.3|Fire damage models



Input

Wildfire Perimeters

2006/08
(n=3436 fire events)

Inventory plots

5th NFI 2005/06
(n=12 258)

ArcGIS overlay tools

Burnt Plots

Burnt plots
"NFI"
(*n=38, 795 trees*)

+

Burnt plots
"non NFI"
(n=203, 1725 trees)

Reverse Engineer
(rebuild the forest before the fire)

Post-fire Forest inventory

Plots(*n=241*)

Trees (*n= 2520*)

Independent Variables

Site description

- Slope
- Altitude
- Aspect

Stand conditions

- G
- dg/G
- N
- Sh
- Sd
- Sd/dg
- Avgh
- Avgdbh

[165 pure +76 mixed forest]

Tree conditions

- h
- g
- dhb
- BAL

Species composition

STAND

Proportion Cover type

Other Broadleaves ***(PBr)***
Eucalypt ***(PEc)***
Conifers ***(PC)***

[0≤*Pcover type*≤1]

TREE

Presence Cover type

Broadleaves ***(Broad)***
n=174
Eucalypt ***(Ec)***
n =939
Conifers ***(Con)***
n= 1271
Oak trees ***(Oak)***
n= 136
[Take value "1" when the tree is from one of the cover types]

Logistic Regresion

Model 1 PDead

STAND LEVEL

Predict whether mortality will occur in a stand after wildfire

Model 2 PdMort

Proportion of trees that died in stands where mortality did occur

Model 3 PdTree

TREE LEVEL

Probability of a tree to die if fire occurs

three-step modelling strategy (Logistic Regression)

4.4|Calculate the impact of wildfires

Management-oriented post-fire mortality stand-level models

#1. Predict whether mortality will occur in a **stand** after wildfire

$$Psd = \frac{1}{1+e^{-(-0{,}7882+1{,}1079.PBr+2{,}1698.PC-0{,}5553.G+4{,}328.\frac{G}{dq}+3{,}2549.\frac{Sd}{dq})}}$$

#2. Proportion of trees that died in **stands** where mortality did occur **(0≤*Pr*≥1)**

$$PMort = \frac{1}{1+e^{-(0{,}3579-0{,}1361.PEc-1{,}3872.PBr+0{,}0525.Slope+0{,}0017.Alt+0{,}0393.AVGdbh)}}$$

Management-oriented post-fire mortality tree-level

#3. Probability of a **tree** to die if fire occurs

$$PdTree2 = \frac{1}{1+e^{-(1{,}5896+1{,}1315.Con+0{,}6714.Ec-0{,}9362.Oak+0{,}0128.Slope-0{,}0679.h-0{,}0846.G+0{,}000697.N)}}$$

4.5|Calculate the impact of wildfires

Variables descriptions

- **0 ≤ *Pcover type* ≤1**, proportion of cover type in the stand

PBr : proportion of broadleaves ("0" indicating no presence and "1" indicating that stand is purely occupied by broadleaves

PEc : proportion of eucalypt

PC : proportion of conifers

The predictor *G/dg* is non-linearly related to the number of trees per hectare

G: basal area (m^2 ha^{-1}); ***dg*** : quadratic mean diameter of trees (cm)

N: number of trees per hectare

The predictor *Sd/dg* expresses the relative variability of tree diameters

- ***sd*** : the standard deviation of trees' diameters at breast height (cm)
- ***AVGdbh*** the mean tree diameter at breast height of the stand (cm)
- ***Alt***: altitude (m); ***Slope*** : declive (º)

[tree level]

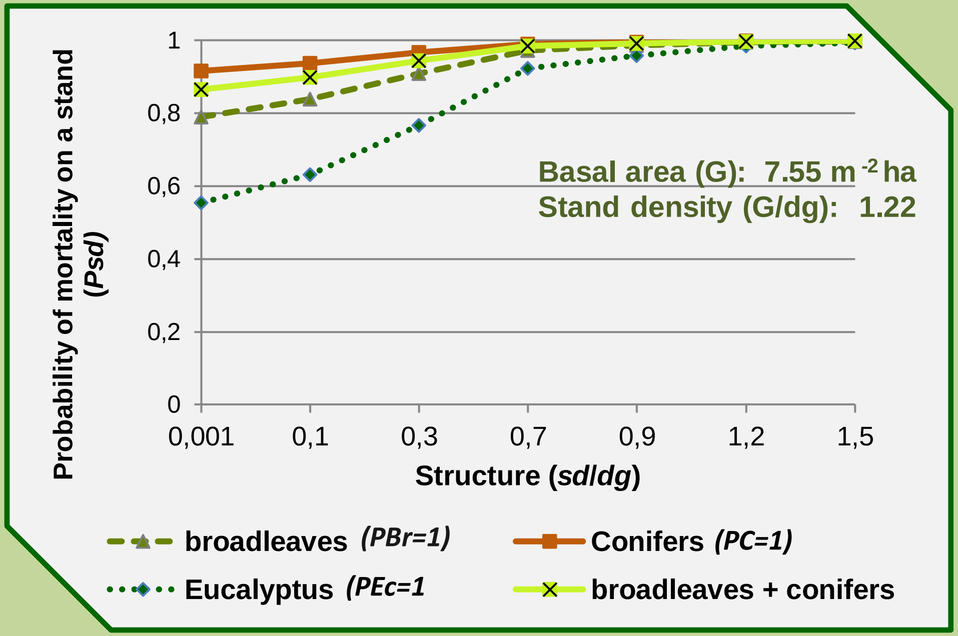
Broad, Con, Ec, Oak **: dummy variable to identify presence of cover type** (Take value "1" when the tree is from one of the cover types)

4.6|Calculate the impact of wildfires

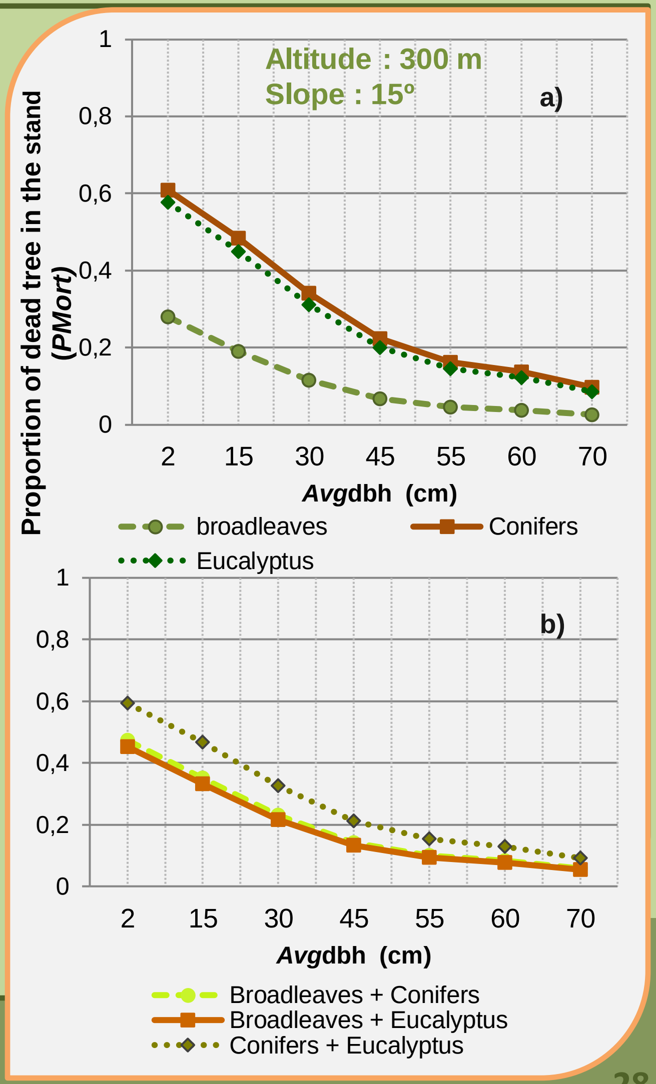
Stand – level models : Application

Step I – Stand level

- The probability of death to occur is smaller in Eucalypt stands and higher in conifer stands when compared to the broadleaves For a stand located:



- Pure stands of broadleaves exhibits a noticeably higher fire resistance than mixed stands of broadleaves and others species composition.

