SuFoRun

Models and decision SUpport tools for integrated FOrest policy development underglobal change and associated Risk and UNcertainty

MODIFRE
Promoting fire risk reduction in harvest-scheduling problems

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The New York Times

Portugal Fires Kill More Than 60, Including Drivers Trapped in Cars

Flames and smoke cut off roads on Sunday in Capela Sao Neitel, in central Portugal, where members of the National Guard tried to contain several forest fires. Paulo Cunha/European Pressphoto Agency

Background

- In 2017, wildfires in Portugal claimed over 110 lives and destroyed property worth over one thousand million euros.

- Need for the development of an effective regulatory services framework.

- For us researchers
  Methods and tools that may help integrate forest and fire management planning activities currently still being carried out mostly independently of each other.

Background

Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/forestsystems
doi: http://dx.doi.org/10.5424/fs/2112211-11374

Forest Systems 2012 21(1): 111-120
ISSN: 2171-5068
eISSN: 2171-9845

Assessing wildfire occurrence probability in *Pinus pinaster* Ait. stands in Portugal

S. Marques[1]*, J. Garcia-Gonzalo[1], B. Botequim[1], A. Ricardo[1],
J. G. Borges[1], M. Tome[1], M. M. Oliveira[1,2]
[1] *Centro de Estudos Florestais, Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Portugal*
[2] *Centro de Investigação em Matemática e Aplicações,Universidade de Évora, Portugal*

Forest dynamics

Modeling variables related to fire dynamics

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)]

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 im-

sustainability

MDPI

Article

Addressing Wildfire Risk in Forest Management Planning with Multiple Criteria Decision Making Methods

Susete Marques [1,*], Marco Marto [1], Vladimir Bushenkov [2], Marc McDill [3] and José G. Borges [1]

Towards decision-making

Harvest-scheduling

- The implementation of harvest-scheduling formulations oriented to include fuel treatment activities can be simplified by spatially decomposing factors such as wind.

- Trying to promote simplicity.

- Wildfire simulators

i. interaction between complex spatial dynamics
ii. need to parametrize the toolbox for the specific conditions of the study area
iii. people use what they are capable to understand
iv. integration in harvest-scheduling optimization problems

Fire burn probabilities

- The estimation of fire risk probability is complex.

- The probability that a forest stand will burn within a given time interval depends on stand-level characteristics, biophysical factors, adjacency relationships and the characteristics of neighboring forest stands.

- Flammability
  annual probability of a given stand to burn

- Fire burn probability
- Flammability + Spatial patterns & Adjacency constraints

Matrix-case scenarios

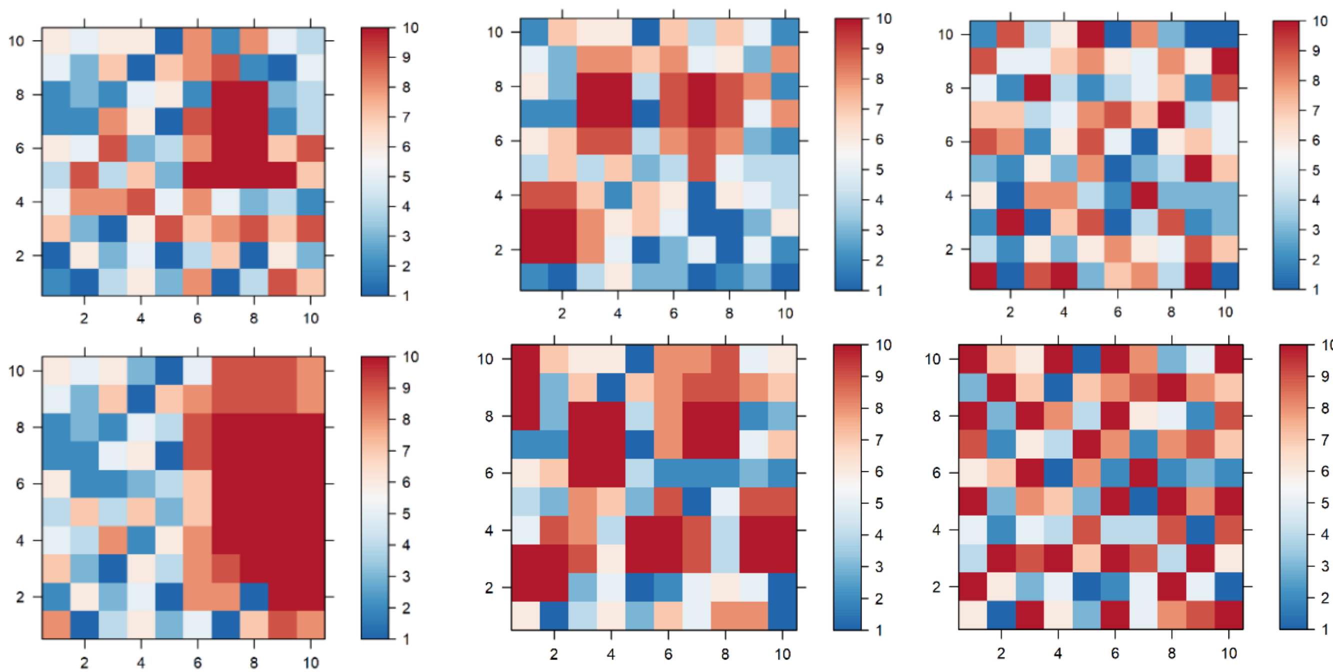
Ground data for eucalyptus stands in Portugal

