Estimating Fire Hazard in a Protected area of central Spain (Cabañeros National Park) by a full characterization of vegetation using LiDAR

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The main objective of fire risk analysis is to estimate the probability of exposure of high value resources and assets to forest fires at different levels of intensity and to predict the responses of these resources and values. Consequently, forest fire risk can be defined as the multiplicative interaction between the hazard (probability and intensity of a fire) and its impact (exposure and vulnerability).
**COMPONENTS OF RISK AND VULNERABILITY**

<table>
<thead>
<tr>
<th>Exposed values</th>
<th>Hazard magnitude</th>
<th>Susceptibility</th>
<th>Lack of adaptive capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P</strong> Provisioning</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>R</strong> Regulating</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>C</strong> Cultural</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>S</strong> Supporting</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

- **Intrinsic factors**
  - Structural characteristics
    - Vertical and horizontal continuity
    - Fuel load
    - Basal area
    - Leaf Area Index
    - Height/diameter ratio
    - Functional characteristics
      - Bark thickness
      - Flammability
      - Hydraulic traits
      - Rooting depth
      - Functional diversity
  - Lack of extinction capacity
    - Distance to water bodies
    - Distance to fire stations
    - Warning system
    - Pesticide use

- **Extrinsic factors**
  - Climate-change hazards
    - Wildfires
    - Drought
    - Insect outbreaks
    - Windstorms

**Figure 3.** Indicators for each of the components of risk and vulnerability for the four main climate-change hazards considered in this study (wildfires, drought, pests, and windstorms).

OBJECTIVES

Main Objective:

1. To classify the landscape by:
   • its “fire hazard” using the Fuel Models (FMs) as framework
   • its “resistance” and “resilience” to forest fires as main disturbance using plant functional traits

Specific Objectives:

1. To pre-process adequately LiDAR data to derive forest metrics as accurate as possible. Sensitivity analysis of filter algorithms to classify the points cloud (ground-no ground).

2. To develop FMs complexes to characterize the structure, the composition and the moisture content of vegetation (at both pixel and polygon scales).

3. To link the developed FMs with standard FMs as those done by Scott and Burgan (2005) and Rothermel (1972).

4. To carry out fire spread simulations at landscape scale based on the FMs using the FLAMMAP soft.
MATERIAL AND METHODS

LIDAR DATA

- FCC (total, trees, understory)
- Height statistics
- Total and by vegetation strata:
  Low (< 1m); Medium (1-2m); Tall (2-4m)

NATURAL VEGETATION SYSTEMS MAP

Community types:
- Grasses
- Shrubs
- Forests (conifers, broadleaved: evergreen-deciduous)

NATIONAL FOREST MAP + AUXILIARY DATA

Dominant species (first three ones)

Functional traits: resistance and resilience to forest fires

Vegetation structure

Vegetation composition

Flammability
LIDAR DATA

1. The LiDAR sensor responsible for the emission and reception of the laser pulse, measurement of the reading angle and the time it takes for the emitted pulse to reflect on a surface.
2. The Global Positioning System (GPS-GNSS) whose function is to determine the $x$, $y$, $z$ coordinates of the LiDAR sensor during its trajectory together with a GPS ground station.
3. The inertial measurement unit (IMU) measures the heading of the aircraft. This is combined with the LiDAR sensor, which establishes the angular orientation for each pulse.
## SPANISH LIDAR DATA (since 2008)

