

D3.3 - Analysis of WUI exposure conditions

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Executive summary

This document presents the development of a wildfire exposure map for wildland-urban interface (WUI) areas within six Italian national parks: Appennino Tosco-Emiliano, Val Grande, Pollino, Gargano, Stelvio and Maddalena.

The exposure map was created using a GIS-based approach that integrates environmental variables known to influence wildfire behaviour, including terrain slope, tree cover and wind speed. Spatial datasets from different sources were harmonised to a common spatial resolution of 30 m and processed in a GIS environment. Continuous variables were reclassified into discrete classes and combined to generate a composite exposure index representing potential wildfire exposure conditions.

The resulting index, ranging from 3 to 8, was aggregated into three exposure classes (low, medium and high) to improve its interpretability and facilitate its application in forest fire exposure assessment. The exposure map provides a spatially explicit representation of areas potentially most susceptible to wildfire spread and can support risk management, prevention planning, and emergency preparedness strategies in protected areas and WUI landscapes.

Keywords

WUI, Wildfires, National parks, Urban Interface area, Exposure



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1. Introduction

The Exposure Map is a spatial tool designed to represent the degree of exposure to wildfires in Wildland–Urban Interface (WUI) areas, where settlements and vegetation are in close contact and where the interaction between human presence and fire-prone landscapes becomes particularly critical (Argañaraz et al., 2017). In these contexts, wildfire exposure is not only related to the likelihood of fire spread, but also to the potential consequences for people, buildings, infrastructure, and emergency response activities (Modaresi Rad et al. 2023). For this reason, WUI areas are widely recognised as priority zones for wildfire risk assessment and management.

Within the framework of the FIRE-BOX project, an exposure map of WUI areas was developed for six Italian National Parks: Appennino Tosco-Emiliano, Val Grande, Pollino, Gargano, Stelvio, and Maddalena. These protected areas include heterogeneous environmental and landscape conditions and, at the same time, contain settlements and infrastructures embedded in or adjacent to forested and semi-natural vegetation. This combination makes them suitable case studies for analysing wildfire exposure in territories where natural value, human presence, and fire risk intersect.

The map was produced by integrating a set of environmental and climatic variables recognised as relevant to wildfire behaviour and to the operational complexity of fire events, namely terrain slope, tree cover, and wind speed. These variables were selected because they influence key aspects of wildfire dynamics. Slope affects the rate and direction of fire spread and may increase the difficulty of suppression activities in steep terrain. Tree cover serves as a proxy for vegetation continuity and fuel density, which are fundamental elements in determining the potential for fire propagation. Wind speed is a major driver of fire behaviour, as it can accelerate flame spread, modify fire intensity, and reduce the effectiveness of control operations.

By combining these variables in a GIS-based framework, the Exposure Map provides a spatially explicit representation of conditions that may aggravate wildfire scenarios in WUI areas. In particular, it highlights locations where environmental characteristics may increase suppression difficulties, complicate emergency management, and reduce safe evacuation or escape opportunities during hazardous events. The resulting product is therefore intended as a support tool for prevention planning, prioritisation of mitigation measures, and preparedness activities in protected areas exposed to wildfire risk.

The following sections describe the datasets used, the spatial processing workflow adopted for map construction, and the criteria applied to derive and aggregate the final exposure classes.

Materials and methods

The development of the Exposure Map was carried out using ArcGIS and began with the download of raster WUI maps derived from the dataset developed by D’Este et al. (2021),



which provides a spatial representation of WUI areas across the Italian peninsula with a spatial resolution of 30 m.

The dataset classifies WUI into nine classes, obtained from the combination of building density and tree cover, as described below:

1. Isolated buildings with low tree cover: ≤ 3 buildings and tree cover between 0 and 64%.
2. Isolated buildings with medium tree cover: ≤ 3 buildings and tree cover between 65 and 89%.
3. Isolated buildings with high tree cover: ≤ 3 buildings and tree cover between 90 and 100%.
4. Scattered buildings with low tree cover: 4–49 buildings and tree cover between 0 and 64%.
5. Scattered buildings with medium tree cover: 4–49 buildings and tree cover between 65 and 89%.
6. Scattered buildings with high tree cover: 4–49 buildings and tree cover between 90 and 100%.
7. Clustered buildings with low tree cover: ≥ 50 buildings and tree cover between 0 and 64%.
8. Clustered buildings with medium tree cover: ≥ 50 buildings and tree cover between 65 and 89%.
9. Clustered buildings with high tree cover: ≥ 50 buildings and tree cover between 90 and 100%.

Once downloaded, the WUI dataset was clipped to the boundaries of the six selected Italian National Parks, in order to obtain only the WUI raster layers located within park boundaries.