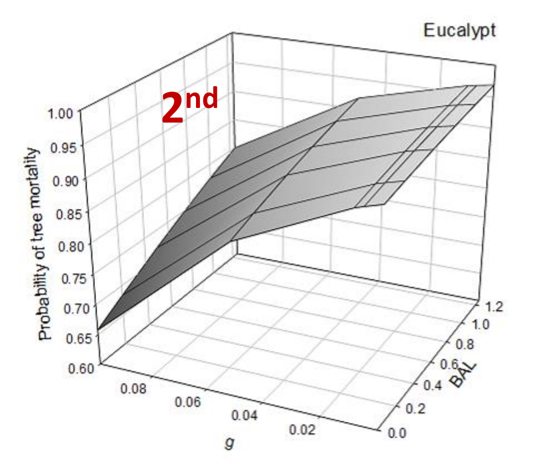


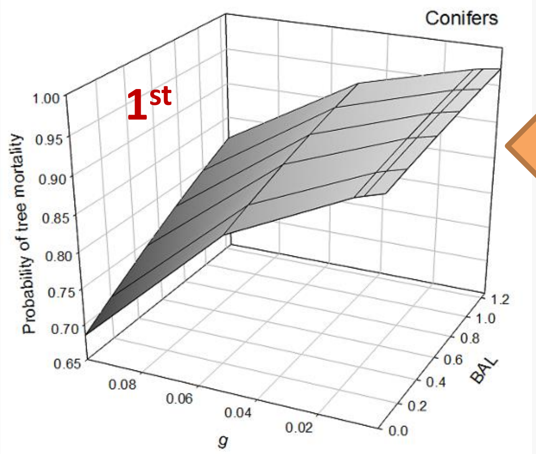
Step II– Stand level

4.7|Calculate the impact of wildfires

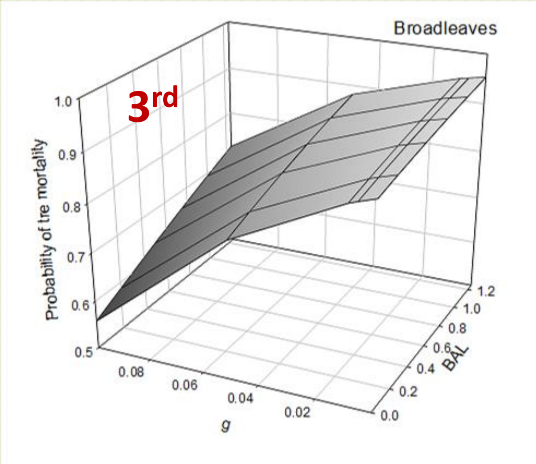
Tree– level model : Application

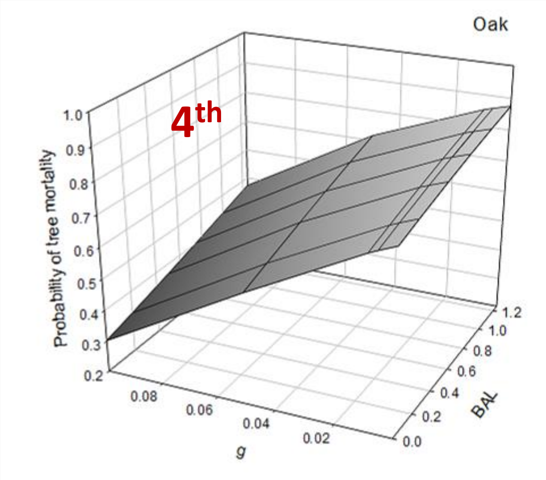
Step III – Tree level





less resistant

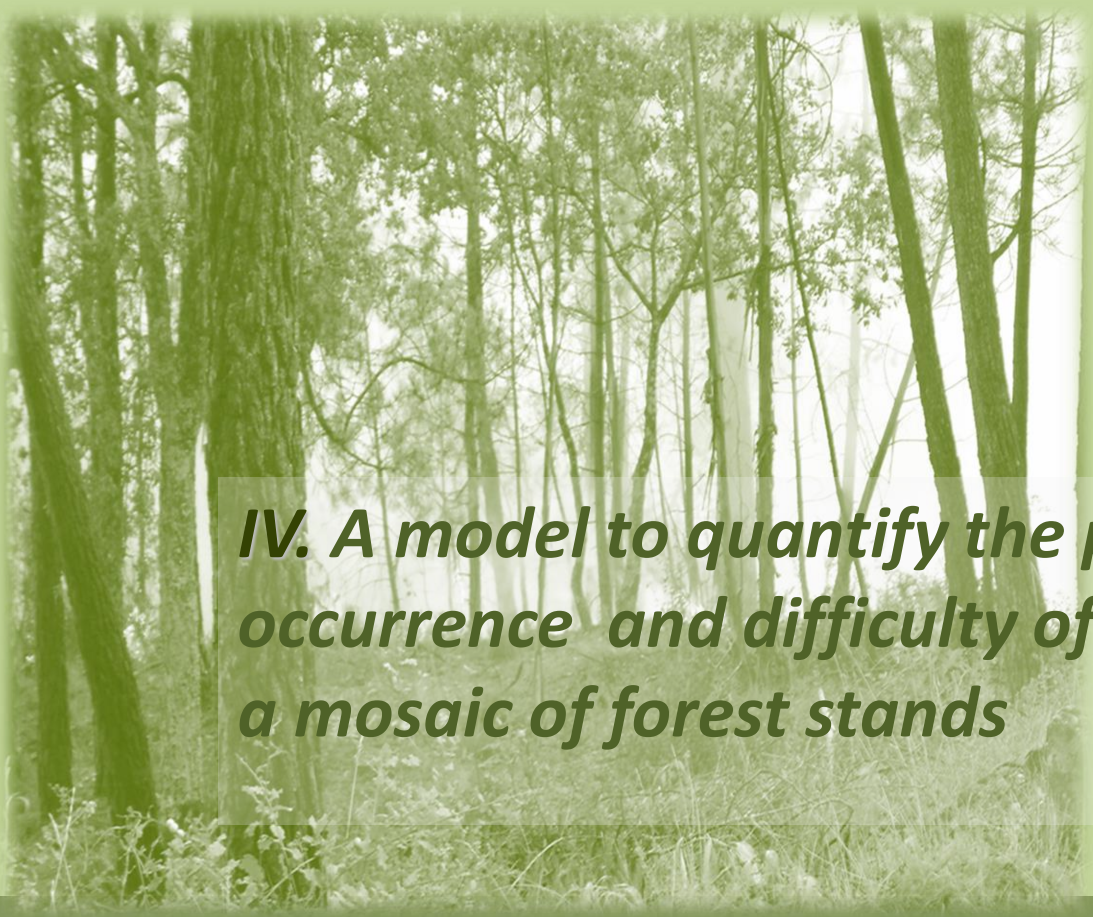




Most resistant

- Trees with **higher BAL** and **less basal** area are more prone to die if a wildfire occurs

Fire Behavior



IV. A model to quantify the potential crown fire occurrence and difficulty of fire suppression for a mosaic of forest stands

5.1|Fire Behaviour Models

Vale de sousa (Vsousa)

- ❑ A mixed Forest with multiple non-industrial private forest owners in the North
  - *Q. suber, Q. robur, Q. faginea, Fagus sylvatica, P.pinaster, P. pinea, E. globulus*
  - (12308 ha)

Mata Nacional de Leiria (MNL)

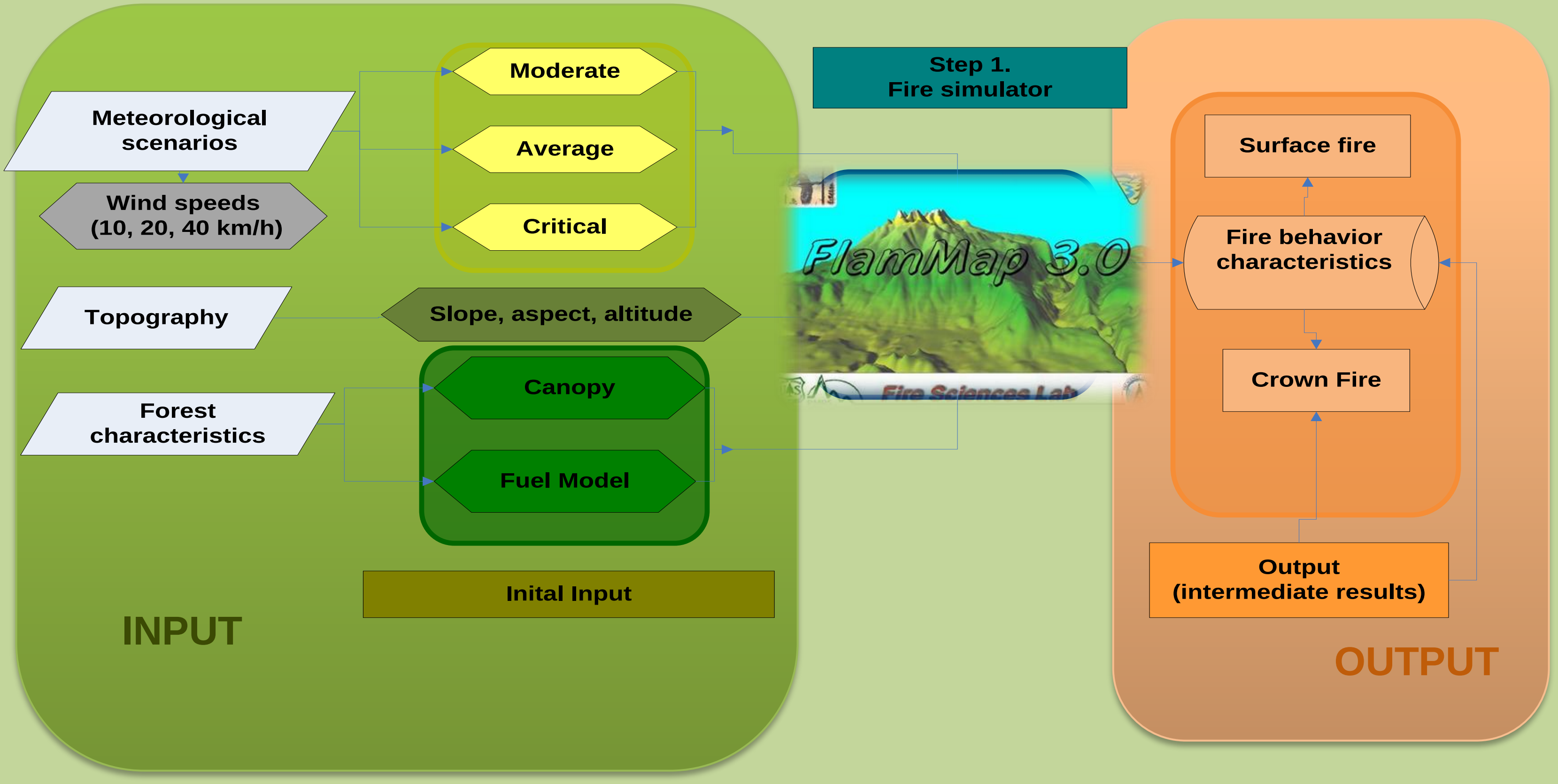
- ❑ A maritime pine public forest in the Centre
  - *Pinus pinaster* Ait (10 881 ha)

"Globland Area" (Glob)

- ❑ A group of pulp mills' properties where eucalypt is predominant
  - *Eucaliptus globulus* (11882 ha)

Biometric variables from 2504 inventories plots

5.2| Compute Fire Behavior



Meteorological scenarios

Wind speeds (10, 20, 40 km/h)

Moderate

Average

Critical

Topography

Slope, aspect, altitude

Forest characteristics

Canopy

Fuel Model

Inital Input

INPUT

Step 1.
Fire simulator

Surface fire

Fire behavior characteristics

Crown Fire

Output (intermediate results)

OUTPUT

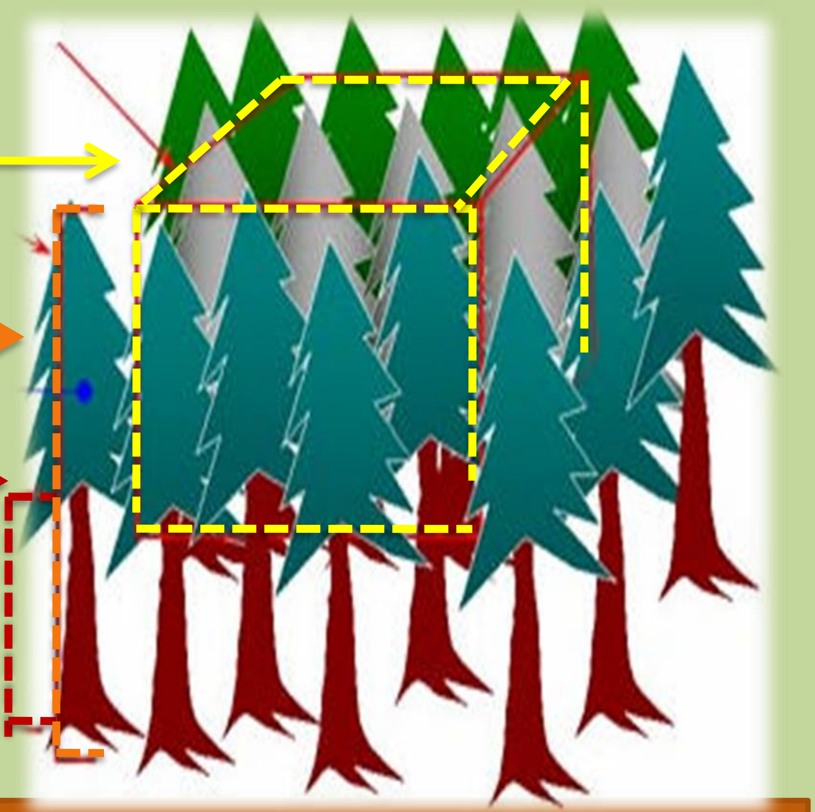
5.3|Vegetation data

Area	Fuel Model	Description	References
MNL	PPIN-05	Mature P.pinaster plantation	**Cruz , M. 2005**
	F-PIN	Pinus pinaster litter	**Fernandes *et al.*, 2009**
	M-PIN	P. pinaster litter and understorey	
	V-MAb	Small (< 1 m) Erica, Ulex ou Pteropartum tridentatum shrubland	
Globland	M-EUC	E. globulus litter and understorey	**Fernandes *et al.*, 2009**
	M-EUCd	E. Globulus with descontiinuous surface fuel model	
	V-MAb	Mato baixo (< 1 m) de urze, tojo ou carqueja	
Vale do Sousa	M-CAD	Broadleave evergreen	**Fernandes *et al.*, 2009** **Cruz, M. 2005**
	M-EUC	E. globulus litter and understorey	
	M-PIN	P. pinaster litter and understorey	
	V-Hb	Herbaceous understory(< 0,5 m)	
	V-MAb	Small (< 1 m) Erica, Ulex ou Pteropartum tridentatum shrubland	
	V-MH	Young shrubs and grassland	
	V-MMa	Tall (> 1 m) Q. coccifera, Cistus ladanifer and Cytisus triatus and others mediterranean shrubs	

