RECIPE

REINFORCING CIVIL PROTECTION CAPABILITIES INTO MULTI-HAZARD RISK ASSESSMENT UNDER CLIMATE CHANGE

Support tool and guidelines for integrated risk assessment and planning for landscapes and wild-land urban interface

ENGLISH SUMMARY

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CONTENTS

1. Introduction

This report is part of the deliverables of the RECIPE Project (**Reinforcing Civil Protection capabilities into multi-hazard risk assessment under climate change**) and corresponds to the Deliverable 4.6 of Task 4.3.

RECIPE is a two-year Prevention Project (January 2020 – November 2021) founded by the Civil Protection Mechanism of the European Commission (call identifier UCPM-2019-PP-AG), with the participation of 8 institutions from 5 EU countries:

- Forest Science and Technology Centre of Catalonia (CTFC), Spain (Project coordinator).
- Pau Costa Foundation (PCF), Spain.
- Civil Protection General Directorate of Catalonia (DGPC CAT), Spain.
- Forest Research Institute Baden-Württemberg (FVA), Germany.
- CIMA Research Foundation (CIMA), Italy.
- Austrian Research Centre for Forest Natural Hazards and Landscape (BFW), Austria.
- Institute of Cartography and Geology of Catalonia (ICGC), Spain.
- School of Agriculture, University of Lisbon (ISA), Portugal.

The RECIPE Project seeks to develop operational recommendations and tools to reinforce Civil Protection capabilities into emergency management and risk planning of different natural hazards across Europe to address climate change impacts, by using an integrated risk management approach and the exchange of lessons learned and best practices.

By means of putting together multi-hazards' expertise from science and practice on **wildfires, floods, storms, avalanches, rockfalls and landslides**, main impacts of climate change in risk management will be identified. The potential scenarios of unprecedented multi-risk events will be considered. The interactions between prevention-preparedness-response-recovery actions in projected climate change scenarios will be analysed with an active participation of practitioners and other users. Accordingly, Civil Protection requirements to face new risk management challenges about climate change impacts will be identified.

Based on the above, transferable guidelines will be edited to incorporate the projected multi-risk impacts of climate change into operational decision support systems (DSS) that are used for risk management. Complementary, specific operational tools will be developed at pilot site level for each natural hazard to reinforce Civil Protection capabilities. Participation of public agencies will be promoted from the beginning to achieve an end-user oriented focus. Results will be actively disseminated into Civil Protection systems.

Furthermore, the project's workshops will promote the knowledge exchange in the existing networks to reinforce European landscapes' resilience to natural hazards.

The project is divided in 5 work packages (WP) as follows:

- WP1 Management and coordination of the action.
- WP2 Framing Civil Protection requirements for integrated multi-hazard risk management.
- WP3 Impacts of climate change projections on multi-hazard risk management.
- WP4 Guidelines and decision support tools to integrate climate scenarios into risk assessment and planning.
- WP5 Publicity and project outcomes transference.

Task 4.2 is part of the work package 4. This WP is composed by three tasks and serves to develop guidelines and support tools to incorporate climate change projections into risk assessment and planning of natural hazards and provide valuable information and resources that can help on the decision making. Task 4.3 aims at the production of a set of multi-hazards risk decision support tools addressing civil protection requirements in the climate scenarios into risk assessment and planning.

Based on pre-identified risk management needs during the project preparation, a set of support tools for civil protection are developed.

- Guidelines for flood and fire civil protection planning with participatory approach with an operational tool for collecting citizens monitoring observations in emergency situations.
- Decision-support tool and accompanying handbook for dynamic risk planning procedures for rock falls and landslides.
- Guidelines for a participatory crisis management plan to manage wind throw along roads.
- Visualizer tool for managing emergency situations in case of high avalanche risk.
- Support tool and guidelines for integrated risk assessment and planning for landscape and wild-land urban interface fires.
- Protocol for wildfire and avalanche risk management in mountain areas.

This Deliverable correspond to the **Support tool and guidelines for integrated risk assessment and planning for landscape and wild-land urban interface fires** and includes the description in local language to facilitate its dissemination among national Civil Protection bodies, and the summary in English.

2. Objectives and methodology

The **Support tool and guidelines for integrated risk assessment and planning for landscape and wild-land urban interface fires** includes complementary methodologies and novel approaches to manage wildfire risk aimed at reinforcing civil protection and copying capacity to reduce wildfire impacts in society, infrastructures, and ecosystem services.

