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## Supplementary Material

# Predictive modeling of fire occurrences from different fire spread patterns in Mediterranean landscapes

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## Appendix S1

*Description of the variables introduced into the model*

This appendix details the variables introduced into the model. It includes their description, the main data sources used and the computational building process when necessary. Their hypothetical effect on the different fire spread patterns is also displayed. A resume of this appendix is presented in Table 3 in the manuscript.

The main factors identified to explain fire spread pattern occurrences were chosen according to the factors describing the fire behavior triangle (Parisien and Moritz 2009): topography, climate (as a proxy of weather) and vegetation. Factors were introduced into the model in raster format at 250-m resolution. The size was chosen to be consistent with source data resolution, because this resolution includes enough information to understand landscape features at the scale of large fires and covers all the area under study with a small computational load.

*Topographic factors*

These factors explain topographic landscape arrangements relevant to fire spread in some specific situations. Data sources are the digital elevation model (DEM) of Catalonia (Institut Cartogràfic de Catalunya 2011) at 30 m and 1 : 50 000 topographic maps.

i. <u>Slope</u>

- Description: mean slope (in degrees) 1 km around each pixel.
- Hypothesis: slope can be relevant in topography-driven fires because the angle of flame with respect to the surrounding terrain can influence fire spread (fire spreads faster uphill (Rothermel 1972)). In wind-driven fires, the interaction of wind with terrain can influence fire spread if there is an alignment between wind direction and uphill slope (Campbell 1995).

ii. <u>Slope standard deviation</u>

- Description: standard deviation of slope values within a 1-km radius around each pixel. This provides information about terrain heterogeneity. The larger the standard deviation, the higher the slope divergences around each pixel.
- Building: from slope data (50-m resolution), standard deviation is calculated within the pixels inside a 1-km radius around each pixel.
- Hypothesis: terrain heterogeneity may influence the spread of topography-driven and wind-driven fires, as flame spread may be favoured by a higher number of uphill runs (Rothermel 1972).

iii. <u>Ravine junctions</u>

- Description: number of ravine junctions around each pixel. A ravine junction is defined as the place where two or more ravines, gorges or rivers join.
- Building: the river-crossing segment nodes were selected from the topographic map. Then, for each pixel, the sum of the number of ravine junctions within its surroundings (1 km) was determined.
- Hypothesis: the presence of a ravine junction in the evolution of a topography-driven fire may have effects on fire spread, because it defines the possibility of fire development in new watersheds.

iv. <u>Ridge main direction</u>

- Description: percentage of area around each pixel (1 km) covered by areas lying north–south (N–S) or east–west (E–W) (producing two different variables).
- Building: this variable was calculated as a function of the rate of N+S-aspect pixels with respect to E+W pixels. Higher ratio values indicate that east–west ridges dominate in the region, and lower ratio values indicate that north-south ridges dominate. An aspect map was built from DEM at 50 m (N, S, E and W aspects plus flat areas with <2° slope). After calculating the ratio N+S/E+W, east–west ridge direction was chosen if the ratio was >2 and north–south ridge direction was chosen if the ratio was <0.5. However, this ratio also includes troughs. In order to exclude them, a mask selecting only pixels at least 20 m above their surroundings was applied. One layer per main direction was obtained (N–S or E–W), indicating whether a pixel was a ridge in that direction or not. From these layers, the percentage area covered by ridges of a specific direction around each pixel was calculated.
- Hypothesis: wind interaction with main terrain alignment may be relevant in the evolution of a wind-driven fire. Whereas perpendicular ridges create specific streams on the upwind face, parallel ridges can increase wind effect.

v. <u>Elevation dominance</u>

- Description: this variable provides information about the relative height of each pixel with respect to its surroundings.
- Building: average height of the surroundings (1 km) of each pixel was first considered. Then, this value was subtracted from the height value of each pixel. Positive values indicate that the pixel is above its surroundings, and vice versa.
- Hypothesis: this elevation position can determine topography-driven or wind-driven fire spread, as uphill runs (which theoretically are more fire-prone) are more prevalent at certain relative elevation positions (when height dominance is negative).