Surface fuel models calibrated to Portugal

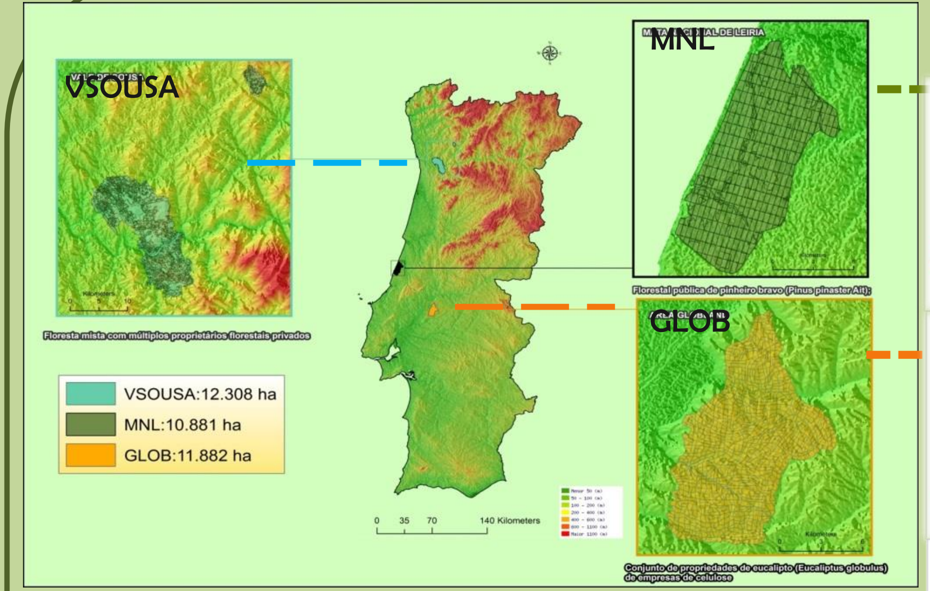
5.4|Vegetation data

- **Crown Bulk Density** (CBD,kg/m³)
- **Stand height** (Hdom,m)
- **Crown Base Height** (CBH, m)
- obtained with specific models from Mediterranean's species



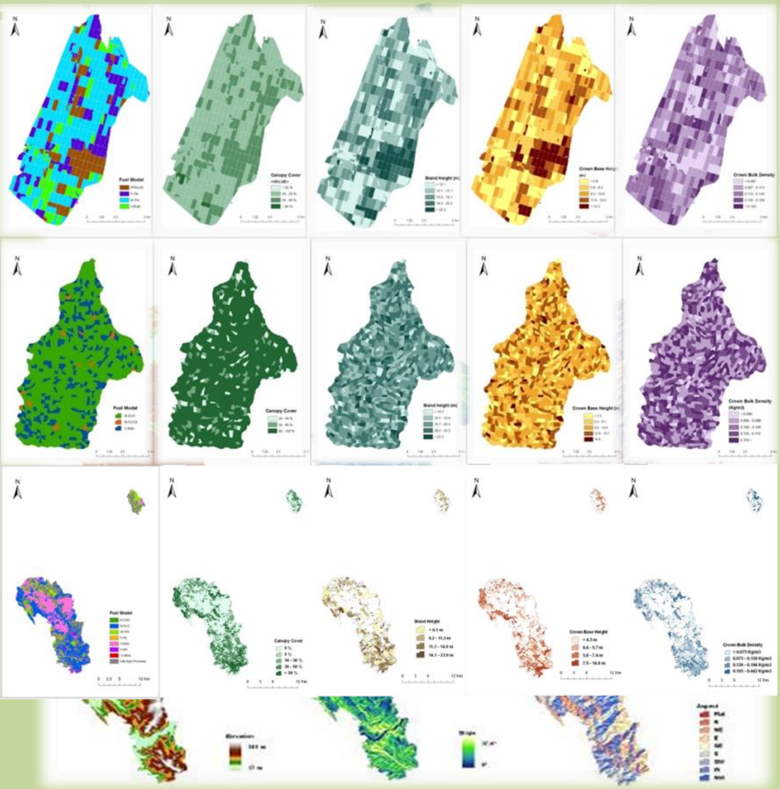
Forest Canopy characteristics

5.4| Input fire simulator



F. model CCover SH CBH CBD

ALTITUDE SLOPE ASPECT



Case study	V.Sousa	MNL	Glob.
DTM (resolution)	90x90	25x25	25x25
	Min/Max	**Min/Max**	**Min/Max**
Altitude(m)	37-541	4-142	0-192
Slope (º)	0-37.4	0-35	0-35.9
Aspect (more freq.)	Sw	Nw	Sw

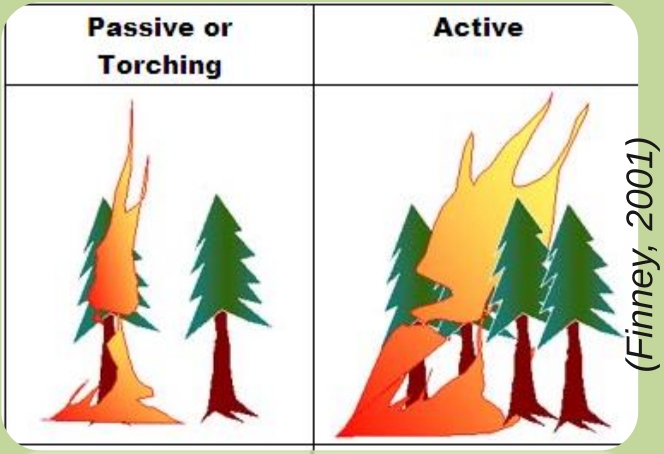
5.5| Output fire simulator

Maps of specific elements of each fire were produced

- OUTPUTS DATA
- **Wildfire spread parameters:**
  - ☐ Rate of Spread (m/min or feet per hour)
  - ☐ Fireline intensity (kw/m)

(i.e., how hot it burns and how long its flame is)

- **Potential occurence of crown Fire:**
  - ☐ Surface
  - ☐ Passive
  - ☐ Active

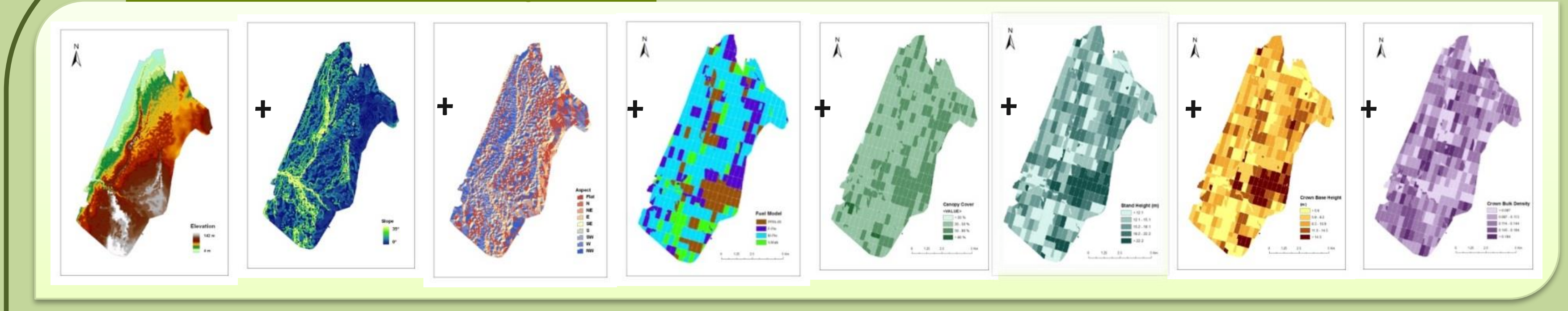


(Finney, 2001)

5.6| Combine landscape layers

MNL landscape

INPUT : initial landscape data

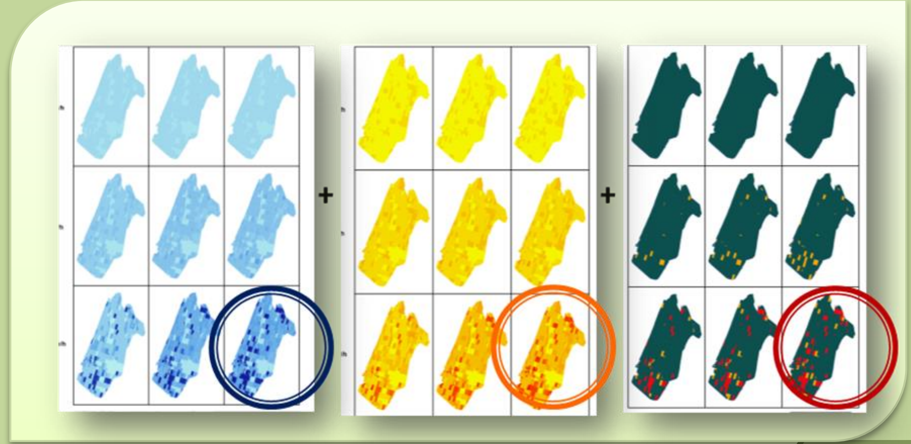


+

BIOMETRIC STAND VARIABLES

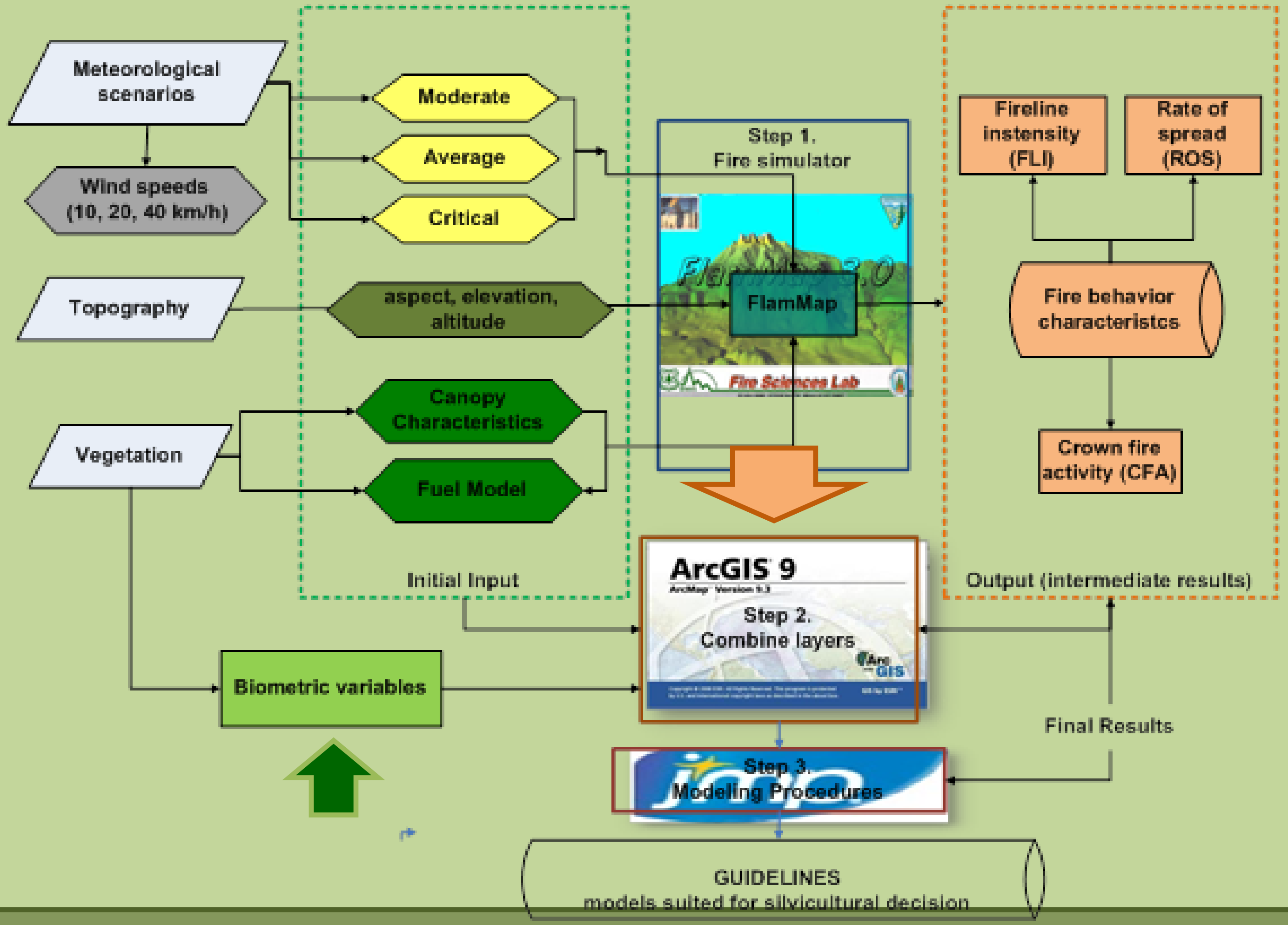
Tree density (N, Nº trees per ha)
Basal area (G, m^2/ha
Quadratic mean diameter in the stand (Dg, m)
Dominant height (Hdom, m)