More concretely, through the implementation of different pilot sites, methods developed and tested within RECIPE project seek to move forwards towards:

i) Integrated and better-balanced prevention-preparedness-response-recovery wildfire risk assessment and planning (WRA&P) approaches,
ii) Enhanced wildfire risk awareness at local community level, and;
iii) inclusive stakeholders' participation and engagement into the risk planning promoting risk culture and co-shared risk governance.

Pilot sites are developed in Spain and Portugal. On one hand, CTFC develops a novel method to analyse and plan wildfire risk with the objective to integrate the civil protection requirements into the risk assessment and planning and with the participation of the local stakeholders (pilot site I). To analyse the consistency and applied focus of the pilot site, the methods are tested and implemented in a real case. The administrative level chosen is the municipality (El Bruc, in Catalonia, Spain) since normally prevention and preparedness planning tools are concreted at local level according to the legal frame. Within this case study, risk awareness with public and private/public relevant actors is included. This sub-task is developed by CTFC with the collaboration of PCF and DGPC CAT.

Within the same pilot site of El Bruc, two exercises of risk awareness were developed by PCF; a workshop with the kids of the primary school in the municipality, and the organization of a Wildfire Preparedness Day with the aim to boost community participation in the Disaster Risk Reduction strategies. This sub-action is led by PCF with the participation of DGPC CAT and the CTFC's collaboration.

Finally, a decision support system (DSS) was drawn by ISA team and tested on Mafra municipality from Portugal (pilot site II). This DSS has the purpose to rank which are the most at risk infrastructures in the wildland urban interface in order to help prioritize the land clearing and inspection from the national authorities. Although by law, every house and infrastructure must do a 50m or 100m buffer of land clearing, some of these are not really at risk and it is possible to be more cost efficient if the authorities and homeowners could prioritize their actions.

2.1 Pilot site I: a) Integrated wildfire risk assessment and planning method and stakeholder engagement for resilient communities at local level and, b) Enhancing wildfire risk awareness among society exposed to risk

Within the pilot site situated in the municipality of El Bruc two sub-action have been coordinated:

- A method for an integrated wildfire risk assessment and planning at landscape and local scale of application, aimed at optimising the synergies between prevention, preparedness, response and recovery actions, tackling together not only the physical but also the social vulnerability reduction, with a specific focus on the reinforcement of the Civil Protection capabilities in the territory. This sub-action is conducted by CTFC with the collaboration of PCF and DGPC CAT.
- Tools for enhancing wildfire risk culture and awareness of children and WUI communities. With the aim to boost community participation, understanding the exposed population as a proactive stakeholder in the Disaster Risk Reduction strategies. This sub-action is led by PCF with the participation of DGPC CAT and the CTFC's collaboration.

The objective of the methodology is to enhance the policy coherence and to improve the cost-efficient balance among the prevention-preparedness-response-recovery risk mitigation measures, including the role of the community and private and public stakeholders related to the wildfire risk driven factors in the territory. At the end, this will offer a frame where the activities of the territory are embedded into the Risk Management Cycle from a resilient and better prepared community perspective to face the impact of wildfires.

On that sense, community involvement is a crucial issue considering the exposed population as a proactive actor of the Disaster Risk Reduction strategies. This pilot site has been used to adapt successful participatory approaches developed in other countries (e.g., Firewise USA® or Safer Together approach in Australia) to the regional conditions.

This integrated and bottom-up approach should serve to deliver operational recommendations for risk reduction considering all the legal, financial, social and cultural components, and to enhance the risk governance in the territory in a sustainable manner.

The pilot site chosen: El Bruc municipality

The village of El Bruc is situated in the limit of the metropolitan area of Barcelona (40km far from the city) and is representative of the different values at risk typically present in the Mediterranean landscapes such as protected areas (Natural Park of the Montserrat Mountain, and Roques Blanques Nature2000 site), strategic and extensive local road network, different types of settlements (WUI, isolated houses, city centre) critical infrastructures (e.g., oil station) or tourist resorts and sites. In the municipality diverse land uses exist (forest and burnt areas under regeneration, crops, urban or industrial) and the tourist and recreational activities are significant motivated by the high quality of the landscape, the presence of one of the most relevant natural park of Catalonia where, moreover, climbing, running, cycling or walking activities are very popular. Therefore, high concentrated and disseminated visitors' sites and activities are found in the area.