*Climate factors*

Some climatic conditions vary over the landscape and can determine certain landscape arrangements linked to moisture vegetation content or wind predisposition. Source layers are the Digital Climatic Atlas of Catalonia (Ninyerola *et al.* 2000) and the regional wind map (Gencat 2004).

i. Solar radiation and temperature

- Description: solar radiation and air temperature (Ninyerola *et al.* 2000) are good factors to explain vegetation dryness. These two variables were calculated together in order to have one single variable explaining dryness of each site.
- Building: these two variables were evaluated together by annual mean standardisation ($z = x - \mu/\sigma$, where $z$ = standardised value, $x$ = original value, $\mu$ = mean of the original value, $\sigma$ = standard deviation of the original value), in order to bring all of the variables into proportion with one another and thus avoid the absolute values of the original variables giving wrong weightings in the gathering process (i.e. areas with high solar irradiation with high temperatures have larger values than those with low temperatures).
- Hypothesis: fire burns the driest part of vegetation fastest and, therefore, all fires can be influenced by this factor. However, convective and topography-driven fires may be more influenced by this dryness index than wind-driven fires, because the latter may be able to burn regardless of the vegetation conditions.

*ii.* Mean annual wind speed

- Description: average of the mean annual wind speed for a 1-km radius around each pixel.
- Building: average of the mean annual wind speed was obtained from the wind map (Gencat 2004) 1 km around each pixel. This was calculated as the mean annual wind speed 60 m over the surface through deterministic models.
- Hypothesis: wind-driven fires may be the most affected by this factor.

*Vegetation factors*

*Landscape fuel factors*

Landscape fuel factors are the variables that detail non-forest vegetation cover. Data sources were based on different land-cover map versions of the region under study (land cover maps of Catalonia (LCMC) (Ibañez *et al.* 2002) and the Spanish Forest Map at 1 : 50 000 (Vallejo Bombin 2005)).

i. Shrublands

- Description: percentage of shrublands area around each pixel (1 km). Two sorts of shrublands were differentiated according to their origin, because this can influence shrubland shape and composition. Shrublands in Catalonia come from regeneration of bare soil originating basically from crop abandonment or wildfires (Calvo *et al.* 2002).

- Building: shrubland cover was intersected with fire perimeters. If shrublands were inside these perimeters, they were considered burnt shrubs, whereas if not, they were considered shrubs regenerated from crop abandonment.
- Hypothesis: shrublands are a very flammable and thin fuel. Under drought conditions, their branches become extremely fire-prone. Their role in different fires is uncertain, but they may affect all fires.

ii. <u>Herbaceous crops</u>

- Description: percentage of area around each pixel covered by herbaceous crops.
- Hypothesis: a large area of Catalonia is covered by cultivated land (31% according to the third version of the LCMC). Fire can also burn these lands, burning in a different way depending on plant moisture, which in Catalonia is a function of irrigation. Herbaceous crops may influence wind-driven fires, and to a lesser extent topography-driven fires (usually, these crops are situated on flat areas) or convective fires (not enough vegetation accumulation).

iii. <u>Irrigated crops</u>

- Description: percentage of area around each pixel covered by irrigated crops.
- Hypothesis: irrigated crops may not have much effect on fires owing to their high moisture content, except for wind-driven fires, which may be able to burn under several vegetation conditions.

iv. <u>Grasses</u>

- Description: percentage of area around each pixel covered by grasses. Natural grasses (in these latitudes, they usually are alpine grasses) and pasturelands were not differentiated owing to their similar characteristics in terms of fire spread.
- Hypothesis: grasses may have influence on topography-driven and wind-driven fires, but not on convective ones, owing to their low fuel load.

