

# **Landscape changes and wildfire behaviour: new fire scenarios in Spain**

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## **Abstract**

Recent trends in landscape change, in accordance with new models of economic development and new lifestyles, have determined new territorial scenarios for wildfire ignition and propagation.

The main drivers of the landscape change with implications in wildfire behaviour have been the following: (i) abandonment of agricultural and forest land management and the underlying socio-economic processes; (ii) shifts in forest-related policies with consequences in structural causes of wildfires; (iii) proliferation of linear infrastructures, urban sprawls and expansion of the wildland-urban interfaces.

These changes in the landscape have influenced the occurrence and propagation of wildfires. This paper analyses the landscape changes related to wildfire behaviour that have happened in Spain through the last twenty years and predicts future change trends. To do that, the main variables considered are: land use/land cover, fuel load attributes and recent fire history. The final objective is to identify and characterise the new fire scenarios, pursuing the aim of making easier the adaptation and improving the efficiency of the wildfire defence units, as well as reducing territorial vulnerability to forest wildfires.

**Keywords:** wildland-urban interface, integrated wildfire management, territorial dynamics, territories at risk

## **1. Introduction: the territorial scenarios in the context of wildfire integrated management**

Recent trends in landscape change, in accordance with new models of economic development and new lifestyles have determined new territorial scenarios for wildfire ignition and propagation. Besides, taking account of the foreseeable effects that climate change will introduce in the spread and pattern of territories at risk and territorial vulnerability is necessary. The interest in developing a new approach for the integrated management of wildland fires needs to lean on analytical instruments that allowed for knowing the dynamics of the territories at risk and for getting deeper knowledge on fire behaviour in these new scenarios.

The aim of this communication is presenting the conceptual and methodological foundations used to draw a cartography of the various fire scenarios in Spain, both at

the national and regional scales, which allowed for standardisation of the management of protection against wildfires in the various set scenarios<sup>1</sup>.

Fire scenarios are defined as those territorial areas in which certain common characteristics can be set as for the initial conditions and the possible evolution of wildfires. The aim of the spatial demarcation of these areas is to set out, in a coherent manner, the set in motion of strategies for mitigation of and fight against wildfires, as well as a common territorial management on them. Consequently, the used criteria must lean on the elements that condition the adoption of different measures of action both in the prevention and extinction stages.

The definition of scenarios can be carried out at various scales (national, regional) depending on the desired management aims to accomplish. The national scenarios are based in the most relevant structural characteristics related to fire behaviour (regarding the forest ecosystem and the settlement system): they allow for defining the big principles of action for prevention and extinction. The regional scenarios, defined at a more detailed scale, introduce a qualitative assessment of the foreseeable landscape dynamics (processes of agricultural abandonment, scattered urbanisation) and of their incidence on the wildfire propagation conditions and on the circumstances that define the emergency.

## **2. The definition of scenarios at various scales**

### **2.1. National scenarios: a structural characterisation regionally differentiated**

The definition of scenarios at the national level aims at establishing a spatial differentiation based on the structural characteristics of the territory in relation to the risk of wildfires. From the methodological viewpoint, the issues that must be tackled are two: (i) the variables considered in the aforementioned characterisation and (ii) the spatial unit of analysis chosen to calibrate the distribution of the variables. To select the variables, all those aspects of the territory that make the extinction measures to vary have been identified, such as the typology of settlements, fuel model, slope, and flammability, and they have been characterised so that those values at which wildfire management varies have been defined. Thus, management will be different in an area whose forest systems' combustibility and flammability were high, slope was steep, and where estates were scattered. There, any action will be extremely complicated and protecting people will turn out rather difficult, whereas in those areas of smooth slopes, low combustibility and flammability and concentrated settlements, protection against wildfires will be much easier. The elements considered have been:

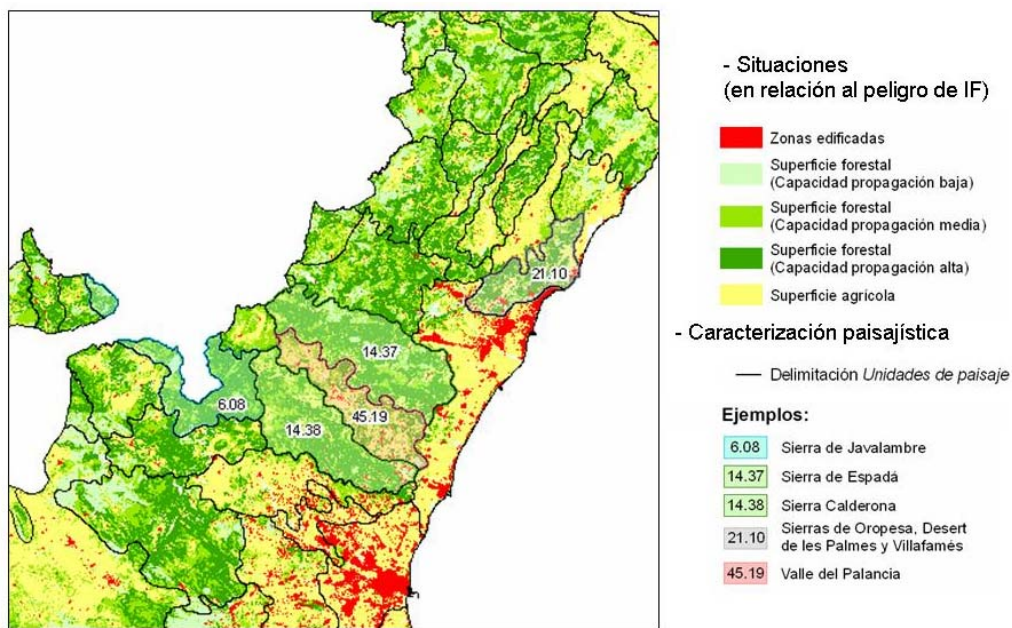
- Settlements: the whole national territory has been mapped in accordance with the kind of settlements, their density and territorial environment (agricultural, forest).
- Forest ecosystem propagation hazard: defined as the intrinsic easiness of a forest system to propagate fire, turning it into a wildfire. It is estimated from the fuel and forest vegetation model (determined by its degree of combustibility and

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<sup>1</sup> Agreement signed by the Complutense University of Madrid and the public enterprise TRAGSATEC.

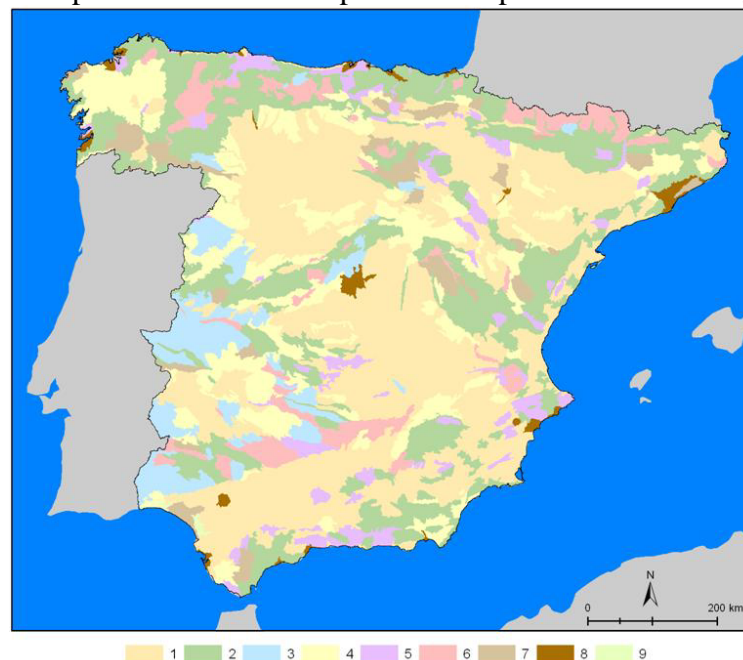
flammability) and the physiography (interpreted through relief and depending on the slope).