### TECHNICAL SPECIFICATIONS LiDAR PNOA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (points/m²)</td>
<td>0.5-1</td>
</tr>
<tr>
<td>Point spacing (m)</td>
<td>1.41</td>
</tr>
<tr>
<td>LiDAR sensor</td>
<td>ALS 50 – II</td>
</tr>
<tr>
<td>FOV (°)</td>
<td>50</td>
</tr>
<tr>
<td>PRF (kHz)</td>
<td>70 min</td>
</tr>
<tr>
<td>Sweep Frequency (Hz)</td>
<td>70Hz</td>
</tr>
<tr>
<td>Speed (knots)</td>
<td>148</td>
</tr>
<tr>
<td>Speed (Km/h)</td>
<td>274</td>
</tr>
<tr>
<td>Transversal overlap (%)</td>
<td>15</td>
</tr>
<tr>
<td>Altimetric discrepancy between passes</td>
<td>≤ 0.40 m</td>
</tr>
<tr>
<td>RMSE</td>
<td>≤ 0.20 m</td>
</tr>
<tr>
<td>Distance to reference stations</td>
<td>≤ 40 km</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>8 bits</td>
</tr>
<tr>
<td>GPS</td>
<td>min. 2Hz</td>
</tr>
<tr>
<td>Pixel size (spatial resolution)</td>
<td>0.25 m</td>
</tr>
<tr>
<td>Maximum length of a longitudinal pass</td>
<td>4 tiles from MTN 50</td>
</tr>
</tbody>
</table>
MATERIAL

NATURAL VEGETATION SYSTEMS MAP

Multilevel legend
NATURAL VEGETATION SYSTEMS MAP

Multilevel legend

Level 1
- cdad_ruderales
- form_arbustivas
- mat_acidoofilos
- pastizal_atlantico
- pastizal_mediterraneo
- sist_abioticos
- sist_antropicos
- sist_bosques_coniferos
- sist_bosques_esclerofilos
- sist_humedales
- vech_hidrofilo

Level 2
- Agua
- Alcornocales
- Bosque_misto_esclerofilico
- Bosques_riviera
- Dehesas
- Encinares
- Espinares
- Formaciones_freatofitas
- Herbazales
- Jorales_brezales_maquis
- Madroñales
- Melojares_rebiedales_rebollares
- Pastizales_diente
- Pastizales_oligotrofos
- Pinares_Pinus_pinaster
- Pinares_Pinus_pinea
- Praderas_juncuales
- Quejigares
- Repoblaciones
- Retamares_escobonales_pioionales
- Sistemas_agricolas
- Sistemas_artificiales
- Turberas
- Vegetacion_acuatica
- roquetos
- vegetacion_canchoales

Level 3
- Abedules_meridionales
- Agua
- Alcornocales
- Alidadas
- Brezales_aranicos
- Brezales_higmotuberosos
- Brezales_negros
- Brezales_Erica_australis
- Choperas
- Cortafuegos
- Cultivos
- Dehesas_Qeaginea
- Dehesas_alcornocales
- Dehesas_encina
- Dehesas_encina_alcornocales
- Encinar_alcornocal
- Encinas_carrascas
- Escobonales
- Fresnedas
- Infraest_viales
- Jorales
- Loreras
- Madroñales
- Melojases
- Pastizales_diente
- Pastos_troficos
- Pastos_troficos_nitrificados
- Pinares_Pinus_pinaster
- Pinares_Pinus_pinea
- Praderas_juncuales
- Quejigares
- Saucedas
- Tamujanes
- Vallesanas
- Vegetacion_acuatica
- Zarzales
- Zonas_ediificadas
- cdlades_cartiles
- vegetacion_canchoales
NATIONAL FOREST MAP (2004)

DOMINANT SPECIES (3 LEVELS)
FLAMMABILITY
DOMINANT SPECIES

NATIONAL FOREST MAP
(2004)
0. PRE-PROCESSING OF THE ORIGINAL CLOUD POINTS

1. lasort

2. Laszip
   - merged

3. Lasinfo
   - Lasvalidate

4. Lasnoise

5. lasduplicate

Original cloud points

Ordered and indexed tiles

Compresed and merged tiles

Information and validation reports

Cleaned cloud points

Depurated cloud points
1. CLASSIFICATION OF ORIGINAL CLOUD POINTS: GROUND – NON GROUND

Filter of Progressive densification (TIN)

TIN = Triangular Irregular Networks

TIN Filters:
- TOWN
- WILD
- SWITCH
- DEFAULT
- SIOSE

Classification of last returns (ground – non ground)