*Forest fuel factors*

Forest structure variables were included to explain fire spread in detail. Source data were forest and cover maps built according to forest inventory timings. Based on Brotons *et al.* (2013), different LCMCs

(Ibañez *et al.* 2002) were used, as well as the 2000 Spanish Forest Map (Vallejo Bombin 2005) and the National Forest Inventory (NFI2 and NFI3; Villaescusa and Díaz 1998; Villanueva 2005) with data available for Catalonia, and continuous layers of forest structure information were generated by applying kriging interpolation techniques (Gunnarsson *et al.* 2012).

i. <u>Forests</u>

- Description: percentage of area around each pixel covered by forests.
- Hypothesis: the presence of forest cover around an ignition pixel may determine fire spread in all types of fires.

ii. <u>Forest structure</u>

- Description: forest structure was identified through factors such as basal area or number of trees per hectare.
- Building: mean basal area and trees per hectare in forest areas around each pixel (1 km) were calculated from forests maps. To calculate these, only tally trees (with a diameter at breast height ≥ 7.5 cm) were taken into account.
- Hypothesis: the role of the variables 'mean basal area' and 'trees per hectare' on fire spread is uncertain, as it is not known exactly how these structures can affect different kinds of fire spread patterns. For instance, although small basal areas and high numbers of trees per hectare could indicate a young forest that can result in more flammable situations (thin and low branches), an old and well-developped forest (high basal area) could create high levels of heat and induce more convection.

iii. <u>Forest composition</u>

- Description: forest structure was assessed separately as conifers and broadleaf, according to main species.
- Building: forest structure was split between conifers or broadleaf, in relation with the main species inside each pixel (selected in terms of basal area) according to the forest map.
- Hypothesis: the main hypothesis is that conifer species would be more prone to fire than broadleaf species (Valette 1990) in all types of fires. Nevertheless, conifer incidence may be higher in convective fires, because they need a specific fuel amount available, which is easier to find in conifer forests, whereas topography-driven or wind-driven fires do not exclusively depend on forest composition.

iv. Forest vertical structure

- Description: forest vertical structure was described by understorey features such as recovery and height.
- Building: mean understorey recovery and height (mean and maximum) in forested areas around each pixel (1 km) was calculated from forest maps.
- Hypothesis: the greater the recovery and height, the greater the probability of convective fire occurrence. Their role on topography-driven or wind-driven fires is not clear.

**v.** Forest canopy cover

- Description: horizontal coverage of forest tree canopies of forest pixels 1 km around each pixel.
- Hypothesis: canopy continuity may influence fire spread in all kinds of fires.

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**Appendix S2**

The present appendix provides a summary of MaxEnt's gain values from the different models used in the variation partitioning analyses. The different groups of variables introduced into the model are shown in the first column. Detailed information about the variables included within each group can be found in Table 3 in the manuscript.

The gain shown corresponds to 'Regularised training gain' units in MaxEnt's output results. Here, we present the average of the gain values from the cross-validation analyses (each replicate represented 15% of the sample data and was used as the validation set; hence, nine repetitions per different spread pattern from each decade were run).

**Table A1. Summary of MaxEnt's gain values from the different models used in the variation partitioning analyses**

| Group of variables introduced to the model | Gain | | | | | |
|---|---|---|---|---|---|---|
| | Decade 1989–99 | | | Decade 2000–12 | | |
| | Topography-driven | Wind-driven | Convective | Topography-driven | Wind-driven | Convective |
| Forest fuel factors | 1.023 | 1.102 | 1.023 | 0.479 | 0.228 | 1.039 |
| Landscape fuel factors | 0.436 | 1.447 | 0.436 | 0.789 | 0.597 | 0.493 |
| Unmanageable factors | 0.714 | 1.703 | 0.714 | 0.292 | 0.923 | 0.805 |
| Forest and landscape fuel factors | 1.109 | 1.844 | 1.109 | 0.919 | 0.715 | 1.163 |
| Forest fuel and unmanageable factors | 1.298 | 2.035 | 1.298 | 0.668 | 1.045 | 1.527 |
| Landscape fuel and unmanageable factors | 0.911 | 2.201 | 0.911 | 0.974 | 1.287 | 1.096 |
| Complete model (all factors) | 1.429 | 2.354 | 1.429 | 1.138 | 1.356 | 1.640 |