1. Age classes
2. Growing stock volume
3. Proportion of shrub biomass & Flammability

Clustered *Dispersed* *Irregular*

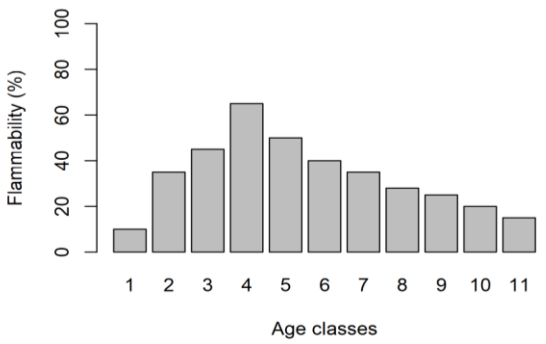
Age-balanced

Age-unbalanced

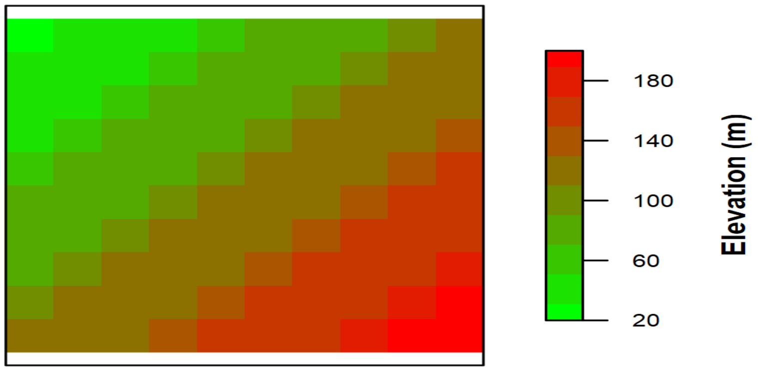


Fire burn probabilities

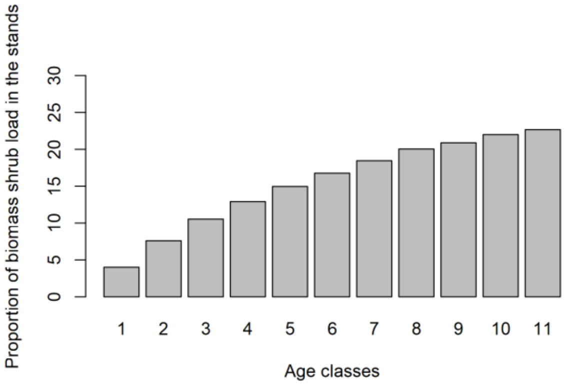
- Flammability



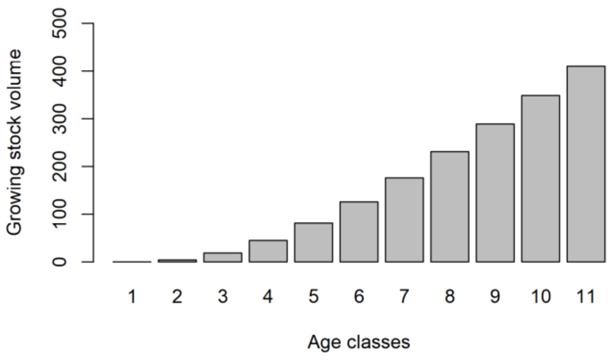
- Sloped and Flat conditions



- Biomass load



- Volume



Fire burn probabilities

- The computation of fire probabilities recognizes elevation, slope, wind directions (d) and the probability that a neighboring cell will burn.

- The spatial effect of wind can be simplified considering four independent cases: Northwest (NW), Northeast (NE), Southwest (SW) and Southeast (SE).

- The wind factor was proportionally scaled: 50% for both NW and NE. Fires could not spread from SW and SE.

- The likelihood of the wind to propagate the flames was 0.5 in the horizontal (*H*) and 0.75 in the diagonal.

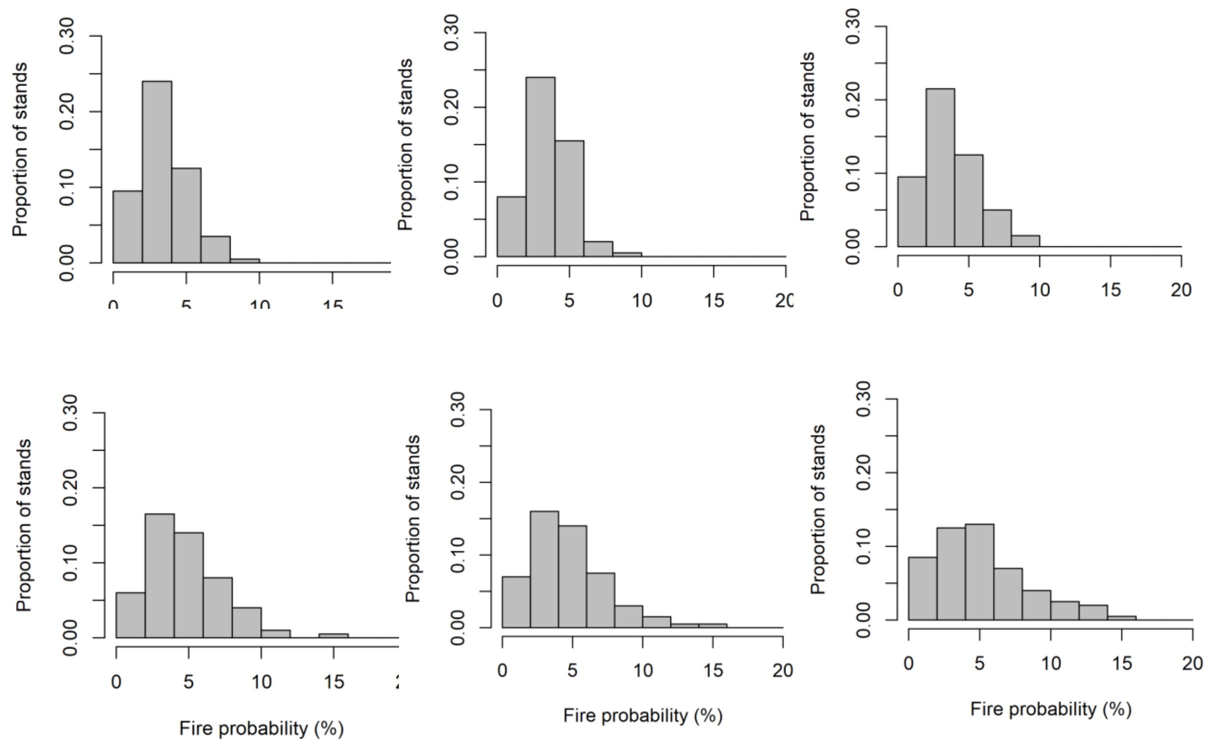
Fire burn probabilities

$$p_i^F|d \cong p_i^I f_i + \left(1 - p_i^I f_i\right) \times \sum_{j\epsilon Adj_i^d} F_j^p \times p_j^F \Big|d \times (p_{ji}^{S_{HT}}\Big| d\ ),$$