OUTPUT: fire behavior characteristics



Critical Scenario:
4% Humidity * 40 km/h wind speed

5.7|combine Landscape Layers



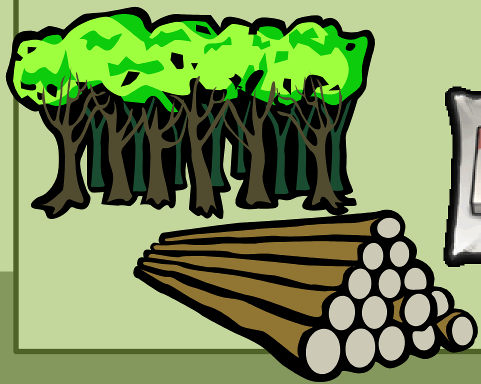
5.8. |MODELLING PROCEDURES : Logistic Regression

I. **Binary Logistic Regression**

- JMP (SAS) version 8.0

$$Y = \frac{1}{1 + e^{-(\beta_0 + \beta_1 \times x_1 + \ldots + \beta_p \times x_p + \varepsilon)}}$$

Two different models depending on the available variables :



Predict crown fire occurence *(PfCrown)*

Y=1 (Probability of crown fire ocurrence)

Models type I: based on simulator input data : slope, Hdom, Crown base height, Fuel model, canopy cover

Models type II: based on easily available inventory data : aspect, Fuel model, basal area (G), density (N) , quadratic mean diameter (Dg), stucture (G/Dg), Hdom (m)

Critical scenario
4% Humidity * 40 km/h wind speed

5.9|crown Fire Occurrence

Model type II

(Botequim et *al.* ...)

Predict potential crown fire occurrence

$$PfCrownII = \frac{1}{1 + e^{-(\beta_0 + \beta_1 \times Fmodel + \beta_2 \times Hdom + \beta_3 \times basal\ area)}}$$

(Eq.3)

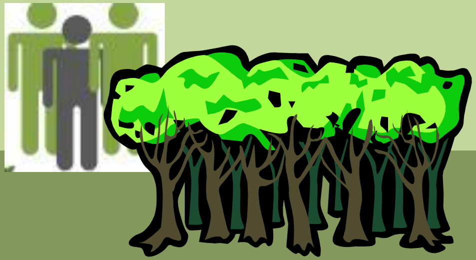
Using easily measurable stand characteristics

$$\begin{cases} \beta_0 = -53.884 \\ \beta_2 = 3.881 \\ \beta_3 = 1.206 \end{cases} \qquad \begin{cases} \beta_1 = 19.891 & \text{If } Fmodel = 0 \\ \beta_1 = -19.891 & \text{If } Fmodel = 1 \end{cases}$$

Dummy variable

Fmodel type	*Fmodel*
Mpin_Vmab	1 (Shrub)
Ppin_Fpin	0 (Litter)

Fmodel: “0” indicating that is dominated by “litter” and “1” indicating that is commonly occupied by “shrubs”



Botequim, B., *Fernandes, P., Garcia-Gonzalo, J., Silva, A., Borges, J.* ***Coupling fire behaviour modelling and stand characteristics to assess and mitigate fire hazard in a maritime pine landscape in Portugal*** *(under review)*

5.10|Crown fire occurrence

Model type II

$Pfcrown_x$: Predict potential crown fire occurrence

Significance level p<0,05

ROC curve:

Eq.3= 0.997

Eq.4= 0.993

Eq.5= 0.979

Forest owners

(Botequim et al. ...)

Modelos	Parâmetros	Variáveis	coeficiente
PfCrownII (Eq. 3)	β_0	Intercept	-53.884
	β_1	Fm	*1
	β_2	hdom	3.881
	β_3	G	1.206
PfCrownII (Eq.4)	β_0	Intercept	-9.490
	β_1	Fm	*2
	β_2	CBH	0.062
	β_3	G	4.012
PfCrownII (Eq.5)	β_0	Intercept	-8.733
	β_1	Fm	*3
	β_2	hdom	1.631

The models give a reasonable characterization of the crown fire activity for use in fire management applications

5.11| Modelling Procedures: CART

II. CLASSIFICATION TREE ANALYSIS

1. FYRE ACTIVITY

☐ surface,

☐passive,

☐active crown fire

2. DIFFICULTY OF FIRE SUPRESSION

(adapted from *Alexander & Lanoville, 1989*)

- ILC < 500 (**Low**)
- 500 <ILC< 2000 (**Moderate**)
- 2000 <ILC< 4000 (**Hight**)
- > 4000 (**Very Hight**)
- > 4000 active (**Extreme**)

Critical scenario

4% Humidity * 40 km/h wind speed

5.12| Fire Activity (CART)

1. Surface (
2. Passive c
3. Active cr

- Illustration of fire behavior according the effect of changes in fuel characteristics with different stand structures

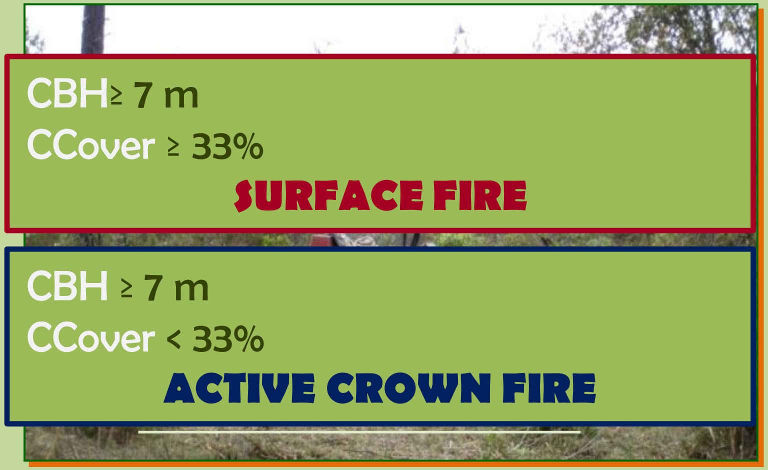
5.13| Fire behaviour models (application)

CBH < 7 m
CBD < 0,101 kg/m^3
Fmodel: Litter
SURFACE FIRE

CBH < 7 m
CBD < 0,101 kg/m^3
Fmodel : Shrubs
PASSIVE CROWN FIRE

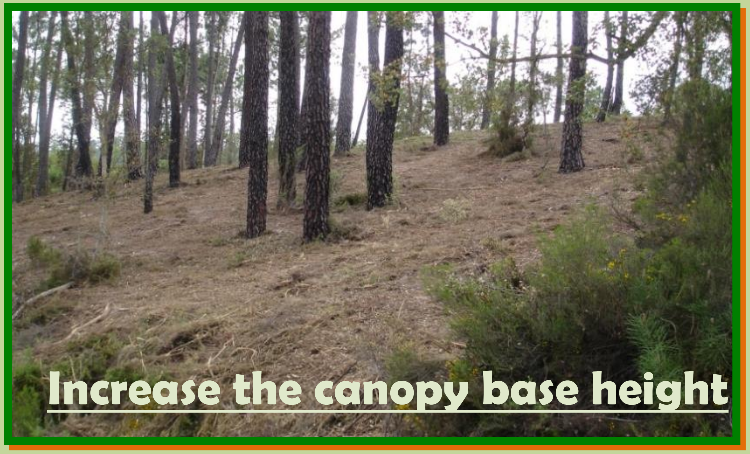
CBH < 6 m
CBD ≥ 0,101 kg/m^3
Fmodel: Sbrubs
ACTIVE CROWN FIRE

Reduce surface fuels



CBH≥ 7 m
CCover ≥ 33%
SURFACE FIRE

CBH ≥ 7 m
CCover < 33%
ACTIVE CROWN FIRE



Increase the canopy base height

Botequim, B., *Fernandes, P., Garcia-Gonzalo, J., Silva, A., Borges, J.* ***Coupling fire behaviour modelling and stand characteristics to assess and mitigate fire hazard in a maritime pine landscape in Portugal*** *(under review)*

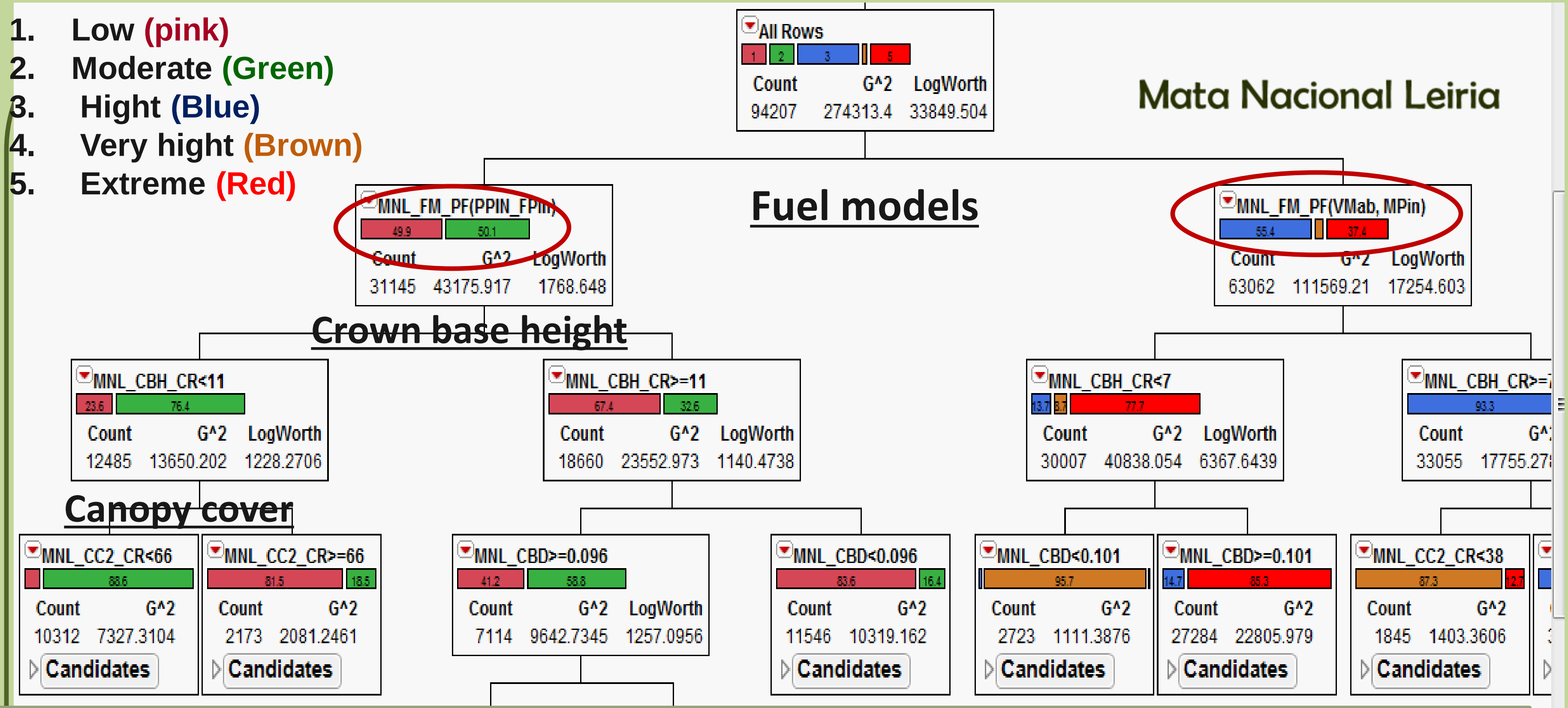
5.14|Difficulty of fire suppression

FIRE DANGER CLASS	DIFICCULTY OF FIRE SUPRESSION ACTIVITIES
Low: **FLI < 500 kw/m**	Possibility of direct attack on the head or flanks of the fire with **hand tools**
Moderate: **500 <FLI < 2000 kw/m**	**Water use or burnout operations are necessary**. Ground supression is effective
High: **2000 <FLI< 4000 kw/m**	**Aerial means** are necessary for direct attack on the head fire
Very high: **FLI > 4000 kw/m**	Direct attack is possible only with **heavy aerial means**. Ground supression crews are forced to fight the flanks and rear of the fire. Spotting is expected.
Extreme: **FLI > 4000 kw/m active**	Spotting induces rapid rate of spread. **Direct attacks on the head fire is ineffective**. Ground crews are forced to fight the flanks and rear of the fire.