DEM generation
METHODOLOGY

2. HEIGHT NORMALIZATION

Classified points (ground-non ground)

Lasheigh -replace_z

NORMALIZED ELEVATION OF THE CLOUD POINTS (MIN= 0)
3. PIT-FREE CANOPY HEIGHT MODEL

Normalized elevation of cloud points

grid_canopy pitfree(0,2,5,10,15,20,30)
4. VEGETATION METRICS

At Polygon Scale

- **Lascanopy**

At Grid Scale

**Fraction Cover** estimated by **Height Bins**
(density of points by height thresholds)

- **Understory**
  - ($< 0.3m$; $< 1m$; $1-2m$ and $2-4m$)
- **Canopy**
  - ($> 4m$)

**Height metrics for Understory and Canopy**
(Mean, Max, Min, SD, Percentiles 5-50-90-95)

Normalized elevation of cloud points
METHODOLOGY

5. TREE TOPS LOCATION

Normalized elevation of cloud points

\[ \text{locate\_trees} (h_{\text{min}} = 4) \]

(Different window sizes: adaptative, fixed 5 and 10)
6. CROWN METRICS

- Height (min, max, mean, sd)
- Length
- Diameter
- Area
- Horizontality
- Sphericity...

Methods: Silva, Dalponte, Watershed
RESULTS

1. SENSITIVITY ANALYSIS OF THE DIFFERENT PROGRESSIVE DENSIFICATION FILTERS

**DEFAULT – SIOSE DEMs**

TIN Filters:
- TOWN
- WILD
- SWITCH
- DEFAULT
- SIOSE
RESULTS

1. SENSITIVITY ANALYSIS OF THE DIFFERENT PROGRESSIVE DENSIFICATION FILTERS

DEFAULT – SWITCH

Steep mountain with trees
Orthoimage 2009
## RESULTS

### 2. FUELS STRUCTURE CHARACTERIZATION (LIDAR DATA)

<table>
<thead>
<tr>
<th>Fractional cover</th>
<th>Understory height</th>
<th>Treeless /Open forests (FCC trees &lt; 25 %)</th>
<th>Transitional forests (FCC trees &lt; 50 %)</th>
<th>Dense forests (FCC trees ≥ 50 %)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LOW LOAD</strong></td>
<td>small: &lt; 1m</td>
<td>OA1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(FCCtot &lt; 25 %)</td>
<td>medium: 1-2m</td>
<td>OA2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>tall: 2-4 m</td>
<td>OA2</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MODERATE LOAD</strong></td>
<td>small: &lt; 1m</td>
<td>MA1</td>
<td>MA4</td>
<td></td>
</tr>
<tr>
<td>(FCCtot ≥ 25 and &lt; 50 %)</td>
<td>medium: 1-2m</td>
<td>MA2</td>
<td>MA5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>tall: 2-4 m</td>
<td>MA3</td>
<td>MA6</td>
<td></td>
</tr>
<tr>
<td><strong>HIGH LOAD</strong></td>
<td>small: &lt; 1m</td>
<td>DA1</td>
<td>DA4</td>
<td>DA7</td>
</tr>
<tr>
<td>(FCCtot ≥ 50 %)</td>
<td>medium: 1-2m</td>
<td>DA2</td>
<td>DA5</td>
<td>DA8</td>
</tr>
<tr>
<td></td>
<td>tall: 2-4 m</td>
<td>DA3</td>
<td>DA6</td>
<td>DA9</td>
</tr>
</tbody>
</table>

**OA**: Open areas (low fuel load)  
**MA**: Medium areas (moderate fuel load)  
**DA**: Dense areas (high fuel load)
RESULTS

FUELS STRUCTURE CHARACTERIZATION (LIDAR)

At Polygon Scale

At Grid Scale (30 m)
RESULTS

FUELS STRUCTURE CHARACTERIZATION (LIDAR)

