“A three-step approach to forest optimization modelling for assessing trade-offs in spatial fuel management strategies”

Botequim B. (ISA), Universidade de Lisboa
Alan A. USDA Forest Service, Oregon
Pacheco A. INESC Porto
Oliveira T. grupo Portucel Soporcel
Barros A. INESC Porto
Claro J. INESC Porto
Borges J.G. (ISA), Universidade de Lisboa
“FLEXIBLE DESIGN OF FOREST FIRE MANAGEMENT SYSETMS ”
(MIT/FSE/0064/2009)
SUMMARY:

Relevance of the problem
- Background

Problems, challenges and ideas
- Purpose of the research

Research design alternatives
- A three-step approach for enhanced decision-making in eucalyptus forest

Points of view
- Addressing trade-offs in spatial fuel management strategies

Ongoing work
We have little or no control over most factors in the fire behavior triangles:

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

The common denominator is fuel

Fire Behavior: influence the intensity and severity of a wildfire reducing the amount and changing the arrangement of fuel before a wildfire erupts.
Quantifying risk for wildfire management

Several definitions of Risk?!

Risk assessment

Let... \[ p(f_i) = \text{Probability of burning intensity level } i \]  
"Exposure"

\[ R(f_i) = \text{Response for intensity } i \]  
"Susceptibility"

\[ E(L) = \text{Expected loss} \]  
"Risk"

\[ E(L) = \sum_{i} p(f_i) \cdot R(f_i) \]  
Finney 2013

Spatial and temporal quantification of risk

Risk management

Impact of changes in “controllable” biometric variables
- stand density, fuel availability at surface level and vertical structure of the stand

Guidelines for fuel and stand structure modification, which are critical for integrating forestry and fire management activities

Using risk assessment to change perceived or actual risk
| BACKGROUND |

- Changing the expect output:
  - reducing wildfire probability $P(f_i)$
  - Reducing wildfire intensity $(f_i)$
  - Reducing the landscape response or susceptibility

The emphasis today in forest management is on forest restoration and fuels reduction.

there is an urgent need for decision support tools to enable effective fire management.
Address the problem of **spatially optimize treatments** to prioritize fuel management activities, aimed at **disrupt fire spread** and **protect eucalyptus areas** from burning without encroaching budget constraints, have loss of important ecological and commercial timber values.

- Developing a **Forest System Dynamic Model** in order to identify temporal stand-scale and fuel dynamics;

- Characterizing for each fuel arrangements the **spread rate curve trends**, thereby allowing the calculation of changes in the annual expected wood;

- Simulating in the **Landscape Treatment Designer** tool the optimal levels of fuel landscape treatment configurations.
GPS FOREST AREAS ("FARMS")

Three properties of pulp mill's from the Grupo Portucel Soporcel (gPS)
How to reach the GPS goals?

National level

- Fire risk
- Fire damage
- Fire behaviour
- Fire suppression

System dynamic model = Forest model

Fuel management strategies
- Prioritization of investments
- Landscape treatment strategies

Regional level

Insight Maker
Ex-RATE
FlamMap LTD

New approach

Tools

models
I. Forest System Dynamic Model (Insight Maker)

II. Calculate Expected spread rate & flame Lenght (FlamMap & Ex-rate)

III. Explore optimal levels for fuel treatments & supression deployment program (LTD)

Fuel management strategies need to be informed by fire risk assessment + fire risk analysis
FIRE-ENGINE

FOREST SYSTEM DYNAMIC MODEL

STEP 1
1.1 | How to solve the timing problem?

• % planting?
• % harvesting?
• % burnt probability?
• % dead trees?
• % fuel model?

each year/ per 10 years
STEP #1

1.2| Burnt Factor adjusted?