(adapted from *Alexander & Lanoville, 1989*)

5.15 | difficulty of fire suppression

1. Low (pink)
2. Moderate (Green)
3. Hight (Blue)
4. Very hight (Brown)
5. Extreme (Red)



Mata Nacional Leiria

Fuel models

Crown base height

Canopy cover

- **Stands with litter in the understory, crown base height <11m and canopy cover <66% are more likely to moderate fire suppression (88,6%).**

(Botequim et al. ...)

Fuel treatments locations

VI. Optimizing time-scaling fuel treatments in eucalyptus plantation in Portugal

6.1. Optimizing time-scaling

Forest Systems
25(2), eRC09, 9 pages (2016)
eISSN: 2171-9845
http://dx.doi.org/10.5424/fs/2016252-09293
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)

RESOURCE COMMUNICATION

OPEN ACCESS

Temporal optimisation of fuel treatment design in blue gum (*Eucalyptus globulus*) plantations

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Abstract

Aim of study: This study was conducted to support fire and forest management planning in eucalypt plantations based on economic, ecological and fire prevention criteria, with a focus on strategic prioritisation of fuel treatments over time. The central objective was to strategically locate fuel treatments to minimise losses from wildfire while meeting budget constraints and demands for wood supply for the pulp industry and conserving carbon.

Area of study: The study area was located in Serra do Socorro (Torres Vedras, Portugal, covering ~1449 ha) of predominantly *Eucalyptus globulus* Labill forests managed for pulpwood by The Navigator Company.

Material and methods: At each of four temporal stages (2015-2018-2021-2024) we simulated: (1) surface and canopy fuels, timber volume ($m^3 ha^{-1}$) and carbon storage ($Mg\ ha^{-1}$); (2) fire behaviour characteristics, i.e. rate of spread ($m\ min^{-1}$), and flame length (m), with FlamMap fire modelling software; (3) optimal treatment locations as determined by the Landscape Treatment Designer (LTD).

Main results: The higher pressure of fire behaviour in the earlier stages of the study period triggered most of the spatial fuel treatments within eucalypt plantations in a juvenile stage. At later stages fuel treatments also included shrublands areas. The results were consistent with observations and simulation results that show high fire hazard in juvenile eucalypt stands.

Research highlights: Forest management planning in commercial eucalypt plantations can potentially accomplish multiple objectives such as augmenting profits and sustaining ecological assets while reducing wildfire risk at landscape scale. However, limitations of simulation models including FlamMap and LTD are important to recognise in studies of long term wildfire management strategies.

Keywords: Eucalypt plantations; fire hazard; FlamMap; fuel treatment optimisation; Landscape Treatment Designer; wildfire risk management.

Citation: Martín, A., Botequim, B., Oliveira, T.M., Ager, A., Pirotti, F. (2016). Temporal optimisation of fuel treatment design in blue gum (*Eucalyptus globulus*) plantations. Forest Systems, Volume 25, Issue 2, eRC09. http://dx.doi.org/10.5424/fs/2016252-09293.

Received: 13 Jan 2016. **Accepted**: 05 May 2016

Funding: The authors received no specific funding for this research.

Where to treat?
When to treat?
How should be applied?
Shape and size?

6.2|Optimizing time-scaling

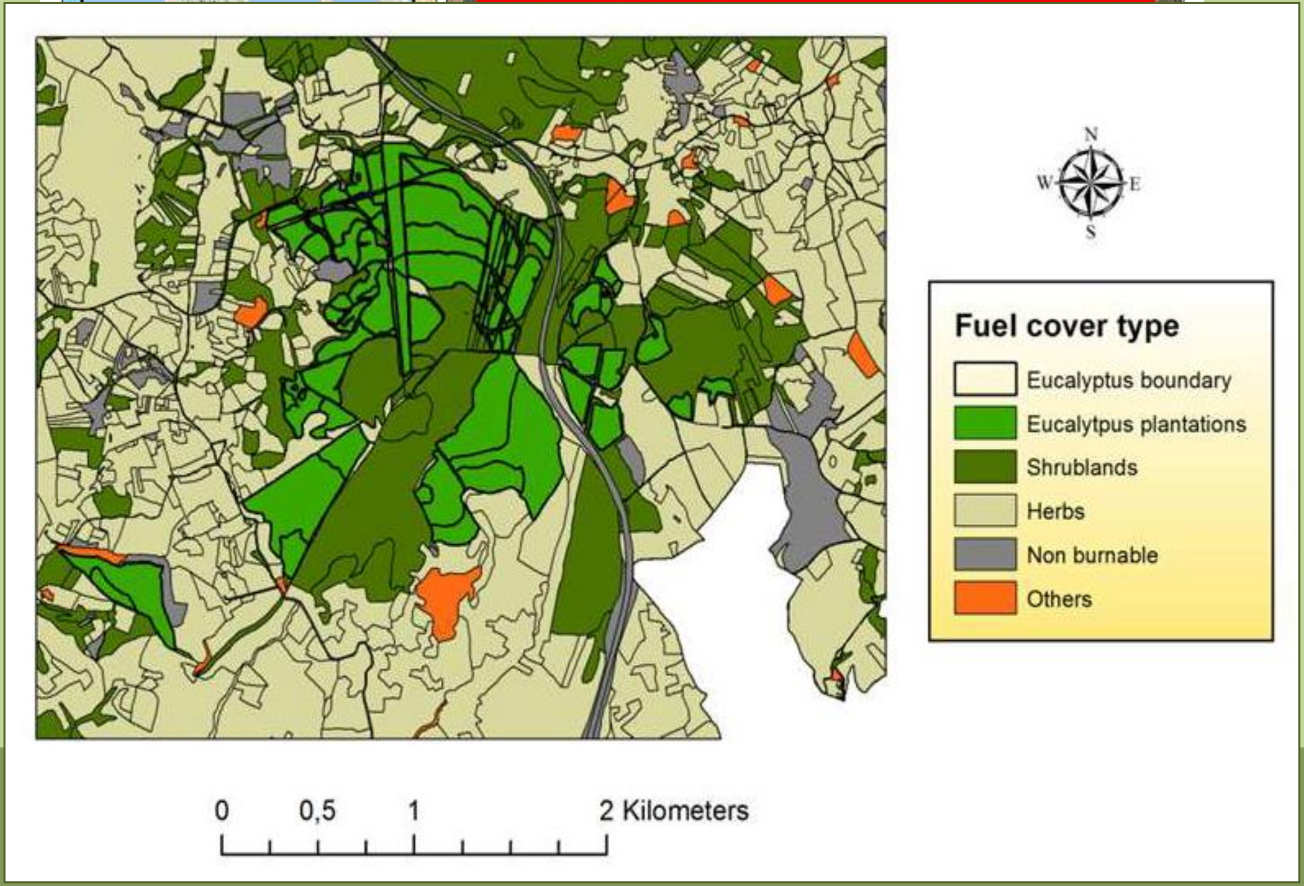
Optimize fuel treatments locations to **disrupt fire spread** when **protecting eucalyptus areas**

meeting **economic, ecological and fire prevention criteria over time 2015-2018-2021-2024**

- ❑ **Four time periods :**
  - ❑ 2015 (t=0),
  - ❑ 2018 (t=1),
  - ❑ 2021 (t=2)
  - ❑ 2024 (t=3).

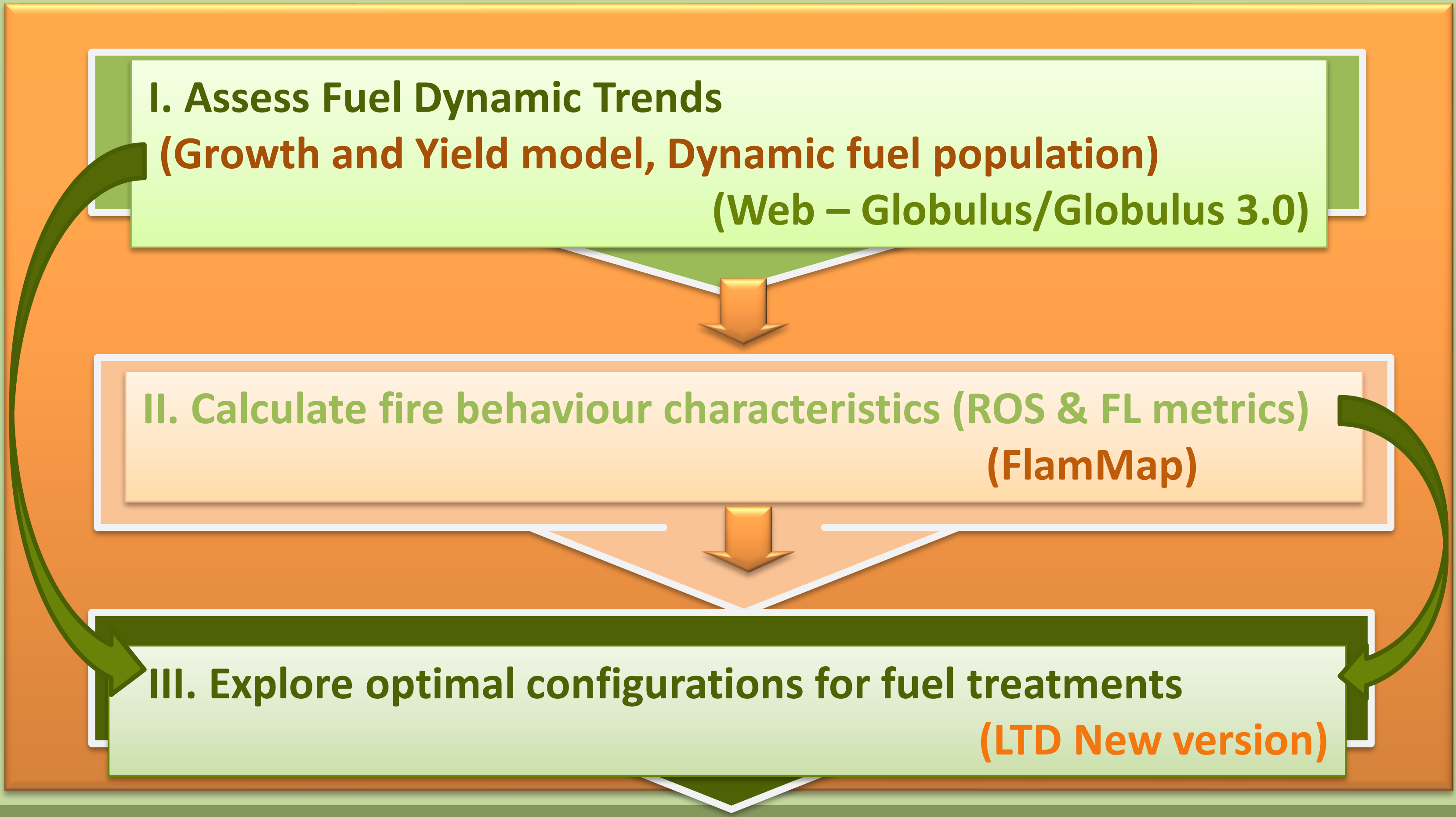
Set of different stages of eucalyptus plantations in Serra do Socorro.

6.3|Serra do Socorro (Torres Vedras)



Property (≈ 174 ha Ec from gPS).