Present state *Clustered* *Dispersed* *Irregular*

Age-balanced

Age-unbalanced



Fire burn probabilities

$$p_i^F|d \cong p_i^I f_i + \left(1 - p_i^I f_i\right) \times \sum_{j \epsilon Adj_i^d} F_j^p \times p_j^F \left| d \times (p_{ji}^{S_{HT}} \right| d\ ),\mathrm{c}$$

Present state

	Mean annual fire burn probability (%)				Maximum annual fire burn probability (%)			
Scenario	Balanced-age		Unbalanced-age		Balanced-age		Unbalanced-age	
Problem	Flat	Sloped	Flat	Sloped	Flat	Sloped	Flat	Sloped
Clustered	3.5	4.7	3.3	4.7	8.2	14.4	8.92	15.8
Dispersed	3.4	4.6	3.1	4.3	8.9	14.2	7.81	13.5
Irregular	3.6	5.1	3.2	4.3	9.0	14.9	8.04	12.1

Harvest-scheduling model

- Objetive: reduced timber expected losses as a result of fire burn probabilities
- One period plan
- Area-based constraints
- Treatments:
  X (harvests; fixed)
  Y (fuel removals, variable)

  $Y = CS = c\ (10,15, 20, 25)$

$$MAX\ \ OF = \sum_{i=1}^{C} [OF_1 + OF_2]$$

$$OF_1 = v_i(a_i) \times X_i$$

$$OF_2 = v_i(a_i + 1) \times (1 - p_i^F) \times (1 - X_i) + v_i(1) \times (1 - p_i^F) \times X_i$$

$$\sum_{i=1}^{C} X_i = |CC|$$

$$\sum_{i=1}^{C} X_i = \frac{C}{K}$$

$$\sum_{i=1}^{C} Y_i = |CS|$$

$$X_i + Y_i \leq 1$$

$$p_i^F|d \cong p_i^I f_i + (1 - p_i^I f_i) \times \sum_{j \epsilon Adj_i^d} F_j^p \times p_j^F\big|d \times (p_{ji}^{SHT}\big|d\ ),$$

$$p_i^F = \sum_{d=1}^{4} p_i^F|d$$

$$f_i = flam(a_i) - flam(a_i) \times \frac{e^{-\beta \times a_i}}{1 + e^{-\beta \times a_i}} \times Y_i,$$

$$0 < \beta \leq 1.$$

$$X_i,\ Y_i \in \{0,1\}, i = 1,2, \dots, C$$

Harvest-scheduling model

- In every interation:

- i) The algorithm accounts for the change in fire burn probability for each cells and its neighboring stands, and

- Ii) distinguish between fuel removals (accounts for shrub biomass) and harvests (accounts for harvested volume)

$$MAX\ \ OF = \sum_{i=1}^{C}[OF_1 + OF_2]$$

$$OF_1 = v_i(a_i) \times X_i$$

$$OF_2 = v_i(a_i + 1) \times (1 - p_i^F) \times (1 - X_i) + v_i(1) \times (1 - p_i^F) \times X_i$$

$$\sum_{i=1}^{C} X_i = |CC|$$

$$\sum_{i=1}^{C} X_i = \frac{C}{K}$$

$$\sum_{i=1}^{C} Y_i = |CS|$$

$$X_i + Y_i \leq 1$$

$$p_i^F|d \cong p_i^I f_i + (1 - p_i^I f_i) \times \sum_{j \epsilon Adj_i^d} F_j^p \times p_j^F|d \times (p_{ji}^{SHT}|d),$$

$$p_i^F = \sum_{d=1}^{4} p_i^F|d$$

$$f_i = flam(a_i) - flam(a_i) \times \frac{e^{-\beta \times a_i}}{1 + e^{-\beta \times a_i}} \times Y_i,$$

$$0 < \beta \leq 1.$$

$$X_i,\ Y_i \in \{0,1\}, i = 1,2, \dots, C$$

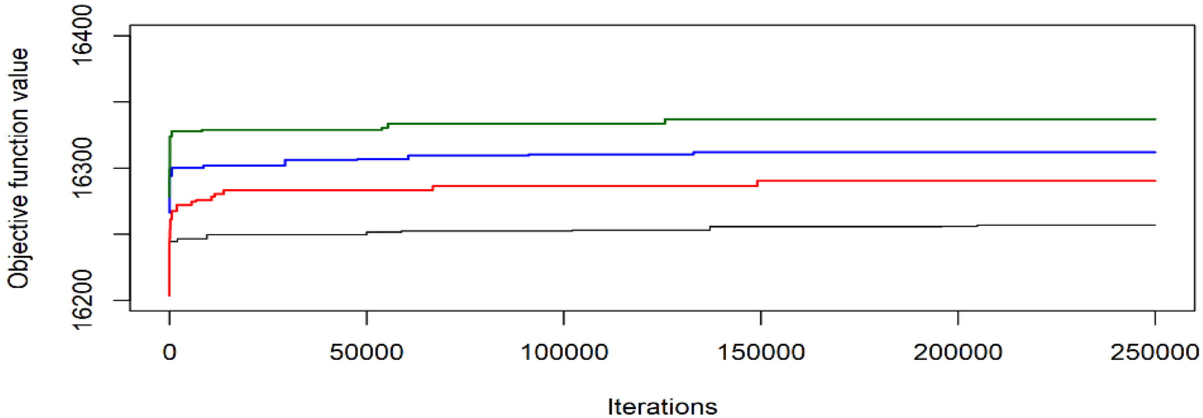
Optimization

- Limited computational effort for the 100-stand matrix

- The use of real forest inventory will upscale the complexity of the problem.