The resulting matrix of the interrelation of kinds of settlement, fuel-related hazard and slope results a total of 54 situations, mapped for the whole territory of Spain (except for the Canaries). The spatial distribution pattern of these situations features high fragmentation. That doesn't allow for their direct use as management areas but provides a valuable interpretation and information on the factors that have an influence on fire propagation and on the management of protection against wildfires. Faced with the need of defining spatial entities somewhat large, that were enough to group these situations into homogenous areas regarding the fight against wildfires, a work hypothesis formulated: to confront the defined situations by means of exercises of landscape character assessment (Countryside Agency, 2004). The landscape units defined from this viewpoint allow for expressing, at a determined scale, the landscape diversity of the territory, resulting of a particular physiognomy that reflects a differentiated and differentiable morphological, functional and visual organisation (Mata, Galiana *et al.*, 2009). The formulated hypothesis was based on the fact that the mentioned morphological and functional organisation should correspond with also differentiated behaviours in view of fire. In that sense, the Atlas de los paisajes de España (Atlas of Spanish landscapes) (Mata *et al.*, 2003), drawn using a simplified application of the methodology established by the British Countryside Commission, provided an identification and characterisation of units for all Spain, with a spatial level of disaggregation that suited the management goals set for the fire scenarios. For that reason, the 54 situations were confronted with the landscape units defined in the atlas. Previously, and in accordance with a demandable disaggregation level for a national scale, simplification was carried out resulting 11 situation: urban environment, settlements in agricultural areas, settlements in forest areas, scattered buildings in agricultural areas, scattered buildings in forest areas, isolated buildings in agricultural areas, isolated buildings in forest areas, agricultural land, high-propagation forest land, medium-propagation forest land, and low-propagation forest land. Once the various (11) existing situations regarding the hazard of wildfire were obtained, they were superposed with the landscape characterisation defined in the Atlas de los paisajes de España, aiming at determining the various fire scenarios as displayed in the Figure 1, proving that there is a direct relation between both maps.



**Figure 1**—Example of superposition of situations regarding the risk of wildfire and landscape characterisation (Source: Atlas de los paisajes de España (2003); Mapa de situaciones (TRAGSATEC) (2009)).

Once the distribution of the areas was studied by means of a cluster analysis, the landscape units were grouped similarly to the simplified situations. That resulted in nine groups, whose spatial distribution in peninsular Spain is shown in Figure 2.



**Figure 2**— Spatial distribution of the clusters with similar distribution of situations regarding the risk of wildfires (Source: see Figure 1).

However, once these groups were made, it was proven that they gathered territorial realities that differed pretty much from each other, as a consequence of the

synthetic nature of the source data (kind of settlement and propagation capacity) so that the need of making a regional reading based on nature arose. To do that, the map of natural regions in Spain drawn by Martínez de Pisón and Molina Holgado (1998) was used. It was superposed with the spatial distribution of the nine groups previously obtained for the whole peninsular Spain. The obtained results (Figure 3) were satisfying so that these natural regions were introduced for the definition of scenarios at the national scale.



**Figure 3.** Spatial distribution of the clusters with similar distribution of situations regarding the risk of wildfires. Natural regions are also demarcated (Source: Figure 1; Martínez de Pisón & Molina Holgado , 1998).

To define the various fire scenarios at the national level, the several situations of the territory regarding the hazard of wildfire were analysed for each and every of the existent natural regions so that, by means of a new grouping based on their similarity, the definitive scenarios would be obtained. The final result of this study is a national-scale cartography that will allow for standardising the management of protection against wildfires in Spain, in the various spatial areas defined, setting guidelines of actions in accordance with the priorities of protection against wildfires (regarding prevention, detection and extinction). From this cartography and by means of a more detailed analysis of the territory, the scenarios will be defined at the regional level too.

## **2.2.Regional scenarios: areas of forest land and wildfire management related to landscape change drivers**

The definition of scenarios at the regional level starts from the national scenarios, incorporating to the structural characterisation of the territory established in them an assessment of the foreseeable landscape evolution in accordance with a pattern of uses and management in that territory. The aim is defining homogeneous areas of differentiated territory management from the viewpoint of wildfires.

The definition of regional scenarios is founded on the demarcation of spatial areas of homogeneous physical and territorial characteristics at the work scale, which can be associated to stages of evolution of the territory in accordance with a model of dynamic of the vegetation and land uses (*wildfire generations*) (see Table 1). The concept of *wildfire generations* therefore arises from the establishment of a model of wildfire evolution towards a predominance of Large Wildland Fires (LWF). The increasing importance of LWF, of high intensity and that escape control capacity, is a consequence of the variations undergone by the available fuel within a territorial and temporal context (in our case, the Spanish Mediterranean coast and its evolution throughout the last 50 years). In each case, the characterisation of the scenarios in accordance with the concept of generation must necessarily adapt to the regional context but always bears common characteristics.