Calculating a Burnt probability adjusted:

<table>
<thead>
<tr>
<th>Regional-scale level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stand-scale level</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Management-oriented model to predict annual wildfire in eucalyptus stands from Botequim et al. 2013</td>
</tr>
</tbody>
</table>
STEP #1

1.3 | calculating BP : Regional-scale level information

**Fire frequency analysis in Portugal (1975–2005), using Landsat-based burnt area maps**

*Sofia L. J. Oliveira\(^A\)C, José M. C. Pereira\(^A\) and João M. B. Carreiras\(^B\)*

\(^A\)Forest Research Centre, School of Agriculture, Technical University of Lisbon, Tapada da Ajuda, 1349-017 Lisbon, Portugal.

\(^B\)Geoinformation for Development Centre, Department of Natural Sciences, Tropical Research Institute, R. Joao de Barros 27, 1300-319 Lisbon, Portugal.

Abstract. Fire frequency in 21 forest planning regions of Portugal during the period 1975–2005 was estimated from historical burnt area maps generated with semi-automatic classification of Landsat Thematic Mapper (TM) satellite imagery. Fire return interval distributions were modelled with the Weibull function and the estimated parameters were used to calculate regional mean, median and modal fire return intervals, as well as regional hazard functions. Arrangement of the available data into three different time series allowed for assessment of the effects of minimum mapping unit, time series length and use of censored data on the Weibull function parameter estimates. Varying the minimum mapping unit between 5 and 35 ha had a negligible effect on parameter estimates, whereas changing the time series length from 22 to 31 years substantially affected the estimates. However, the strongest effect was caused by censored data. Its exclusion led to substantial overestimation of fire frequency and of burning probability dependence on fuel age. We estimated a country-wide mean fire interval of 36 years and an annual burnt area of 1.2%. Regional variations in fire frequency descriptors were interpreted in terms of land cover and land use practices that affect the contemporary fire regime in Portugal.

Additional keywords: censored data, Weibull model.

Received 23 October 2010, accepted 24 April 2011, published online 24 October 2011

Oliveira et al. 2012
STEP #1

1.5 | calculating BP: Regional-scale level information

From ISA team 1: José M. C. Pereira/Inês Melo
STEP #1

1.7 | calculating BP: stand-scale level information

- Management-oriented model to predict annual wildfire risk

Botequim et al. 2013

\[ P_{burnEc} = \frac{1}{1 + e^{(-5.4005 - 0.0540Hdom + 0.3166G/dg + 0.3959Biomass + 0.5372RoadDist)}} \]

\[
\begin{align*}
\text{RoadDist} = 0 & \quad \text{If RoadDistance < 1km} \\
\text{RoadDist} = 1 & \quad \text{If RoadDistance > 1km}
\end{align*}
\]

- **Hdom**: Dominant stand height (m)
- **Biom**: the total biomass of shrubs load (Mg ha\(^{-1}\)).
- 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)
- **RoadDist**: dummy variable, distance to road: < a 1Km - RoadDist take value “0”, otherwise value “1”
STEP #1

1.8| calculating the impact of wildfires

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

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

\[
Psd = \frac{1}{1 + e^{-(-0.7882 + 1.1079.PBr + 2.1698.PC - 0.5553.G + 4.328 \cdot \frac{G}{dg} + 3.2549 \cdot \frac{Sd}{dg})}}
\]

2. Proportion of trees that died in **stands** where mortality did occur \((0 \leq Pr \leq 1)\)

\[
PMort = \frac{1}{1 + e^{-((0.3579 - 0.1361.PEc - 1.3872.PBr + 0.0525.Slope + 0.0017.Alt + 0.0393.AVGdbh)}}
\]

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

\[
PdTree2 = \frac{1}{1 + e^{-((1.5896 + 1.1315.Con + 0.6714.Ec - 0.9362.Oak + 0.0128.Slope - 0.0679.h - 0.0846.G + 0.000697.N} \]

**Botequim, B., Garcia-Gonzalo, J., Silva, A., Marques S, Borges J. G., Oliveira M. M., Tomé, J., Tomé, M.** *Modeling post-fire damage and tree mortality in forest stands in Portugal.* A forest planning oriented model (being edited to be submitted to International forest Review)
**STEP #1**