- **Simulated annealing**-based flowchart

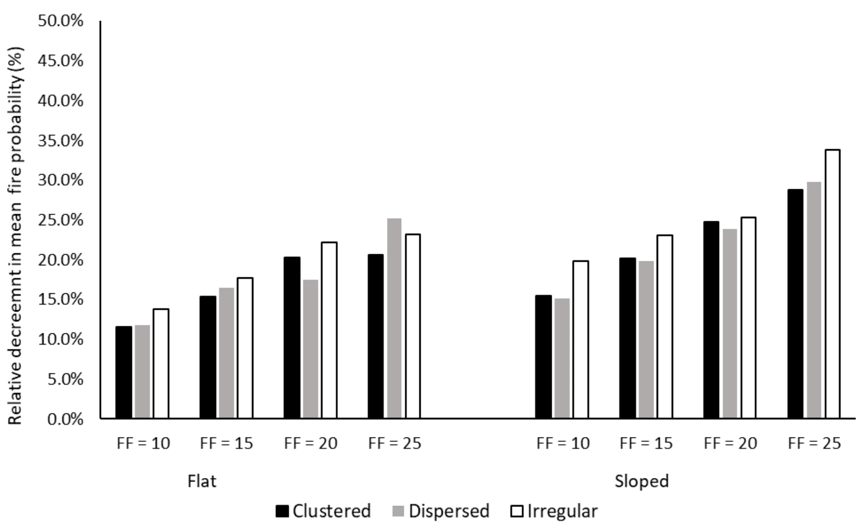
Iterations	OF_1 (m^3)	OF_2 (m^3)	OF (m^3)	Expected timber losses (m^3)	Mean Fire prob (%)
10^4	3427.3	17548.0	38523.3	418.8	2.73
5×10^4	3367.6	17608.7	38585.1	419.0	2.80
10^5	3427.3	17555.5	38538.3	410.9	2.75
5×10^5	3307.9	17676.9	38661.7	412.3	2.74
10^6	3300.0	17645.8	38591.6	412.3	2.73



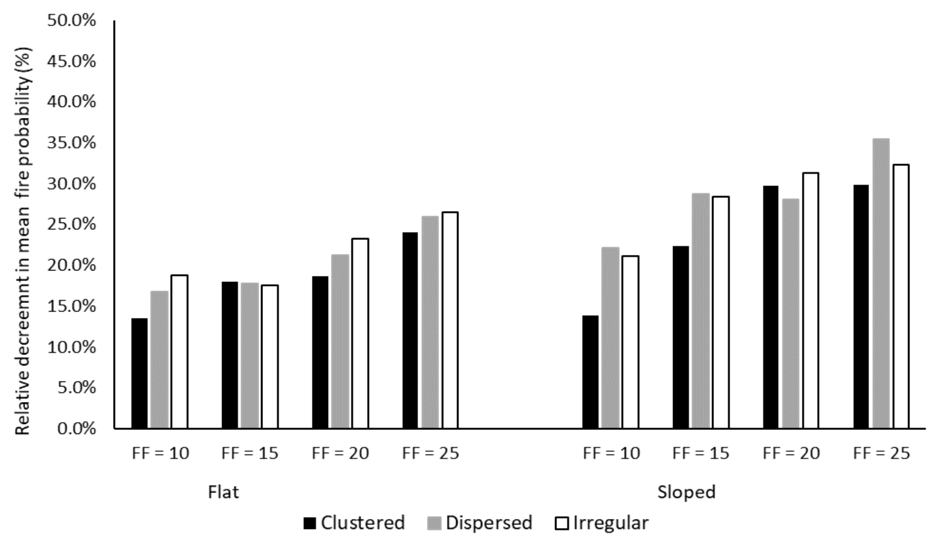
Reduction of fire burn probabilities

$$p_i^F | d \cong p_i^I f_i + \left(1 - p_i^I f_i\right) \times \sum_{j \epsilon Adj_i^d} F_j^p \times p_j^F \left| d \times (p_{ji}^{S_{HT}} \right| d),$$

End of the period



Age-balanced



Age-unbalanced

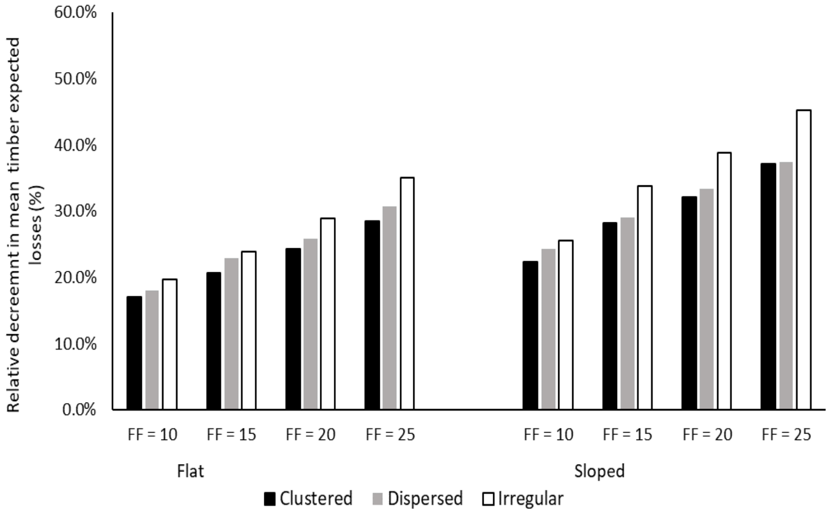
Reduction of timber expected losses

$$MAX\ \ OF = \sum_{i=1}^{C}[OF_1 + OF_2]$$

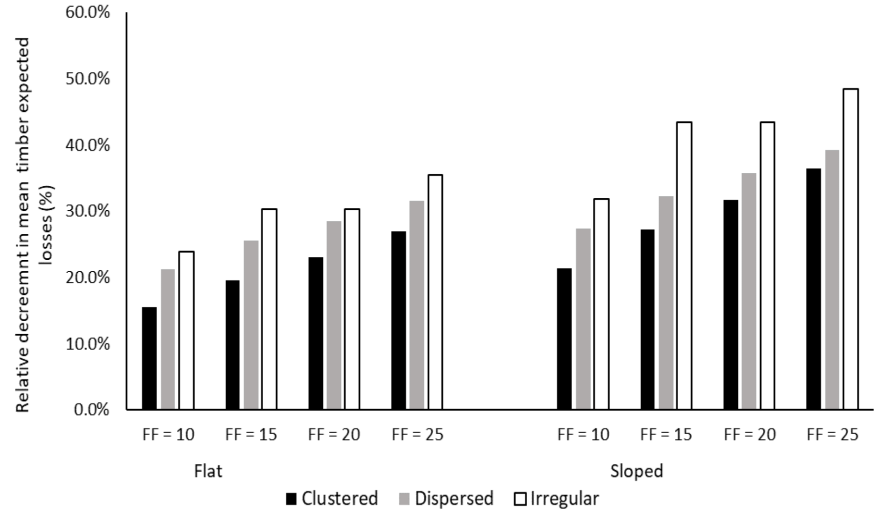
$$OF_1 = \ v_i(a_i) \times X_i$$

End of the period

$$OF_2 = \ v_i(a_i + 1) \times (1 - \ p_i^F) \ \times (1 - X_i) + \ v_i(1) \times (1 - \ p_i^F) \ \times X_i$$