At Polygon Scale

At Grid Scale (30 m)
RESULTS

FUEL MODELS OF MAIN VEGETATION TYPES

At Polygon Scale

At Grid Scale (30 m)
### RESULTS

<table>
<thead>
<tr>
<th>GRASSLANDS (GR) (Scott and Burgan)</th>
<th>Understory height</th>
<th>Treeless /Open forests (FCC trees &lt; 25 %)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VERY LOW LOAD</strong></td>
<td>small: &lt; 1m</td>
<td>GR1-D</td>
</tr>
<tr>
<td><strong>LOW LOAD</strong></td>
<td>small: &lt; 1m</td>
<td>(GR2-D/GR3-H) - GR5-H</td>
</tr>
<tr>
<td><strong>(FCCtot &lt; 25 %)</strong></td>
<td>medium: 1-2m</td>
<td></td>
</tr>
<tr>
<td><strong>TALL: 2-4 m</strong></td>
<td>tall: 2-4 m</td>
<td></td>
</tr>
<tr>
<td><strong>MODERATE LOAD</strong></td>
<td>small: &lt; 1m</td>
<td>(GR4-D/GR6-H)</td>
</tr>
<tr>
<td><strong>(FCCtot ≥ 25 and &lt; 50 %)</strong></td>
<td>medium: 1-2m</td>
<td></td>
</tr>
<tr>
<td><strong>TALL: 2-4 m</strong></td>
<td>tall: 2-4 m</td>
<td></td>
</tr>
<tr>
<td><strong>HIGH LOAD</strong></td>
<td>small: &lt; 1m</td>
<td>GR9-H</td>
</tr>
<tr>
<td><strong>(FCCtot ≥ 50 %)</strong></td>
<td>medium: 1-2m</td>
<td></td>
</tr>
<tr>
<td><strong>TALL: 2-4 m</strong></td>
<td>tall: 2-4 m</td>
<td></td>
</tr>
</tbody>
</table>

**LIDAR + VEGETATION MAP + HUMIDITY CONDITIONS**

D-H: Dry - Humid

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>GR1-D</td>
<td>GR2 (102)</td>
<td>GR3 (103)</td>
</tr>
<tr>
<td>GR2-D/GR3-H</td>
<td>GR4 (104)</td>
<td>GR5 (105)</td>
</tr>
<tr>
<td>GR4-D/GR6-H</td>
<td>GR6 (106)</td>
<td></td>
</tr>
<tr>
<td>GR7-D/GR8-H</td>
<td>GR7 (107)</td>
<td>GR8 (108)</td>
</tr>
<tr>
<td>GR9 (109)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**RESULTS**

- **GR1-D**
- **GR2 (102)**
- **GR3 (103)**
- **GR5 (105)**
- **GR4 (104)**
- **GR6 (106)**
- **GR7 (107)**
- **GR8 (108)**
- **GR9 (109)**
### RESULTS

<table>
<thead>
<tr>
<th>SHRUBS (SH)</th>
<th>Understory height</th>
<th>Treeless / Open forests (FCC trees &lt; 25 %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Scott and Burgan)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>VERY LOW LOAD</strong></td>
<td>small: &lt; 1m</td>
<td></td>
</tr>
<tr>
<td><strong>LOW LOAD</strong> (FCCtot &lt; 25 %)</td>
<td>small: &lt; 1m</td>
<td>(SH1-D/SH6-H)</td>
</tr>
<tr>
<td></td>
<td>medium: 1-2m</td>
<td>SH4-H</td>
</tr>
<tr>
<td></td>
<td>tall: 2-4 m</td>
<td></td>
</tr>
<tr>
<td><strong>MODERATE LOAD</strong> (FCCtot ≥ 25 and &lt; 50 %)</td>
<td>small: &lt; 1m</td>
<td>SH2-D</td>
</tr>
<tr>
<td></td>
<td>medium: 1-2m</td>
<td>SH3-H</td>
</tr>
<tr>
<td></td>
<td>tall: 2-4 m</td>
<td>(SH7-D/SH9-H)</td>
</tr>
<tr>
<td><strong>HIGH LOAD</strong> (FCCtot ≥ 50 %)</td>
<td>small: &lt; 1m</td>
<td>SH8-H</td>
</tr>
<tr>
<td></td>
<td>medium: 1-2m</td>
<td>SH5-D</td>
</tr>
<tr>
<td></td>
<td>tall: 2-4 m</td>
<td>(SH7-D/SH9-H)</td>
</tr>
</tbody>
</table>