### 1.8 calculating the impact of wildfires

- **Variables descriptions of post-fire mortality models**

  - $0 \leq P_{cover \ type} \leq 1$, proportion of cover type in the stand
  - $P_{Br}$: proportion of broadleaves (“0” indicating no presence and “1” indicating that stand is purely occupied by broadleaves)
  - $P_{Ec}$: proportion of eucalypt
  - $P_{C}$: 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 ($^\circ$)

[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)
FIRE-ENGINE

CALCULATE FIRE BEHAVIOUR CHARACTERISTICS

STEP II
### STEP #2

#### 2.1 Characterizing each gPS “farm”

**Inventories data for the conditions of the year 2013 in the study area.**

<table>
<thead>
<tr>
<th>COD_Talhao</th>
<th>COD_UG</th>
<th>Eucalyptus</th>
<th>Cork oak</th>
<th>Broadleaves</th>
<th>Conifers</th>
<th>Shrubs</th>
<th>Area_UG</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50260</td>
<td>58</td>
<td></td>
<td>1</td>
<td>12</td>
<td>72.09538</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T01</td>
<td>11</td>
<td>6</td>
<td>36.41354</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T02</td>
<td>9</td>
<td>3</td>
<td>3.3627</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T03</td>
<td>7</td>
<td>2</td>
<td>2.76499</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T04</td>
<td>29</td>
<td>6</td>
<td>27.47297</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T05</td>
<td>2</td>
<td>0</td>
<td>0.31636</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T800</td>
<td>1</td>
<td>1</td>
<td>1.76482</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50500</td>
<td>105</td>
<td>28</td>
<td>149.0459</td>
<td>133</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T01</td>
<td>77</td>
<td>27</td>
<td>121.4372</td>
<td>104</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T02</td>
<td>1</td>
<td>1</td>
<td>1.13617</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T03</td>
<td>4</td>
<td>1</td>
<td>5.64984</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T600</td>
<td>23</td>
<td>20</td>
<td>20.82269</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50524</td>
<td>12</td>
<td>10</td>
<td>10.79942</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T01</td>
<td>4</td>
<td>2</td>
<td>2.6416</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T02</td>
<td>8</td>
<td>7</td>
<td>8.15782</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50708</td>
<td>16</td>
<td>8</td>
<td>8.39182</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T01</td>
<td>77</td>
<td>27</td>
<td>121.4372</td>
<td>104</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T02</td>
<td>1</td>
<td>1</td>
<td>1.13617</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T03</td>
<td>4</td>
<td>1</td>
<td>5.64984</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T600</td>
<td>23</td>
<td>20</td>
<td>20.82269</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50544</td>
<td>79</td>
<td>19</td>
<td>19.00358</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T01</td>
<td>4</td>
<td>2</td>
<td>2.6416</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T02</td>
<td>8</td>
<td>7</td>
<td>8.15782</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50808</td>
<td>16</td>
<td>8</td>
<td>8.39182</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T01</td>
<td>77</td>
<td>27</td>
<td>121.4372</td>
<td>104</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T02</td>
<td>1</td>
<td>1</td>
<td>1.13617</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T03</td>
<td>4</td>
<td>1</td>
<td>5.64984</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T600</td>
<td>23</td>
<td>20</td>
<td>20.82269</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50844</td>
<td>79</td>
<td>19</td>
<td>19.00358</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T01</td>
<td>4</td>
<td>2</td>
<td>2.6416</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T02</td>
<td>8</td>
<td>7</td>
<td>8.15782</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50906</td>
<td>100</td>
<td>3</td>
<td>34.69739</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T01</td>
<td>66</td>
<td>3</td>
<td>15.52005</td>
<td>66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T05</td>
<td>15</td>
<td>3</td>
<td>7.55571</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T06</td>
<td>16</td>
<td>3</td>
<td>1.48177</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T10</td>
<td>4</td>
<td>2</td>
<td>3.05225</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**
- **Green bars** represent the sum of AREA
- **White bars** represent the count of COD_UG
2.2 | Characterizing fuel arrangements

- Standard fire behaviour fuel models
  - (GR. Grass fuel type models ;
  - GS Grass shrub type model;
  - TU Timber understory fuel type);
  - SB Slash blowdown fuel type)