6.4| three step methodology



I. Assess Fuel Dynamic Trends

(Growth and Yield model, Dynamic fuel population)

(Web – Globulus/Globulus 3.0)

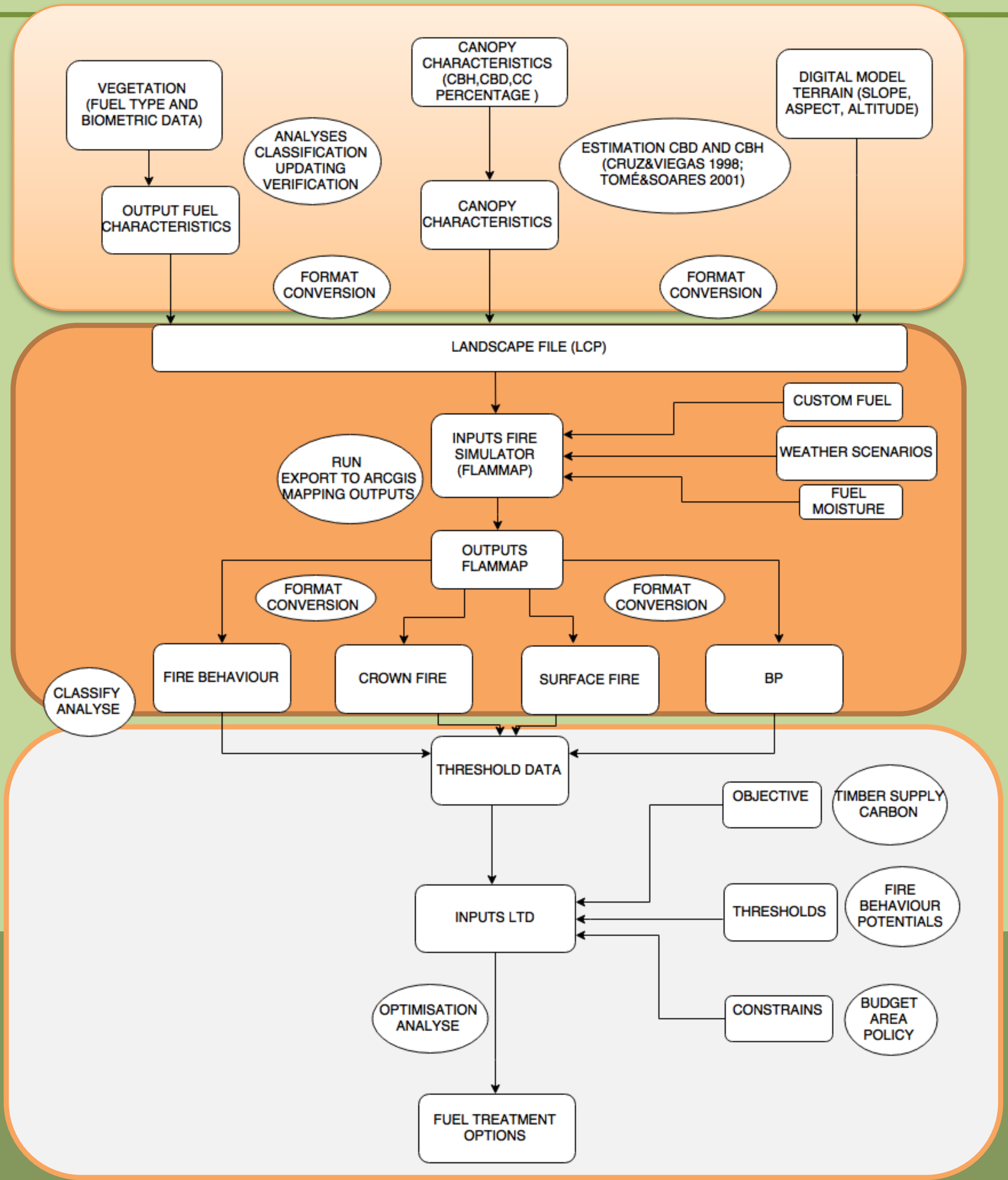
II. Calculate fire behaviour characteristics (ROS & FL metrics)

(FlamMap)

III. Explore optimal configurations for fuel treatments

(LTD New version)

6.5| three step methodology



VEGETATION (FUEL TYPE AND BIOMETRIC DATA)

ANALYSES CLASSIFICATION UPDATING VERIFICATION

OUTPUT FUEL CHARACTERISTICS

CANOPY CHARACTERISTICS (CBH,CBD,CC PERCENTAGE)

CANOPY CHARACTERISTICS

ESTIMATION CBD AND CBH (CRUZ&VIEGAS 1998; TOMÉ&SOARES 2001)

DIGITAL MODEL TERRAIN (SLOPE, ASPECT, ALTITUDE)

FORMAT CONVERSION

FORMAT CONVERSION

LANDSCAPE FILE (LCP)

INPUTS FIRE SIMULATOR (FLAMMAP)

CUSTOM FUEL

WEATHER SCENARIOS

FUEL MOISTURE

RUN EXPORT TO ARCGIS MAPPING OUTPUTS

OUTPUTS FLAMMAP

FORMAT CONVERSION

FORMAT CONVERSION

FIRE BEHAVIOUR

CROWN FIRE

SURFACE FIRE

BP

CLASSIFY ANALYSE

THRESHOLD DATA

OBJECTIVE

TIMBER SUPPLY CARBON

THRESHOLDS

FIRE BEHAVIOUR POTENTIALS

CONSTRAINS

BUDGET AREA POLICY

INPUTS LTD

OPTIMISATION ANALYSE

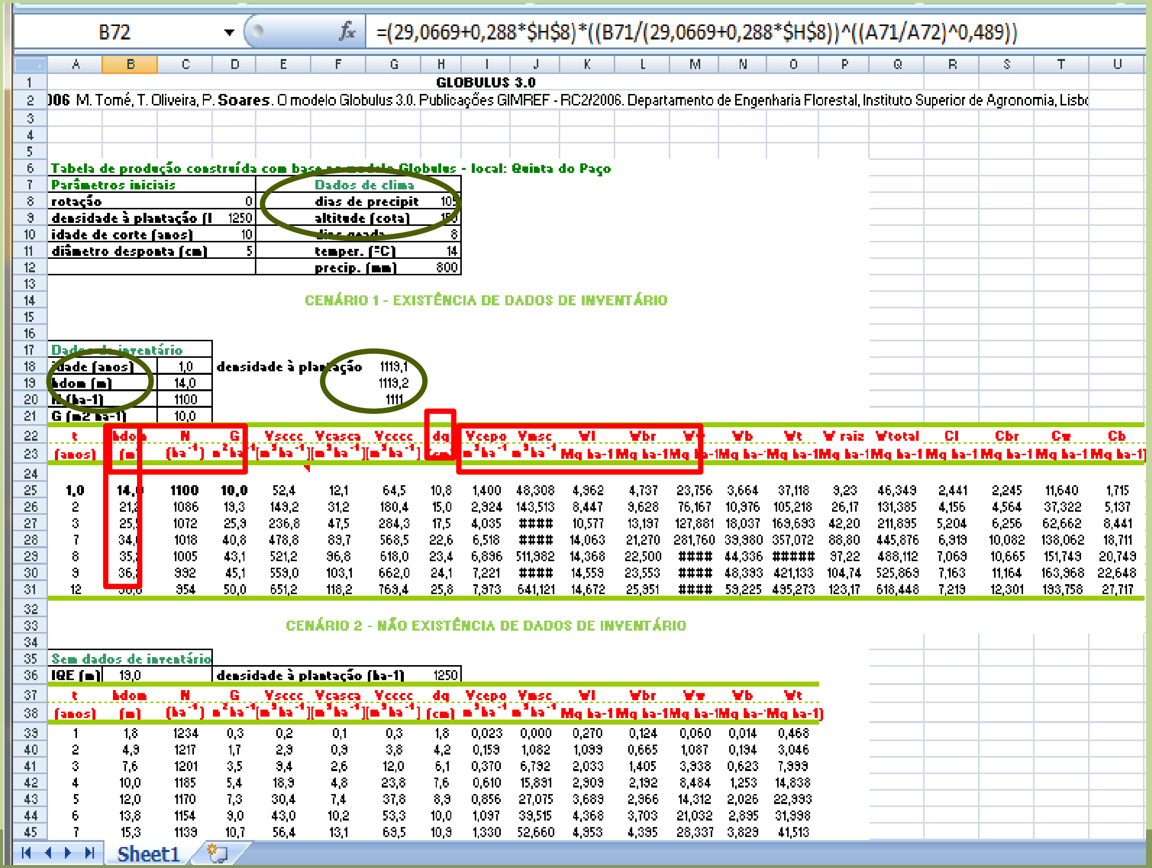
FUEL TREATMENT OPTIONS

I. Fuel Dynamic Trends

U LISBOA UNIVERSIDADE DE LISBOA
INSTITUTO SUPERIOR DE AGRONOMIA Universidade de Lisboa

I.I Growth and Yield model (Globulus 3.0., Tomé et al. 2006)

Simulating stand level growth



B72 `=(29,0669+0,288*$H$8)*((B71/(29,0669+0,288*$H$8))^((A71/A72)^0,489))`

GLOBULUS 3.0

)06 M. Tomé, T. Oliveira, P. **Soares**. O modelo Globulus 3.0. Publicações GIMREF - RC2/2006. Departamento de Engenharia Florestal, Instituto Superior de Agronomia, Lisbc

Tabela de produção construída com base no modelo Globulus - local: Quinta do Paço

Parâmetros iniciais		Dados de clima	
rotação	0	dias de precipit	105
densidade à plantação (I	1250	altitude (cota)	150
idade de corte (anos)	10	dias geada	8
diâmetro desponta (cm)	5	temper. (°C)	14
		precip. (mm)	800

CENÁRIO 1 - EXISTÊNCIA DE DADOS DE INVENTÁRIO

Dados de inventário			
idade (anos)	1,0	densidade à plantação	1119,1
hdom (m)	14,0		1119,2
N (ha-1)	1100		1111
G (m2 ha-1)	10,0		

t (anos)	hdom (m)	N (ha^{-1})	G m^{2}ha^{-1}	Vsccc [m^{3}ha^{-1}]	Vcasca [m^{3}ha^{-1}]	Vcccc [m^{3}ha^{-1}]	dg (cm)	Vcepo m^{3}ha^{-1}	Vmsc m^{3}ha^{-1}	Wl Mg ha-1	Wbr Mg ha-1	Ww Mg ha-1	Wb Mg ha-1	Wt Mg ha-1	W raiz Mg ha-1	Wtotal Mg ha-1	Cl Mg ha-1	Cbr Mg ha-1	Cw Mg ha-1	Cb Mg ha-1
1,0	**14,**	**1100**	**10,0**	52,4	12,1	64,5	10,8	1,400	48,308	4,962	4,737	23,756	3,664	37,118	9,23	46,349	2,441	2,245	11,640	1,715
2	21,	1086	19,3	149,2	31,2	180,4	15,0	2,924	143,513	8,447	9,628	76,167	10,976	105,218	26,17	131,385	4,156	4,564	37,322	5,137
3	25,	1072	25,9	236,8	47,5	284,3	17,5	4,035	####	10,577	13,197	127,881	18,037	169,693	42,20	211,895	5,204	6,256	62,662	8,441
7	34,	1018	40,8	478,8	89,7	568,5	22,6	6,518	####	14,063	21,270	281,760	39,980	357,072	88,80	445,876	6,919	10,082	138,062	18,711
8	35,	1005	43,1	521,2	96,8	618,0	23,4	6,896	511,982	14,368	22,500	####	44,336	#####	97,22	488,112	7,069	10,665	151,749	20,749
9	36,	992	45,1	559,0	103,1	662,0	24,1	7,221	####	14,559	23,553	####	48,393	421,133	104,74	525,869	7,163	11,164	163,968	22,648
12	36,6	954	50,0	651,2	118,2	763,4	25,8	7,973	641,121	14,672	25,951	####	59,225	495,273	123,17	618,448	7,219	12,301	193,758	27,717