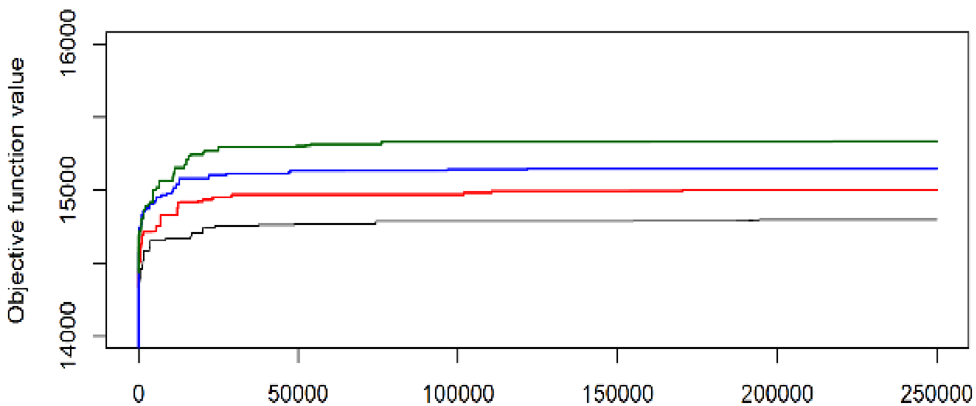


Age-balanced



Age-unbalanced

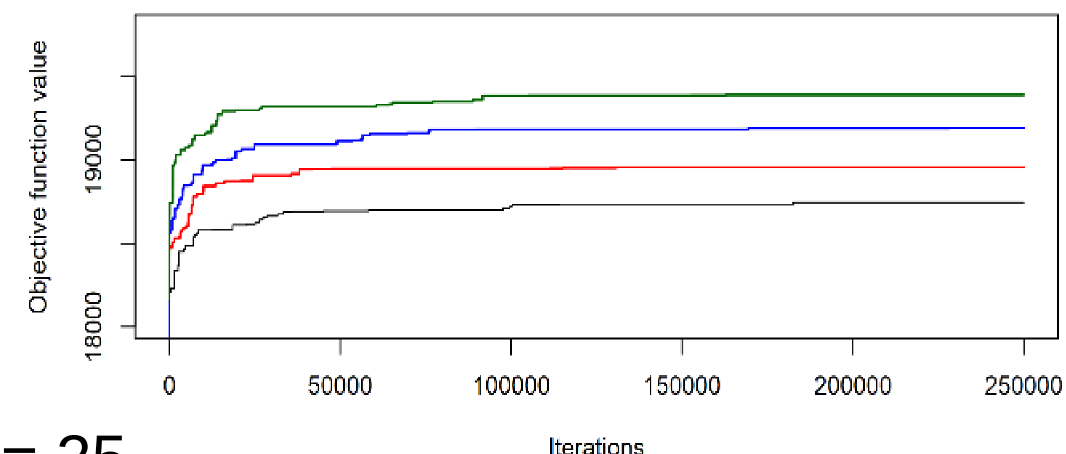
Progress of the optimization



CS = 10

- Optimization convergence = f (CS)

- Fast runs
- 250,000 iterations
- 10.47 – 13.2 min



CS = 25

Discussion

- The computation of fire probability was simplified.
- What is the impact of our approach compared to sophisticated wildfire simulators?

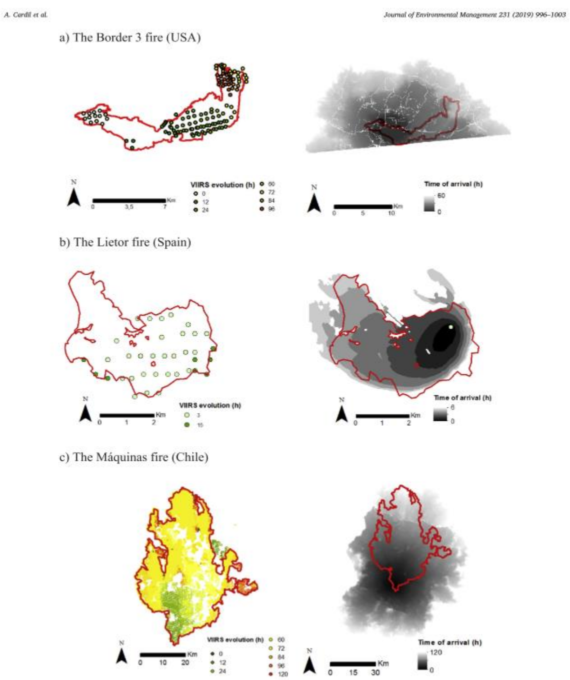


Fig. 2. Real fire perimeter, VIIRS data evolution from the fire start (left) and simulated fire growth without reinitialization (right) in all analyzed wildland fires.

Complexity versus Impact

Journal of Environmental Management 231 (2019) 996–1003

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

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Research article

Assessing and reinitializing wildland fire simulations through satellite active fire data

Adrián Cardil[a,*], Santiago Monedero[a], Joaquin Ramírez[b], Carlos Alberto Silva[c]

[a] Tecnosylva. Parque Tecnológico de León. 24009, León, Spain
[b] Technosylva. UCSD Calit2 Qualcomm Institute, La Jolla, CA 92037, USA
[c] Department of Natural Resources and Society, College of Natural Resources, University of Idaho, (UI), 875 Perimeter Drive, Moscow, ID, 83843, USA