**Table 1**—Classification of wildfire generations (from Rifà & Castellnou, 2007 and Castellnou et al., 2009)

	Fuel	Wildfire characteristics	Territorial and temporal context	Action
1 <sup>st</sup>	Continuity of forest mass, low load (grassland, meadows)	Long perimeters and high propagation speed	Starts in the late 50s and 60s, related to farmland abandonment	Local response: increase of accessibility to the territory; lineal infrastructures of prevention (firebreaks)
2 <sup>nd</sup>	Continuity of forest mass and increase of fuel load (scrubland)	High intensities and high propagation speed; start of secondary seats	Starts in the late 70s-80s due to abandonment of farmland and traditional forest management	Reduction of access time (tracks, quick detection, forceful attack, water spots)
3 <sup>rd</sup>	Homogeneous forests with high densities and vertical continuity	Crown fires that overwhelm the capacity of tactic intervention; multiple secondary seats (advances jumping long distances). Large wildfires, more than 20,000 to 30,000 ha wide	Prolonged lack of forest management (30 to 50 years); extinction of all low- and middle-intensity wildfires	Extinction task forces admit their limits. Use of all extinction techniques. Strategic response: promotion of forest management and prescribed burnings; promotion of self-protection in estates; advance of opportunities (confinement and deceleration); dynamization and flexibilisation of decision-making
4 <sup>th</sup>	Same as 3 <sup>rd</sup> + estates with propagation capacity	Same as 3 <sup>rd</sup> (LWF)+ creation of multiple emergencies (WUI)	Same as 3 <sup>rd</sup> + increase of scattered estates in forest lands	Same as 3 <sup>rd</sup> + differentiation between strategic and tactic levels; decision making at lower levels
5 <sup>th</sup>	Same as 4 <sup>th</sup>	Same as 4 <sup>th</sup> + simultaneity	Same as 4 <sup>th</sup>	Same as 4 <sup>th</sup>

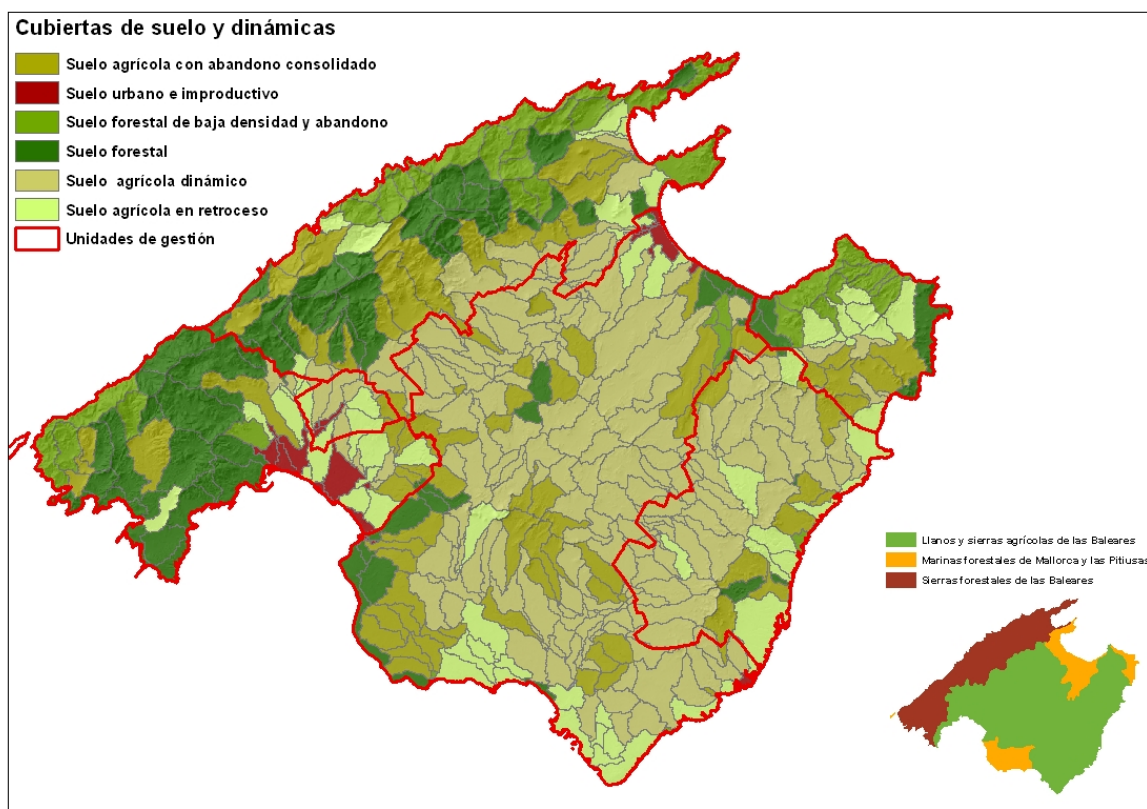
The defined methodology is based on being able to assign each of the units of analysis (drainage basins with an average area of 4.5 km<sup>2</sup>) to a determined stage of landscape evolution in accordance with the defined model (wildfire generations).