CENÁRIO 2 - NÃO EXISTÊNCIA DE DADOS DE INVENTÁRIO

Sem dados de inventário			
IQE (m)	19,0	densidade à plantação (ha-1)	1250

t (anos)	hdom (m)	N (ha^{-1})	G m^{2}ha^{-1}	Vsccc [m^{3}ha^{-1}]	Vcasca [m^{3}ha^{-1}]	Vcccc [m^{3}ha^{-1}]	dg (cm)	Vcepo m^{3}ha^{-1}	Vmsc m^{3}ha^{-1}	Wl Mg ha-1	Wbr Mg ha-1	Ww Mg ha-1	Wb Mg ha-1	Wt Mg ha-1)
1	1,8	1234	0,3	0,2	0,1	0,3	1,8	0,023	0,000	0,270	0,124	0,060	0,014	0,468
2	4,9	1217	1,7	2,9	0,9	3,8	4,2	0,159	1,082	1,099	0,665	1,087	0,194	3,046
3	7,6	1201	3,5	9,4	2,6	12,0	6,1	0,370	6,792	2,033	1,405	3,938	0,623	7,999
4	10,0	1185	5,4	18,9	4,8	23,8	7,6	0,610	15,891	2,909	2,192	8,484	1,253	14,838
5	12,0	1170	7,3	30,4	7,4	37,8	8,9	0,856	27,075	3,689	2,966	14,312	2,026	22,993
6	13,8	1154	9,0	43,0	10,2	53,3	10,0	1,097	39,515	4,368	3,703	21,032	2,895	31,998
7	15,3	1139	10,7	56,4	13,1	69,5	10,9	1,330	52,660	4,953	4,395	28,337	3,829	41,513

Driven by:
- ✓Environmental-climatic
- ✓Stand characteristics (management)
- ✓Biometric data

Outputs with:
- ➢Biometric variables (input FlamMap by canopy eq.)
- ➢Dominant Height
- ➢Wood volume and total biomass

❑ Understory growth was only consider in terms of fuel type change

I. Fuel Dynamic Trends

I. Dynamic fuel population

The fuel model type and CC change over time due to planting operations, harvesting, and vegetation regrowth and thus was correspondingly altered.

Followed :

✓Identification fuel model key (Fernandes et al., 2009)

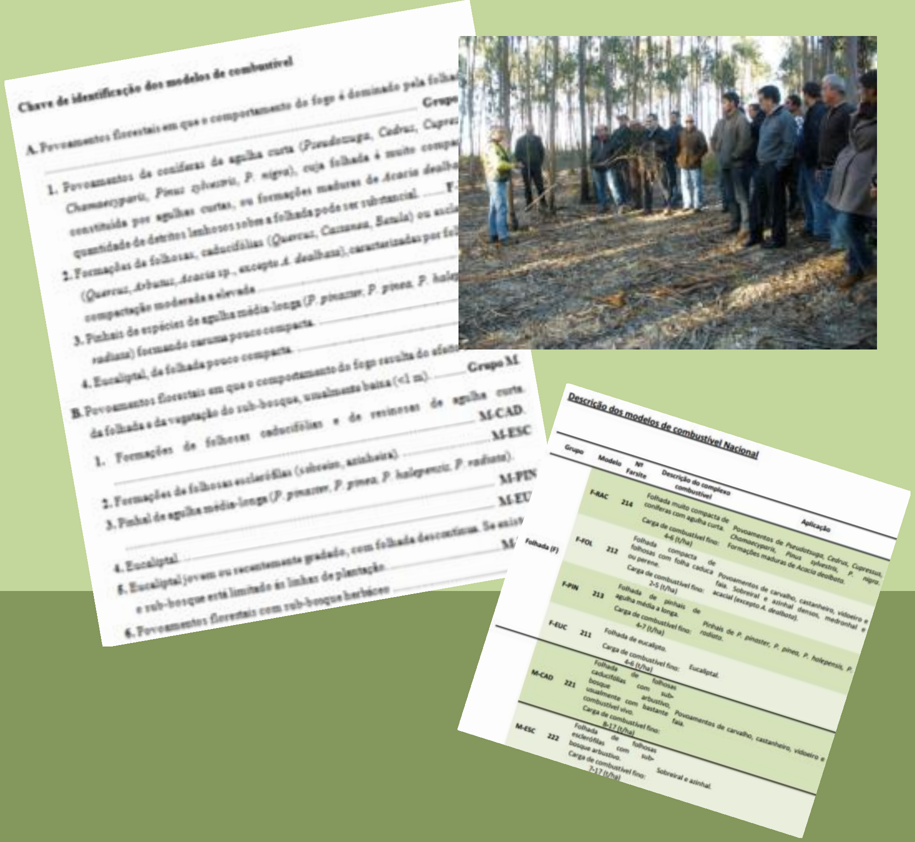
✓Fuel load characterisation

✓Expert knowledge from the mill´s pulp and paper company

➢Outputs:

➢Fuel model type

➢CC percentage



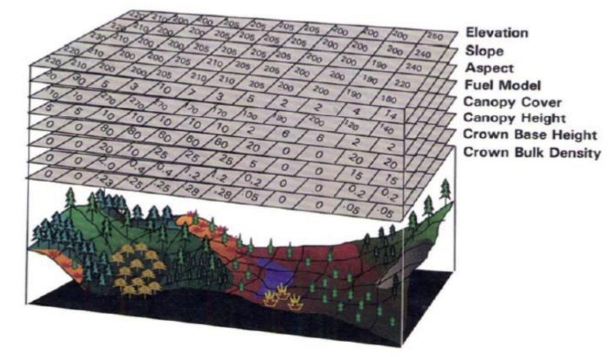
Chave de identificação dos modelos de combustível

Descrição dos modelos de combustível Nacional

II. Fire Behaviour Characteristics

Inputs: fire environment
fuel&weather&topography

- ✓LCP file
  - ✓Fuel and canopy cover
  - ✓Canopy characteristics: CBD, CBH
  - ✓DTM
- ✓7% fuel moisture content
- ✓Wind data-32km/h and 320º
- ✓Fuel custom type



(Finney 2003)

Outputs

- ➢Fire behaviour metrics

FireGlobulus project January 2015

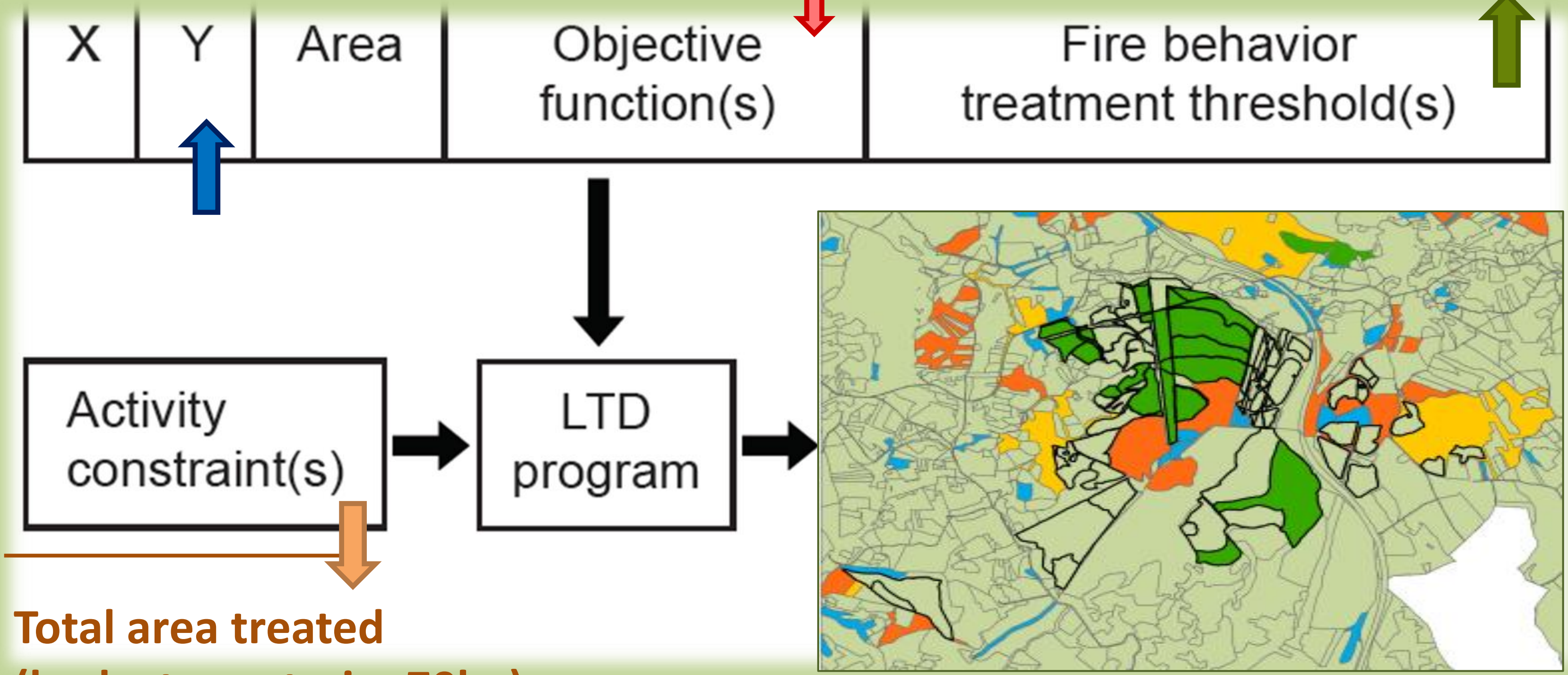
III. Explore optimal levels for fuel treatments

|Inputs LTD

gPS EU farms

Max timber volume and carbon storage

fire characteristics (FL >1.5m and ROS>10m/min)



Total area treated (budget constrain=70ha)

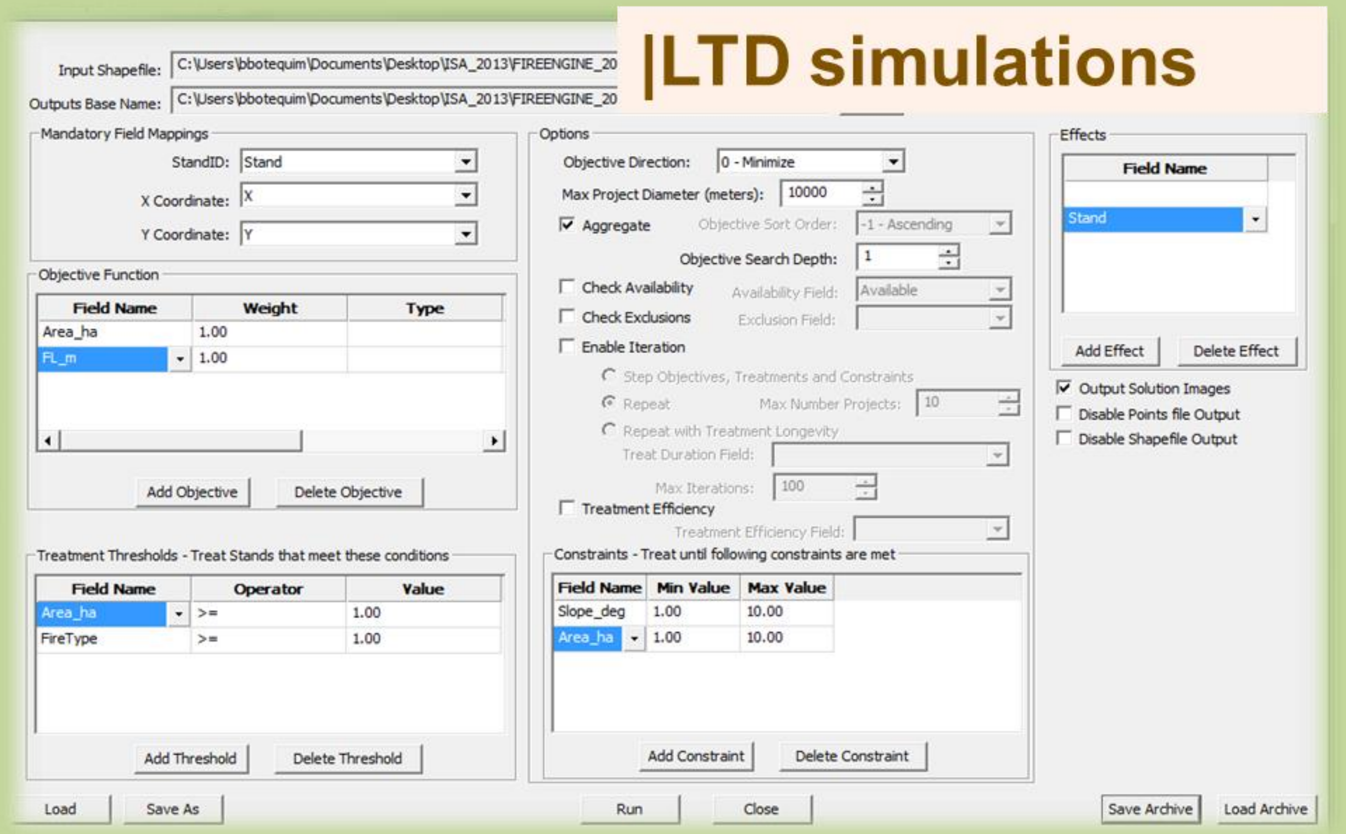
prioritization of project areas for fuel treatments