El Bruc also represents the situation of many small municipalities (2.202 inhabitants in 2020) with limited resources and significant surface to be managed (47,2km^2). The territory has suffered previous large

wildfires the last 40 years (1986, 1994, 2015). Moreover, in the area, innovative EU projects (e.g., LIFE+Montserrat) and prevention measures (e.g., training on prescribed burns or novel strategic wildfire prevention planning) have been implemented.

Figure 1. Situation of El Bruc and example of the landscape present in the municipality

During the project, different field visits have been done to identify and better recognise the elements at risk in the municipality, the risk mitigation measures, the map of stakeholders, the existing planning tools, etc. At the same time, it was developed a risk culture exercise with children in the school.

Figure 2. Left: Field visits analysing the risk sectors. Right: Meeting with the mayor of El Bruc

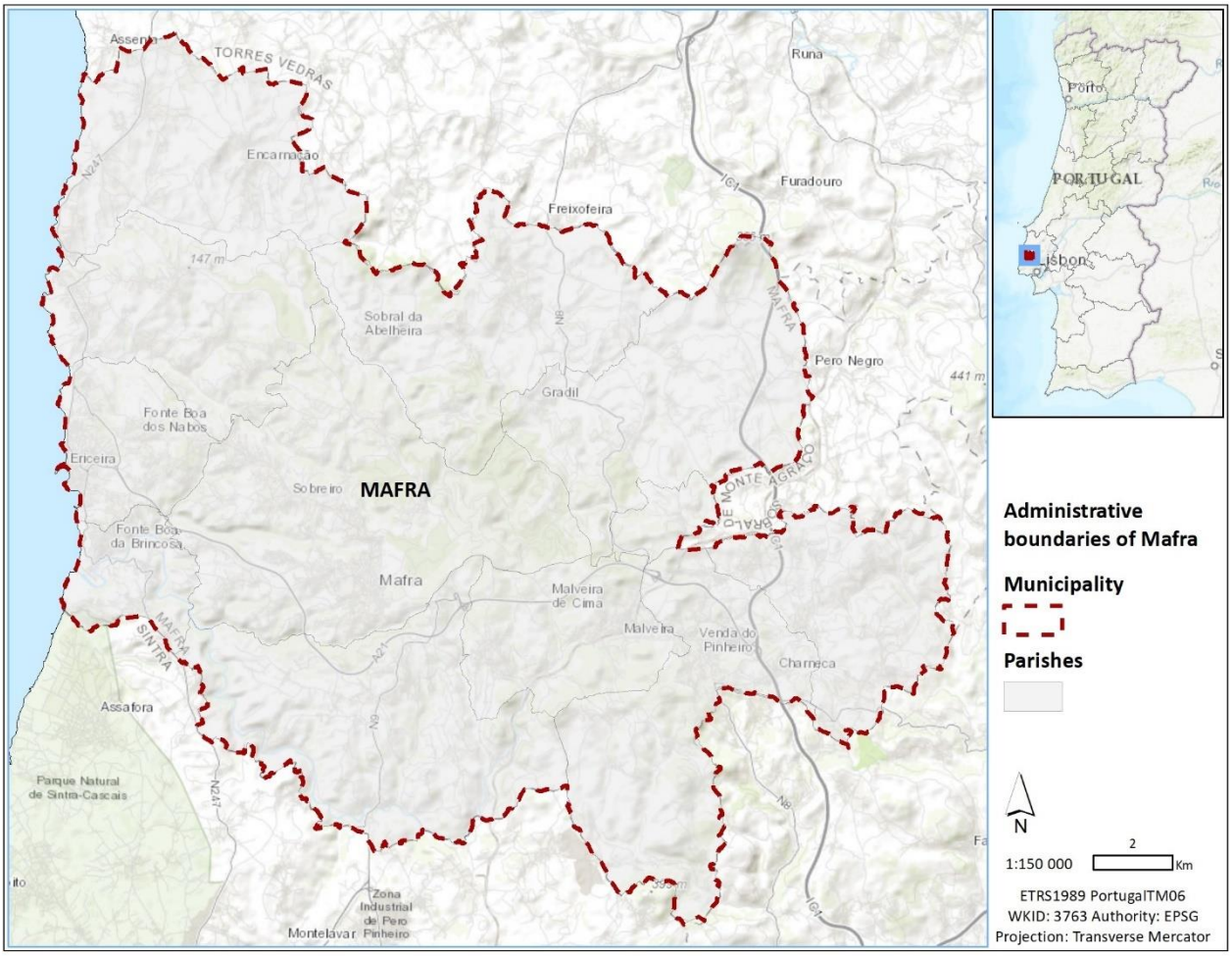
2.2 Pilot site II: Prioritizing fuel management at wildland urban interfaces at the municipal scale in Portugal