Drainage basins feature the advantage that they may be aggregated in homogeneous areas in accordance with the requirements of the multi-scale approach (they may suit larger and smaller scales), and that they allow for, if necessary, an internal differentiation of situations within the forests defined for management.

The selection of attributes therefore lies on the landscape character and dynamic, both the past and foreseeable ones. The identification of territorial uses and dynamics related to wildfire generations (intensity of agricultural abandonment, the existence or not of forest management, scattered estates) is carried out in several stages.

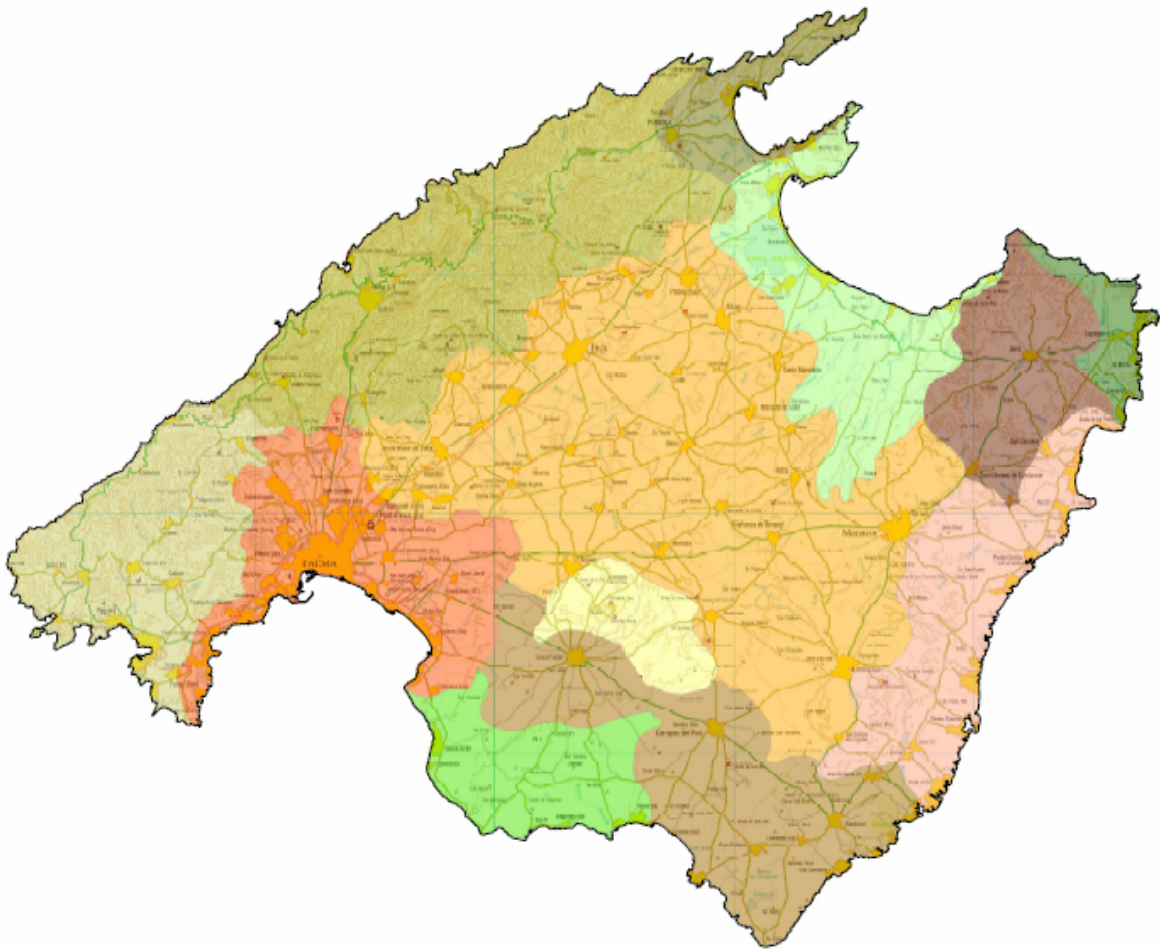
1. Territorial context in relation to the vegetation (forest dynamic and agricultural abandonment dynamic). The used variables (proportion of forest, agricultural and non-productive area; proportion of abandoned farmland between 1990 and 2009) are grouped into 6 classes by means of a cluster analysis (Figure 4) in relation to the land covers and their dynamics. The intensity of agricultural abandonment in relation to the cultivated land is the main criterion to differentiate the situations corresponding to the 1<sup>st</sup> and 2<sup>nd</sup> generations.
2. Junction between forest land and urban area. Likewise, the drainage basins belonging to the 4<sup>th</sup> wildfire generation are identified by the land cover variables (% of urban area, % of dense forest land).
3. Forest management. Calculated for each type of forest formation (average values for each landscape unit – see Figure 1).