- Scott & Burgan (2005)
- Tool: comparemodels4

  *IJWF*.12:167-174
STEP #2

2.3 | Characterizing fuel arrangements & wildfire parameters

- customize fuel model – Portugal to assign fuel distribution

  • specific fuel models collected “in loco” for each gPS’ farm and calibrated to Portugal conditions (Fernandes et al. 2009)

Wilfire behaviour characteristics:

| Fireline intensity (FLI, Kw/m) |
| Rate of spread (ROS, min/m) |

Estimate the change in the annual expected wood loss (WL) due to fire from treatments

\[ E (WL) = \Delta SR \times \Delta FL \]
STEP #2

2.4 Calculating spread rate & flame length across landscapes

- **1** | Calculate Spread Rate (SR)
  
  Run in **Ex-RATE program** for each weather condition

- **2** | Calculate Flame length (FL)

For each fuel arrangement/weather scenario:
- Calculate $\Delta FL$
- Calculate $\Delta SR$
- **Analyze the corresponding sigmoid curve trends**

STEP #2

2.5| Outputs FlamMap

- 8 combinations of wind speed * direction
- 3 fire behaviour parameters
- 24 layers

Scenario: 12km/h - 180

<table>
<thead>
<tr>
<th>FLI</th>
<th>ROS</th>
<th>CFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>738.05</td>
<td>14761</td>
<td>1.381</td>
</tr>
</tbody>
</table>

Scenario: 40km/h - 304

<table>
<thead>
<tr>
<th>FLI</th>
<th>ROS</th>
<th>CFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>1268.55</td>
<td>25371</td>
<td>2.374</td>
</tr>
</tbody>
</table>
STEP #2

2.5 Outputs FlamMap

UG Sul: Odemira

Passive crown fire

Active crown fire

Odemira: Fireline Intensity

12km/m
Direcção:001

Legend

Low
Moderate
High
Very high
Extreme

40km/m
Direcção:338
FIRE-ENGINE

| EXPLORE OPTIMAL LEVEL FOR FUEL TREATMENT |

STEP III
STEP #3

3.1 Landscape treatment designer?

- Where to treat?
- How much?
- Shape and size?
- Examine change in risk

3.2 | Explore optimal levels for fuel treatments

**STEP #3**

3 gPS farms:

- **North** (1471.48 ha)
- **Centre** (173.34 ha)
- **South** (2020.34 ha)

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Objective function(s)**

- e.g. Max SR
- Min E(WL)

**Fire behavior treatment threshold(s)**

**Activity constraint(s)**

- e.g. Annual Budget for fuel treatments
- Total area treated
- Policy constraints

**LTD program**

- e.g. spatial prioritization of fuel treatments

* e.g. fire characteristics (FL), biometric targets from fire behaviour models
3.3 Explore optimal levels for fuel treatments
FIRE-ENGINE

| Remarks

| Points of view
REMARKS

The research contains spatial and temporal dimensions to integrate landscape-scale properties required to meet fire management goals in *eucalyptus farms* distributed over Portugal.

- The framework was driven taking into account several decision support tools of the United States Wildfire Modeling System for wildfire risk management, focuses on a three-tiered approach strategy calibrated and applied in Portugal.

- The approach provided an overview of management guidelines for fuel modifications to make the gPS eucalyptus farms, in Portuguese conditions, more resistant to fire, selecting priority intervention areas and designing effective strategies, without encroaching budget constraints.
Project "Flexible design of forest fire management systems - FIRE-ENGINE" (MIT/FSE/0064/2009), financiado por fundos nacionais através da FCT/MCTES (PIDDAC) e co-financiado pelo Fundo Europeu de Desenvolvimento Regional (FEDER).

Ph.D. Grant of Brigite Botequim, “Tools to support the design of fire-resistant landscapes in Portuguese ecosystems” SFRH/BD/44830/2008, Financiado pela Fundação para a Ciência e Tecnologia.

ACKNOWLEDGMENTS
Muito Obrigada!