Subsequently, the TINITALY Digital Elevation Model (DEM) with a spatial resolution of 10 m (Tarquini et al., 2007) was downloaded, from which the topographic slope variable was derived.

Next, the global tree cover dataset produced by Global Forest Change (Hansen et al., 2013) was downloaded, available at: <https://storage.googleapis.com/earthenginepartners-hansen/GFC-2024-v1.12/download.html>. Finally, a raster dataset of mean wind speed from the Global Wind Atlas, with a spatial resolution of 1 km at the national scale, was downloaded from: <https://globalwindatlas.info/en/> Once the input variables were obtained, the slope and wind speed maps were resampled in order to match the spatial resolution of the WUI dataset (30 m). This operation ensured spatial consistency and alignment of raster grids, enabling the integration of the different variables within a single analytical framework for the construction of the final wildfire exposure map. Table 1 reports the variables used for the development of the exposure map.



Table 1 Variables used for the development of the exposure map for the selected national parks.

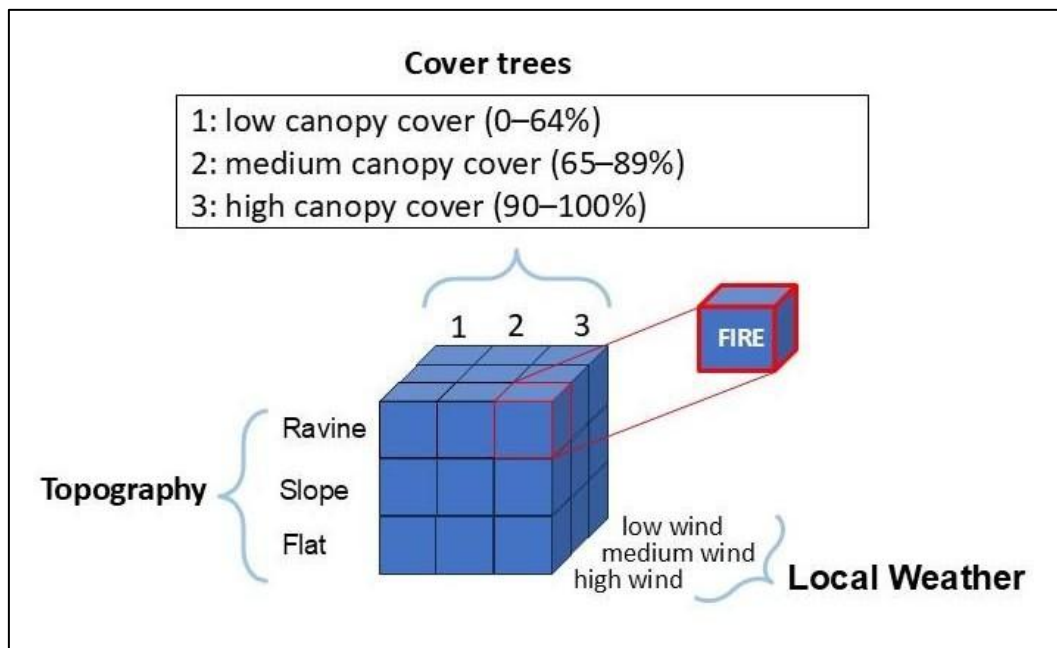
Variable	Description	Data source	Spatial resolution
WUI (Wildland–Urban Interface)	WUI classes based on building density and tree cover (9 classes)	Italian WUI Dataset (D’Este et al., 2021)	30 m
Slope	Terrain slope derived from DEM	TINITALY DEM (Tarquini et al., 2007)	30 m (derived)
Tree cover	Percentage of forest canopy cover	Global Forest Change (Hansen et al., 2013)	30 m
Wind speed	Mean wind speed	Global Wind Atlas	30 m (derived)
Park boundaries	Administrative boundaries of National Parks	Official national park datasets	Vector

After ensuring spatial consistency and proper alignment of raster grids across all input variables, the datasets were reclassified into discrete classes using the Raster Calculator tool.

This reclassification allowed the transformation of continuous variables into categorical variables, facilitating their integration into the analytical framework and enabling their combination for the construction of the final wildfire exposure map (Figure 1).



Figure 1. Combination of categorized variables used for the development of the Exposure Map.



The slope variable was divided into three classes:

- Flat areas (Flat): $< 5^\circ$
- Moderate slopes (Slope): $5\text{--}29^\circ$
- Steep slopes (Ravine): $\geq 30^\circ$

Steeper slopes were considered more prone to severe fire propagation conditions.

Wind speed at 10 m above ground was classified into three categories based on the Beaufort scale:

- Low wind: 0–1.5 m/s (light air)
- Medium wind: 1.6–7.9 m/s (from light breeze to moderate wind)
- High wind: > 7.8 m/s (fresh wind and stronger)

This classification allows the consistent representation of the influence of wind conditions on wildfire dynamics.