The creation of ISA decision support system (DSS) resulted from a request that came directly from the municipality of Mafra during a meeting about fire in the wildland interface. As a response, ISA team developed the theoretical and conceptual DSS which was tested and discussed with the civil protection head of Mafra municipality. The simplicity and practical application in the field are some of the most important criteria to be included in the DSS creation.

The pilot site chosen: Municipality of Mafra

The municipality of Mafra is located in the coastal side of the south-central region of mainland Portugal, within Lisbon District (Figure 3). It covers an area of 291 km2 and consists of 11 parishes. Mafra has an important cultural and built heritage value, as well as valuable natural and landscape resources. This municipality still maintains its rural characteristics with the advantages of an urban environment (CM, 2021).

Figure 3. Location of the municipality of Mafra, Lisbon District, Portugal



Population in Mafra have been increasing since 1991, and preliminary results for the 2021 census estimates population at 86.523 (851,4 people per Km2) (INE, 2021). Employment is mainly related to the tertiary sector (approx. 74,5% of the population), and only partly related to the primary sector (2,6% of the population). Despite the little importance of the primary sector, there are a number of families in Mafra engaged in agriculture as their secondary activity, which leads to a more frequent use of fire in these areas. In addition, the municipality has an heterogeneous relief, with coastal areas with various slopes. These terrain variations cause changes in wind direction, wind speed, and in vegetation distribution, with significant implications for forest fire defense.

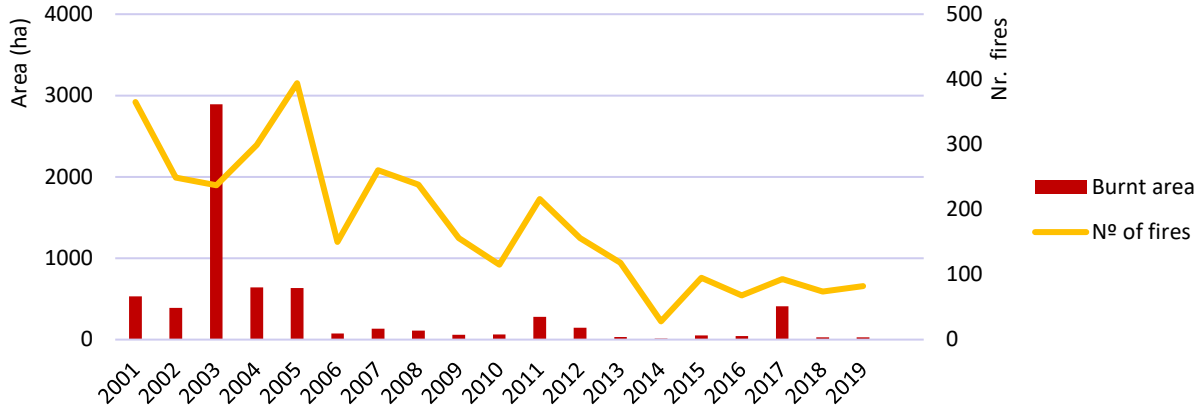
Mafra's climate is temperate with dry and mild summers (Csb). The average annual temperature is around 17,4 °C, with a maximum average of 24,9 °C in August. June, July, and September present similar temperatures. The conditions are usually ideal for the ignition and spread of a fire during these months, given that high temperatures are associated with low humidity and no rainfall for a long period (IPAM 2021).

Average annual rainfall is 774 mm. Rainfall occurs throughout the year, reaching its maximum in autumn and winter months. When associated with mild temperature months, vegetative growth is very high, which in case of non-fuel treatments will increase fuel continuity.