**LIDAR + VEGETATION MAP + HUMIDITY CONDITIONS**

D-H: Dry - Humid

<table>
<thead>
<tr>
<th>(SH1-D/SH6-H)</th>
<th>OA1-SHRUBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SH4-H</td>
<td>OA2-SHRUBS</td>
</tr>
<tr>
<td></td>
<td>OA3-SHRUBS</td>
</tr>
<tr>
<td>SH2-D</td>
<td>MA1-SHRUBS</td>
</tr>
<tr>
<td>SH3-H</td>
<td>MA2-SHRUBS</td>
</tr>
<tr>
<td></td>
<td>MA3-SHRUBS</td>
</tr>
<tr>
<td>SH8-H</td>
<td>DA1-SHRUBS</td>
</tr>
<tr>
<td>SH5-D</td>
<td>DA2-SHRUBS</td>
</tr>
<tr>
<td>(SH7-D/SH9-H)</td>
<td>DA3-SHRUBS</td>
</tr>
</tbody>
</table>
# Results

<table>
<thead>
<tr>
<th>TIMBER UNDERSTORY (Scott and Burgan)</th>
<th>Understory height</th>
<th>Transitional forests (FCC trees &lt; 50 %)</th>
<th>Dense forests (FCC trees ≥ 50 %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERY LOW LOAD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOW LOAD (FCCtot &lt; 25 %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MODERATE LOAD (FCCtot ≥ 25 and &lt; 50 %)</td>
<td>litter: &lt; 1m grass-shrub: 1-2m shrub: 2-4 m</td>
<td>(TU1-D/TU3-H) TU2</td>
<td></td>
</tr>
<tr>
<td>HIGH LOAD (FCCtot ≥ 50 %)</td>
<td>litter: &lt; 1m grass-shrub: 1-2m shrub: 2-4 m</td>
<td>TU5</td>
<td>(TL1-C TL8-C) /TL2-B (TL3-C/TL6-B) (TL5-C/TL9-B)</td>
</tr>
</tbody>
</table>

LIDAR + VEGETATION MAP + HUMIDITY CONDITIONS

- (TU1-D/TU3-H) MA5-GS
- TU2 MA6-GS
- TU5 DA6-S
- (TL1-C TL8-C) /TL2-B DA7-CB
- (TL3-C/TL6-B) DA8-CB
- (TL5-C/TL9-B) DA9-CB

C-B: Conifer – Broadleaved forests  D-H: Dry - Humid
The TIN filter based on default switches for separating “ground –non ground” points was more accurate than the other TIN switches.

The Silva´s and Dalponte´s segmentation methods to identify the trees crowns were best than the watershed one.

Our “own” fuel models (FMs) were based on vegetation structure (Lidar data): the percentage of vegetation cover (fuel load), the height of the understory, and distinguishing between open-transitional-dense Forests.

The link between our own FMs and standard FMs as the Scott and Burgan´s ones requires to cross our FMs with Vegetation and Forests maps to allow identifying dominant species and then, to be able for differentiating between Grass-Shrubs and between Conifers-Broadleaved Forests.

**Future work:**
To get other auxiliary information as proxy of the fuel moisture such as the wetness index of the Tasseled Cap Transformation from Landsat, the LAI/FPAR from MODIS images, topographic wetness index...

To characterize vegetation vulnerability based on the flammability conditions and the capacity to cope with fire of the different plant functional traits.
THANK YOU