Tree cover, derived from the Hansen dataset, was classified into three classes according to canopy cover percentage:

- Low: 0–64%
- Medium: 65–89%
- High: 90–100%

This variable was used as a proxy for vegetation fuel continuity and density, key factors influencing wildfire spread potential.



Table 2 summarizes the reclassified input variables.

Table 2. Reclassified input variables and their corresponding discrete classes used for the construction of the Exposure Map. Continuous variables (slope, wind speed, and tree cover) were subdivided into classes based on topographic thresholds, anemological criteria (Beaufort scale), and forest cover percentages, in order to standardize the datasets and facilitate their integration within the spatial analysis framework.

Variable	Discrete value	Class	Range	Description
Slope	1	Flat	< 5°	flat or nearly flat terrain
	2	Slope	5–29°	moderate slopes
	3	Ravine	≥ 30°	steep slopes
Wind speed (10 m)	1	Low	0–1.5 m/s	calm to light air
	2	Medium	1.6–7.9 m/s	light breeze to moderate wind
	3	High	> 7.8 m/s	fresh wind and stronger
Tree cover (Hansen)	1	Low	0–64%	low canopy cover
	2	Medium	65–89%	medium canopy cover
	3	High	90–100%	high canopy cover

Once the discrete values of the considered variables were obtained, a fishnet grid with the same spatial resolution as the input rasters was generated.

For each grid cell, the corresponding discrete values of slope, wind speed, and tree cover were assigned. Subsequently, a composite exposure index was calculated as the sum of the discrete values associated with each variable, providing a synthetic measure of overall exposure for each grid cell.

Once the Exposure Map was constructed, with values ranging from 3 to 8 depending on the combination of factors considered, the exposure index was further reclassified into three discrete classes to facilitate interpretation.

2. Exposure map

The aggregated exposure classes (EXP) were derived from the original exposure index defined as the sum of discrete values (1–3) associated with the three environmental variables: slope, tree cover, and wind speed.

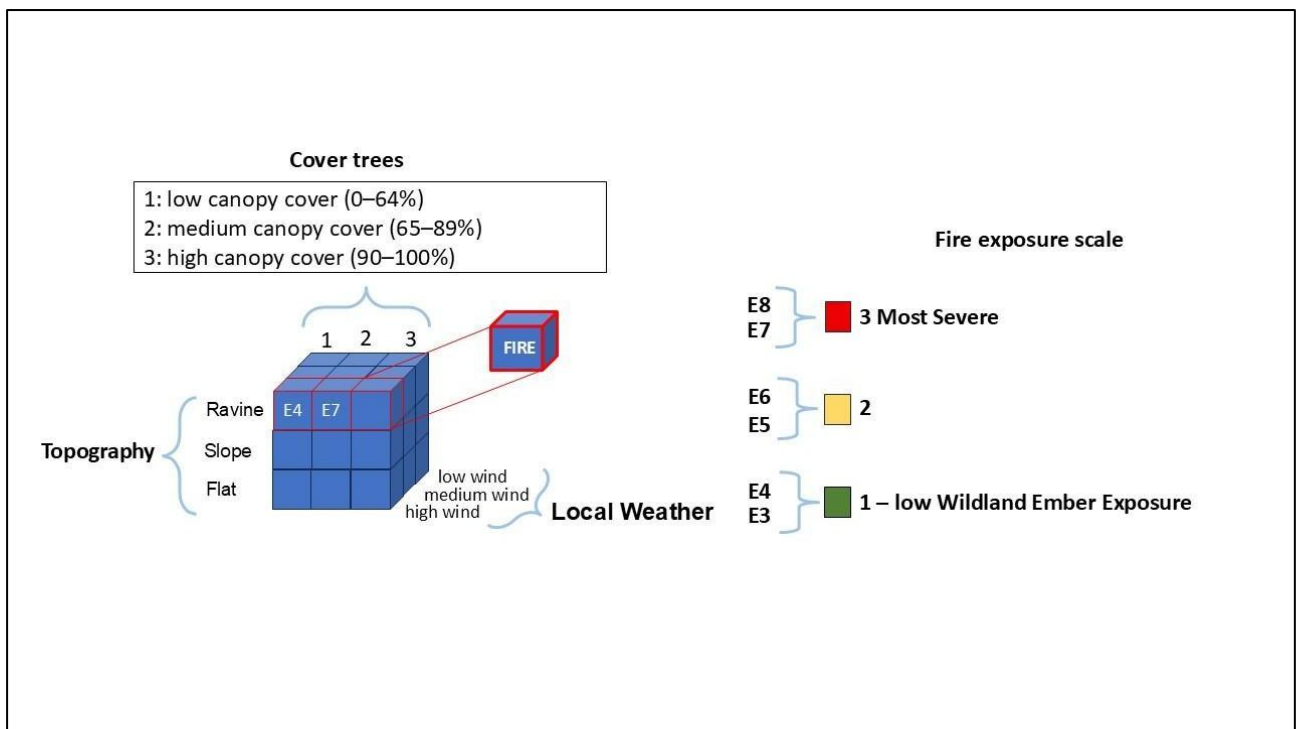
The resulting index ranges from 3 to 8, representing an increasing gradient of conditions potentially favorable to wildfire propagation.