Discussion

- Importance of fuel treatments in operational forestry

- Matrix-based design to validate the algorithm.
- Simplicity was promote

- Limitations at this development stage: one planning period

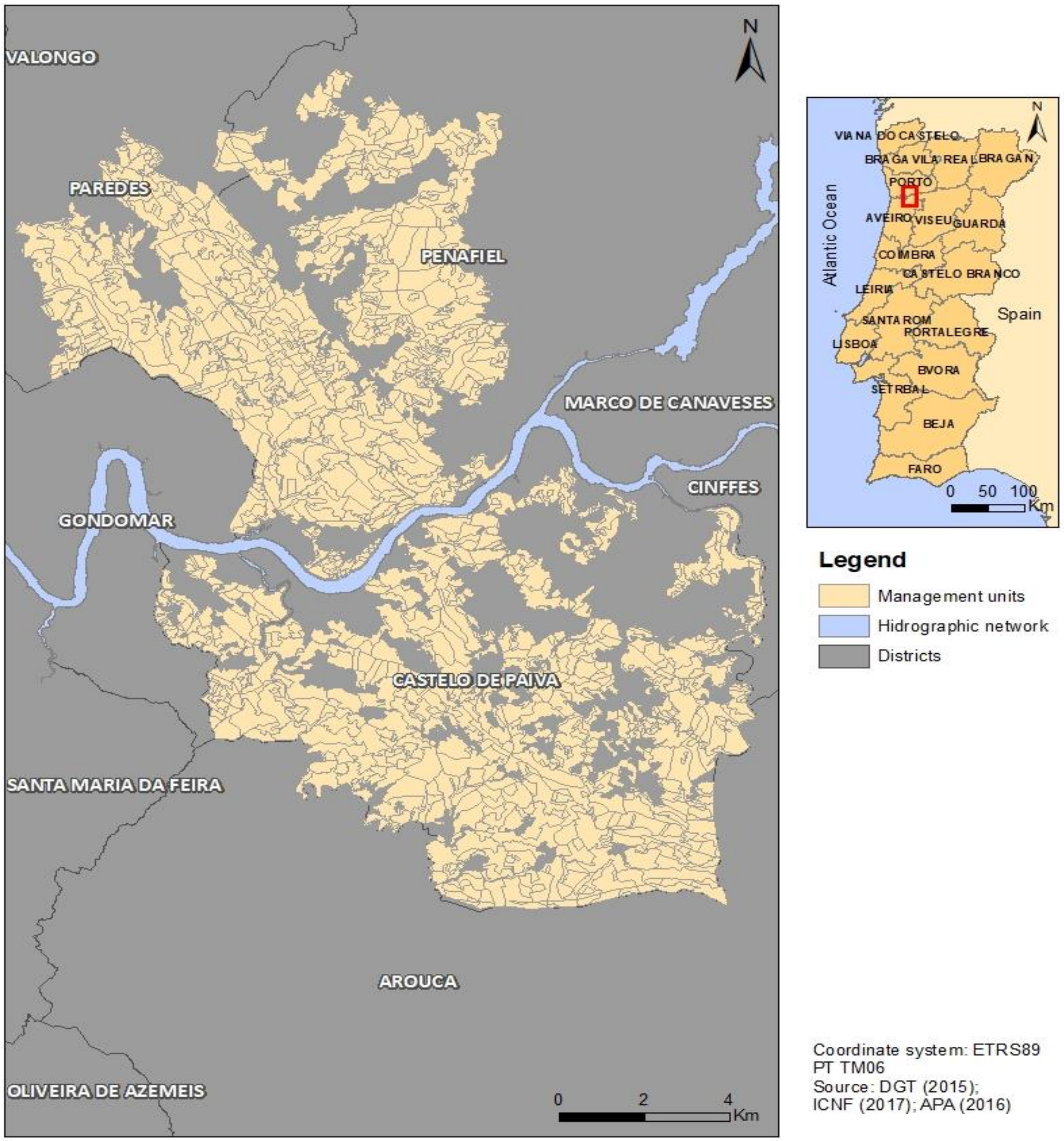
- Preliminary step to implement the methodology using real forest inventory data combined with wildifre simulators to predict flammability and fire burn probability

- Coming challenges

Progress of MODFIRE

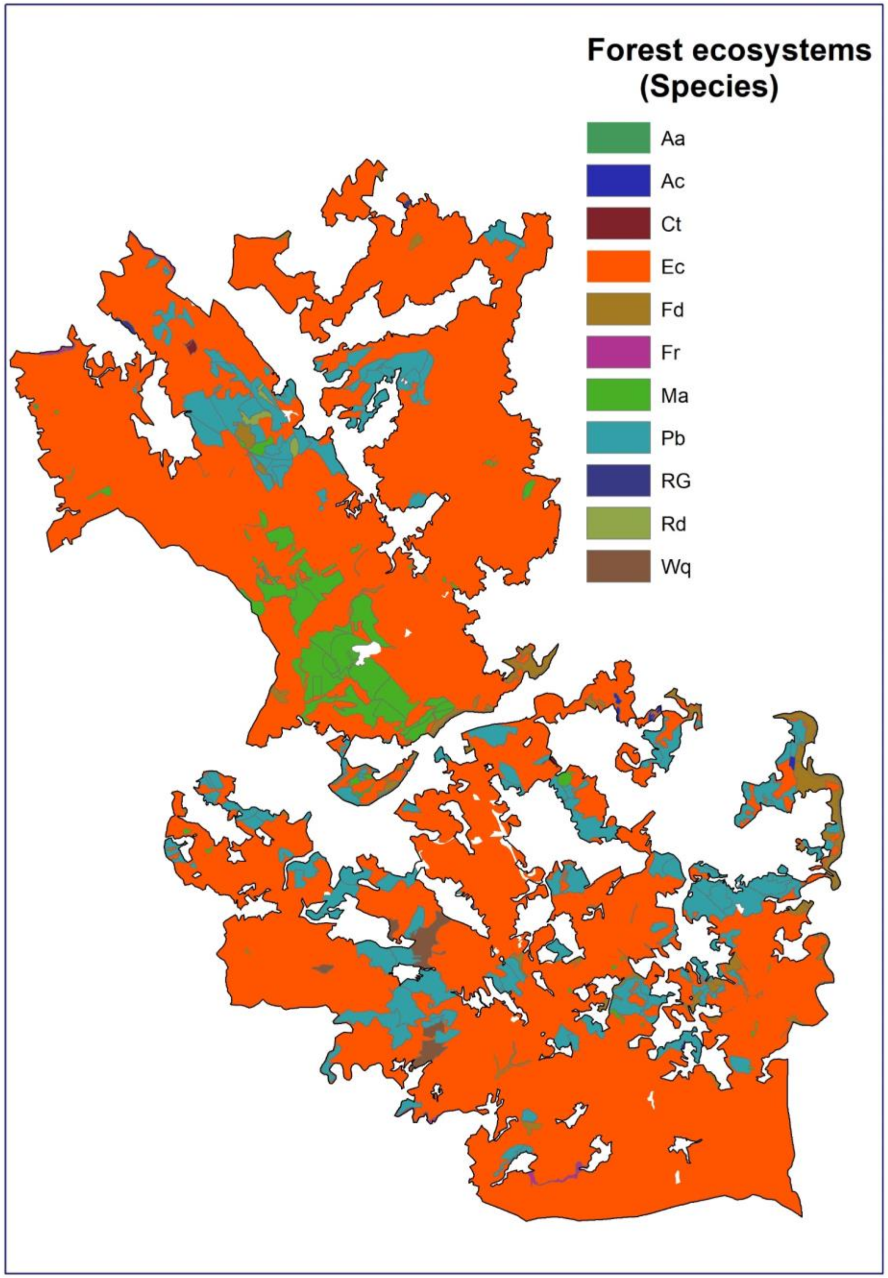
- Forest inventory data (ground data and satellite images)
- Step 0: Algorithm to account for fire burn probabilities
- Step 1: Integration of fire burn probability in HS models
- Step 2: HS based on área-based units with real data at tactical and operational planning
- Step 3: HS based on tree-level information in operational planning
- 2019 - 2022