Ager et al 2012

III. Explore optimal levels for fuel treatments

|Inputs LTD

|LTD simulations



Input Shapefile: C:\Users\bbotequim\Documents\Desktop\ISA_2013\FIREENGINE_20

Outputs Base Name: C:\Users\bbotequim\Documents\Desktop\ISA_2013\FIREENGINE_20

Mandatory Field Mappings

StandID: Stand

X Coordinate: X

Y Coordinate: Y

Objective Function

Field Name	Weight	Type
Area_ha	1.00	
FL_m	1.00	

Treatment Thresholds - Treat Stands that meet these conditions

Field Name	Operator	Value
Area_ha	>=	1.00
FireType	>=	1.00

Options

Objective Direction: 0 - Minimize

Max Project Diameter (meters): 10000

☑ Aggregate

Objective Sort Order: -1 - Ascending

Objective Search Depth: 1

☐ Check Availability

Availability Field: Available

☐ Check Exclusions

Exclusion Field:

☐ Enable Iteration

○ Step Objectives, Treatments and Constraints

● Repeat

Max Number Projects: 10

○ Repeat with Treatment Longevity

Treat Duration Field:

Max Iterations: 100

☐ Treatment Efficiency

Treatment Efficiency Field:

Constraints - Treat until following constraints are met

Field Name	Min Value	Max Value
Slope_deg	1.00	10.00
Area_ha	1.00	10.00

Effects

Field Name
Stand

☑ Output Solution Images

☐ Disable Points file Output

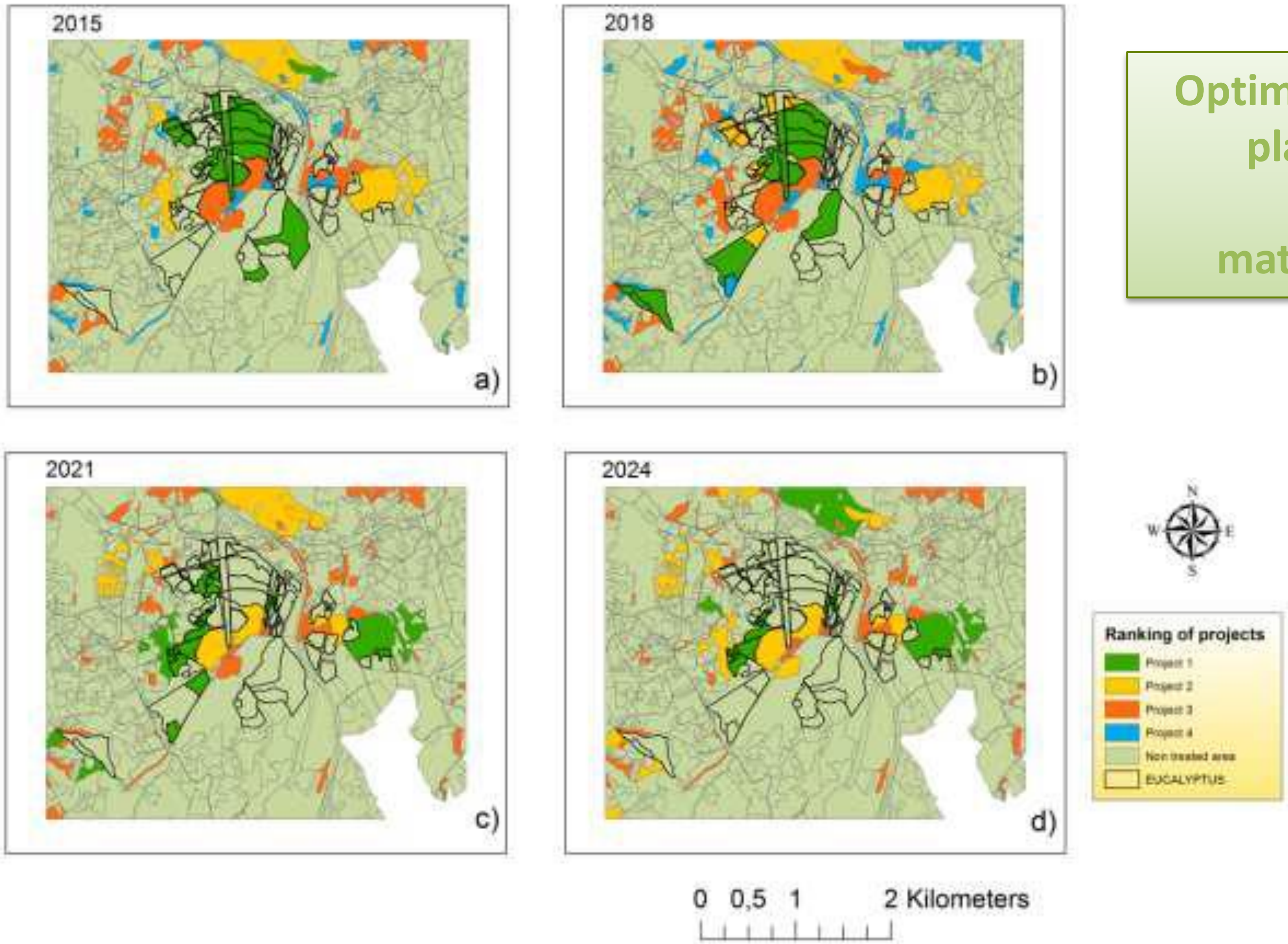
☐ Disable Shapefile Output

Ager et al 2012

Ager, A.A.; Vaillant, N.M.; McMahan, A. 2013. *Restoration of fire in managed forests: a model to prioritize landscapes and analyze tradeoffs.* Ecosphere 4:art29.

6.6| Results

|Assessing strategic fuel location 70 ha / non-aggregate

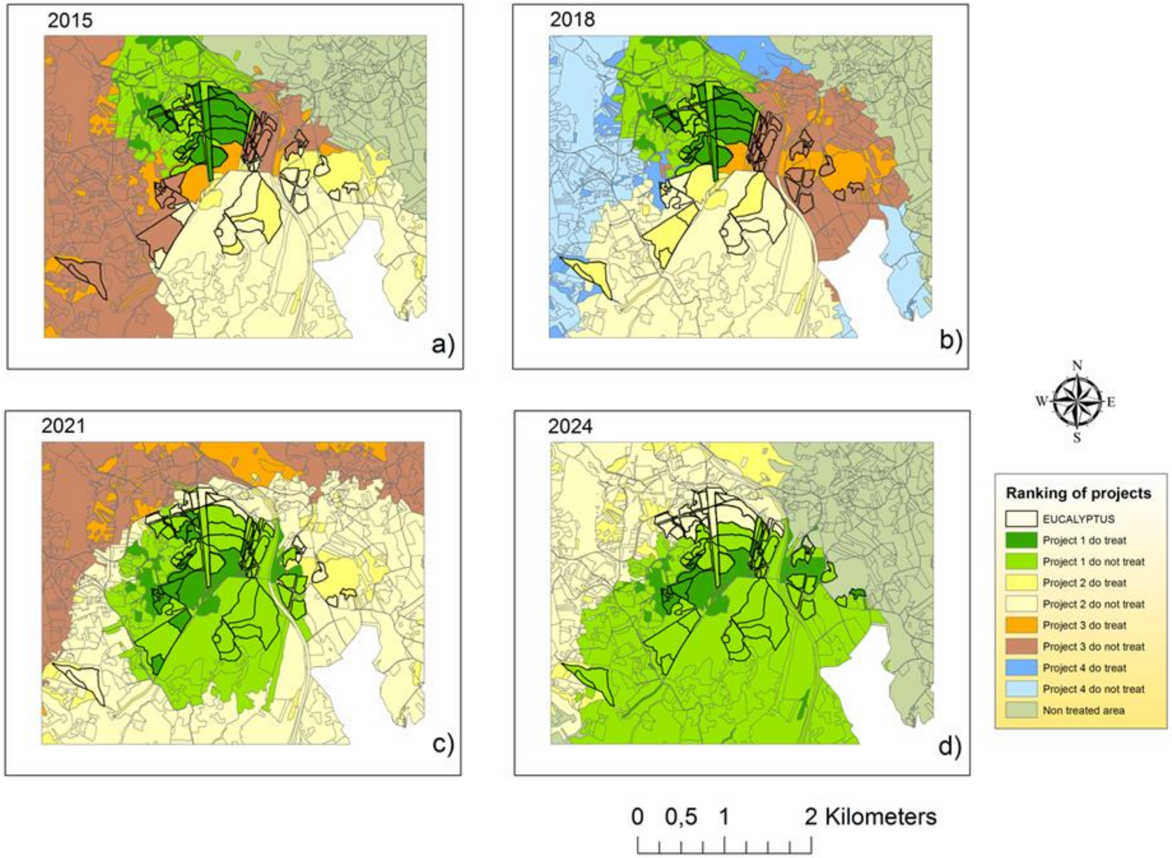


Optimazing young plantations vs mature stands

- ❑ Ranking of projects in term of maximizing objectives subject to treatment area constrains and ROS and FL thresholds

6.7| Results

|Assessing strategic fuel location 70 ha / non-aggregate



Optimazing young plantations vs mature stands

- ❑ Ranking of aggregated treatment plans – treatment to build large patches

| Take home messages

| *Some considerations …*

Phase I & Phase II

❑Our research is in line with principles of Fire-Resistant Forests

Forest Inventory

wildfire occurrence detection

timber salvage estimation

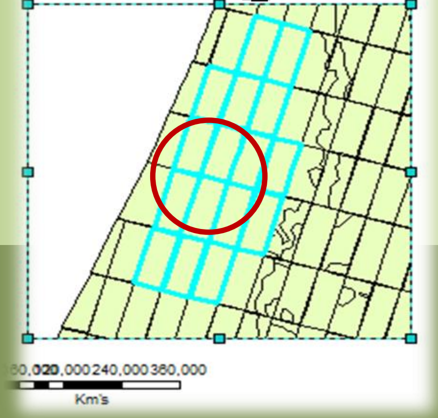
Crown fire detection

Fire suppression

Did mortality occur?

Level of mortality?

How many dead trees?



Optimize fuel levels of treatment locations

Instrumental for innovative and effective integration of forest and fire management activities and are valuable to address the most important forest catastrophic event in portugal

PREVENTIVE SILVICULTURAL PRACTICES!

Acknowledgments

- PhDs of Brigite Botequim ***Tools to support the design of fire resistant landscapes in Portuguese ecosystems***", (SFRH-BD-44830-2008) funded by the Portuguese Science Foundation
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Obrigada pela vossa atenção…

Thank you!

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