**Figure 4**—Map of territorial diagnosis (Island of Mallorca).

Finally, the demarcation of regional scenarios is carried out through the interpretation of the maps of territorial diagnosis and land occupation, grouping the

drainage basins into homogeneous spatial areas from the viewpoint of wildfire propagation (Figure 5). These spatial areas demarcated after this procedure can make up differentiated areas for territory management regarding wildfires. These scenarios could be put on an equal footing with what could be named *forest massif*: homogeneous biogeographical unit limited by natural or agricultural features, suitable for forest management or defense against wildfires management.



**Figure 5**—Map of regional scenarios (Island of Mallorca).

### **3. Conclusions: utility of fire scenarios**

The scenarios, defined as spatial areas with common characteristics regarding their initial conditions, possible evolution and repercussion of wildfires, may be demarcated at various territorial scales. In the approaches at lower scales (1:1,000,000), the spatial attributes used aim at reflecting the structural elements that condition the



propagation of wildfires (forest land hazard, relief) and the gravity and difficulty that their extinction may involve (impact on populated areas). In turn, the approaches at higher detail level, regional scale (1:50,000), allow for going deeper, from this first structural characterisation of the territory, into the foreseeable dynamic of land use and land cover, linking it to the future fire behaviour. In order to set the correspondence between territorial dynamics and fire behaviour, a model that defines various stages of evolution of the territory (wildfire generation) was suggested, in accordance with the characteristics of those wildfires that could result in situations of highest risk (LWF).

These exercises of zoning and characterising the territory require establishing special spatial units to analyse the variability of the attributes previously defined for their relevance on wildfires (from both the structural and dynamic viewpoints). Turning to the landscape units resulting from landscape character assessments has proven to be pretty convenient to make the approaches at the lower scale. For the approaches at the higher scale, drainage basins feature the advantage of being easy to define automatically (by means of GIS and terrain models), and of being easily grouped depending on the work scale.

The establishment of scenarios at various scales is directly related to the requirements of the territorial and wildfire policies defined by the Authorities of the several levels. In Spain, these responsibilities are mainly of the regions (Autonomous Communities) yet the State has competences for inter-regional coordination of the activities of protection against wildfires.

Framed within this context, the national scenarios correspond to the competences of the State Authorities and they make up an operational approach to the territory from the viewpoint of coordination activities of which the state is in charge: support to means of extinctions; establishment of protocols for inter-regional cooperation, etc.

Nevertheless, regional scenarios are the most interesting regarding management, given that regional Authorities have most of the competences in fight against wildfires. These spatial areas may be useful to define several questions spatially: development of regulation and planning; regulation of uses that may cause wildfires; determination of the wildland-urban interfaces at risk of wildfire; organisation and coordination of means of extinction and civil protection; programmes to raise awareness, amongst others.

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