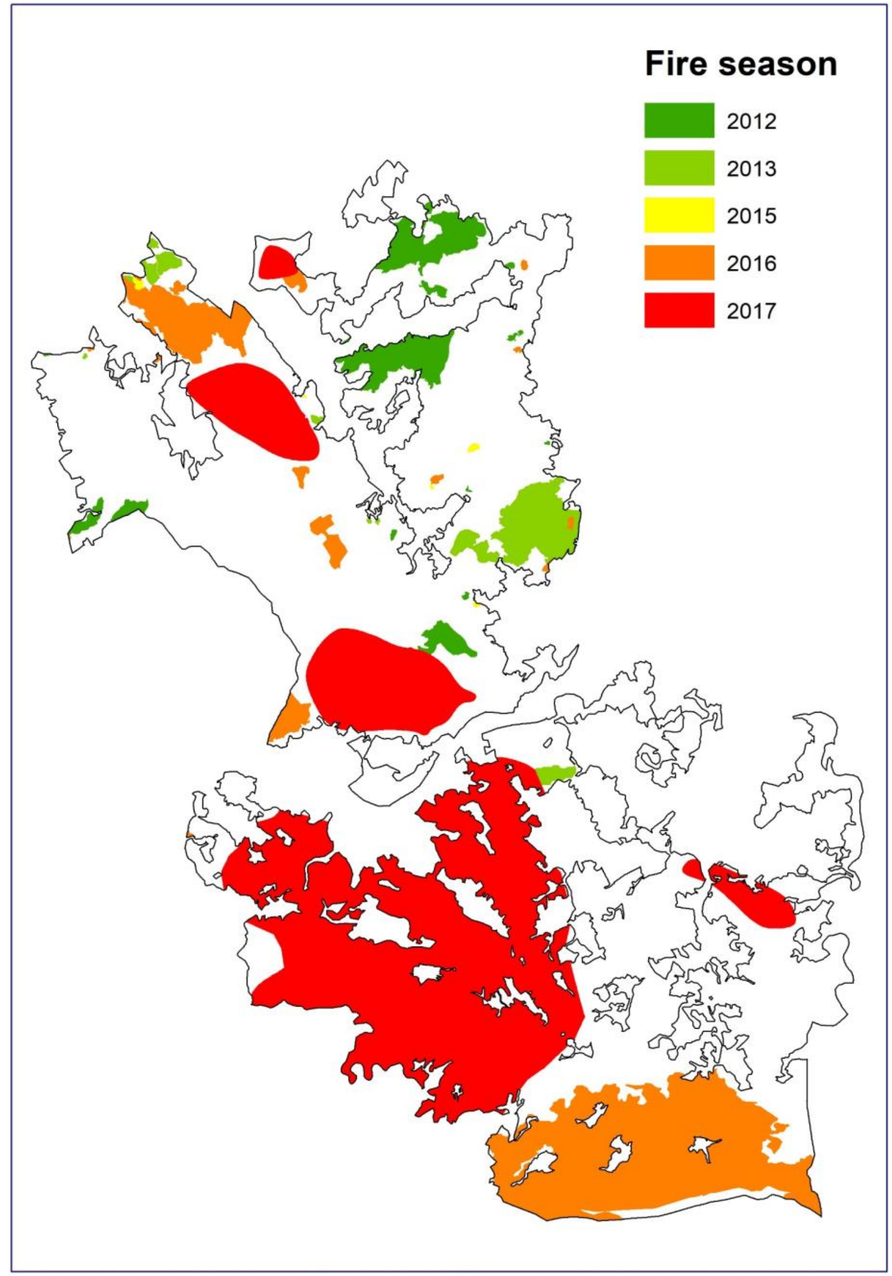
Vale do Sousa
Management Units Framework