In order to reduce interpretative complexity and improve the readability of results, the original index values were aggregated into three ordinal exposure classes, as described below and illustrated in Figure 2.



- **Class 1 – Low exposure**
Includes index values 3 and 4, corresponding to combinations where the considered factors predominantly assume low or medium–low values.
These conditions reflect contexts characterized by limited slopes, low or moderate tree cover, and low wind speeds, associated with a low potential for wildfire spread and fire behavior intensification.
- **Class 2 – Intermediate exposure**
Includes index values 5 and 6, resulting from intermediate combinations of environmental factors in which at least one variable assumes medium–high values.
This class represents moderate exposure conditions, with wildfire spread potential higher than Class 1 but lower than the most extreme scenarios.
- **Class 3 – High exposure**
Includes index values 7 and 8, derived from combinations in which several factors assume high values.
These conditions are typically associated with steep slopes, high tree cover, and medium to high wind speeds, representing contexts characterized by high exposure and a strong potential for intense wildfire behavior.

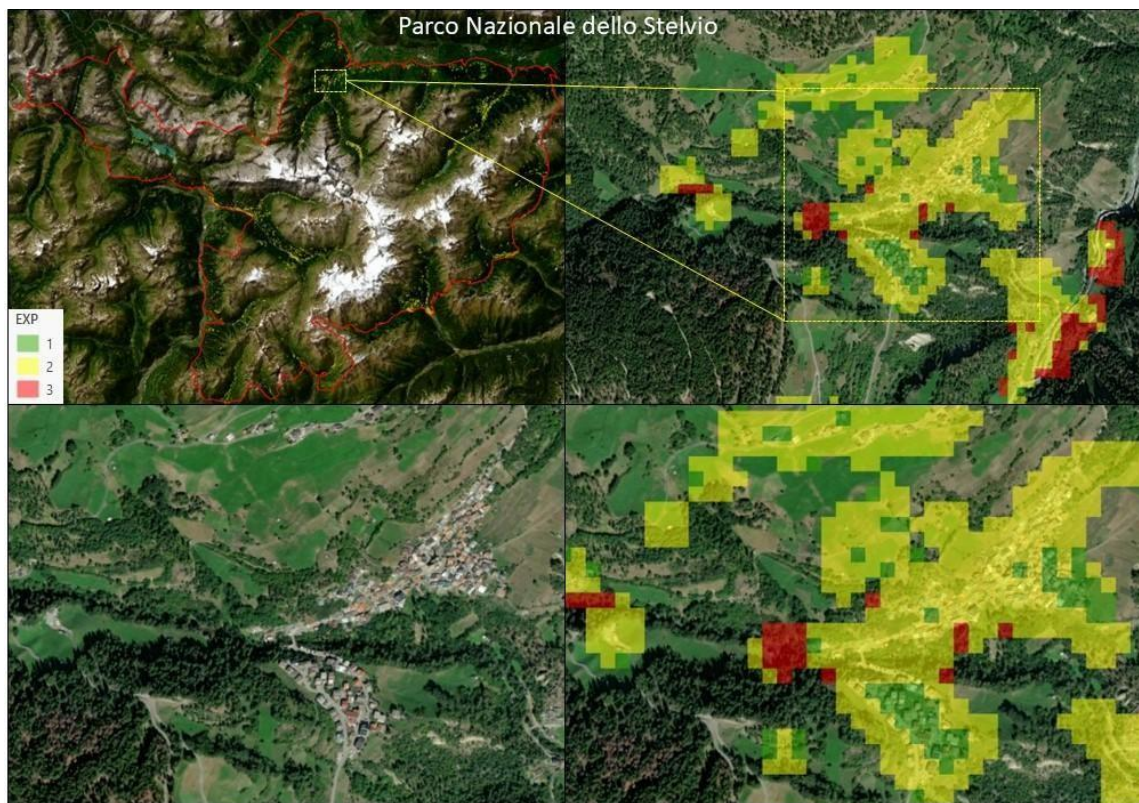
Figure 2. Aggregation of the six original index values into three exposure classes.





Finally, for illustrative purposes, a detailed view of the Exposure Map is shown for a WUI area within Stelvio National Park, characterized by the presence of all three exposure classes considered.

Figure 3. Exposure Map classes in WUI areas within Stelvio National Park.





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