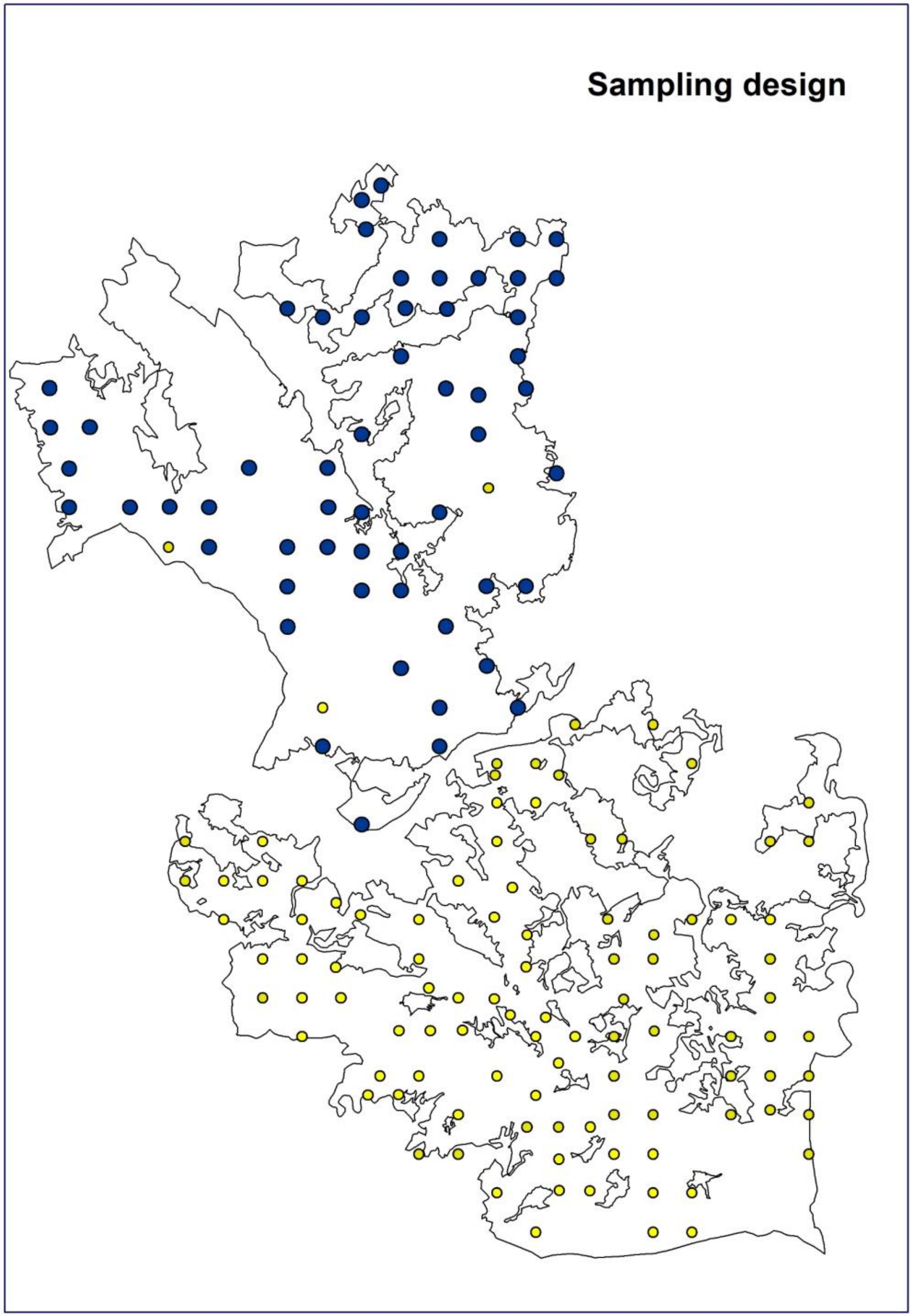


MODFIRE

- Recent fire trends
- Updating of the forest inventory
- 160 plots
- Traditional and RS-based forest inventory
- Validation of the developed HS formulation using real forest data


Forest ecosystems
(Species)
Aa
Ac
Ct
Ec
Fd
Fr
Ma
Pb
RG
Rd
Wq


Fire season
2012
2013
2015
2016
2017



MODFIRE

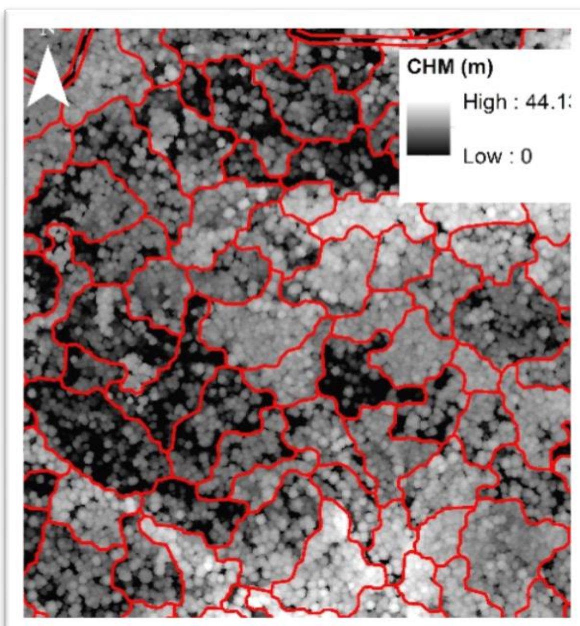
- Sampling design
- To be completed in late November 2019
- Use of **Pléiades** images to downscale the resolution
- Better capturing of fire patterns

Towards improved solutions

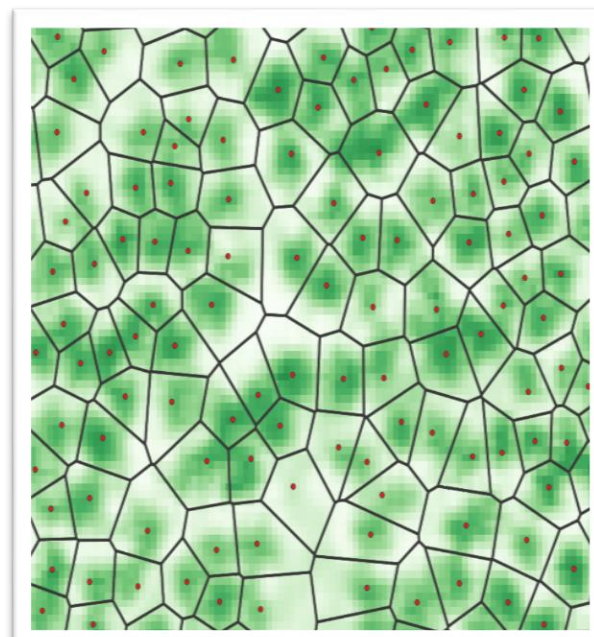
- Proportion of edge shared with neighboring units for each tested directional distribution

$$p_i^F | d \cong p_i^I f_i + \left(1 - p_i^I f_i\right) \times \sum_{j \epsilon Adj_i^d} F_j^p \times p_j^F \Big| d \times (p_{ji}^{S_{HT}} \Big| d),$$

Area / Stand-level



Tree-level



Acnowledgements

- MODFIRE project—A multiple criteria approach to integrate wildfire behavior in forest management planning (PCIF/MOS/0217/2017)

- This research was also partially funded by national Portugese funds through FCT – Fundação para a Ciência e a Tecnologia, I.P. in the scope of Norma Transitória – DL57/2016/CP5151903067/CT4151900586 and DL57/2016/CP5151806364/CT4151803715

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