Mafra has an undulating topography and is mostly occupied by agricultural areas (38,3%). Forests occupies 13,9% of the municipality, mostly located in areas with the steepest slopes. Forest is dominated by Eucaliptus globulus, Pinus pinaster mixed with natural regeneration of *Quercus* sp. According to the latter Portuguese land use land cover map (COS), almost 39,2% of Mafra's forest are pure stands of Eucalyptus. Degraded forest areas are located in areas with a slope higher than 20%, where fire detection and extinguishing are difficult. The presence of flammable forest biomass on steep slopes contributes to an increase in fire spread due to a combination of slope, wind, and impact factors.

Concerning fire events in the municipality of Mafra, 1990 to 2005 was the period that registered more fire occurrences and more burned area. Over the past two decades (2001-2019), 6563,6 hectares were burned (i.e., 22,5% of the municipality total area). 9,3% of that total amount (i.e., 2756 hectares) correspond to the September 2003 fire (Figure 4) (CMMafra, 2020). From 2006 there has been a significant decrease in burned area and in fire occurrence, except for 2011 and 2017, when a slight increase was observed. Currently, small fires with less than 1 ha represent 86,8% of the occurrences and correspond to approx. 9,5% of the total burned area. Fires with burned area of 1 to 10 ha correspond to 21% of the total area burned.

Figure 4. Annual distribution of the burned area and number of fires from 2001 to 2019 in the municipality of Mafra. Source: CM Mafra, 2020



According to the PMDFCI, Mafra's forest fire problem is seasonal. July to October was the period with more burned area in the last two decades, representing 90% of the average area burned in the period 2001-2018.

High values in burned areas are usually associated with burnings for agricultural purposes. Such fires tend to spread to shrubs or forests as the moisture content in these areas is very low during summer and autumn. Other than in the critical period of July to October, few fire occurrences and burned areas take place in Mafra.

Apart from the undetermined causes of fire (77%), burnings for agricultural purposes are the main cause of the fire (15%), followed by electric lines (2,3%) and arson (1,82%).

Although fire ignitions are evenly distributed throughout the municipality, the concentration pattern tends to be higher close to more urbanized areas with higher population density (CM Mafra, 2020).

In summary, Mafra has several territorial characteristics that may influence fire behavior, such as, having almost half of the territory with slopes greater than 10%; presents rapid changes in wind speed and direction, and the average speed of the prevailing wind (N-NW) is stronger in critical months; more than half of the territory faces south, which promotes rapid drying and accumulation of dry biomass; and, summer months present with low rainfall and high temperatures. Additionally, fire data showed how important it is to continue raising awareness among the community, to avoid risky behaviors during critical periods, and to improve prevention actions, such as fuel management and respective inspection. Therefore, Mafra is an interesting case study to apply the RECIPE DSS Module.

2.3 Definition of risk factors and stages of the risk management cycle

In this report, the concepts of risk factors (Hazard, Exposition and Vulnerability) and Risk Management Cycle phases (Prevention, Preparedness, Response and Recovery) are understood according to the terminology of the UNDRR (Box 1). Moreover, cross-sectoral components of risk management strategies may be considered as well during the method or results explanations (Table 1).

Box 1. Definition of risk factors and phases of Risk Management Cycle (Source: UNDRR)

Risk factors

Hazard: A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.

Exposure: The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.

Vulnerability: The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

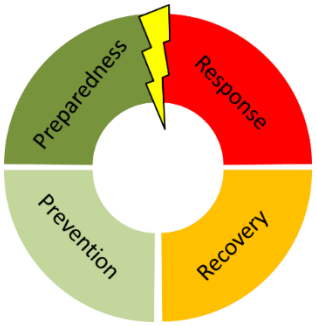
Risk Management Cycle

Prevention: activities and measures to avoid existing and new disaster risks.

Preparedness: aims at building the needed capacities to efficiently manage emergencies and achieve orderly transitions from the response to a sustained recovery phase.

Response: actions taken directly before, during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected.

Recovery: the restoring or improving of livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and "build back better", to avoid or reduce future disaster risk



According to the UNDRR, hazards may be natural, anthropogenic or socionatural in origin; "**Natural hazards** are predominantly associated with natural processes and phenomena. **Anthropogenic hazards**, or human-induced hazards, are induced entirely or predominantly by human activities and choices". On that sense, "Several hazards are socionatural, in that they are associated with a combination of natural and anthropogenic factors, including environmental degradation and climate change", which is specially pertinent in the case of wildfires since fire severity highly depends on the amount of fuels and landscape management.

Following UNDRR terminology, **Disaster** is "A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts", which indicates the needed interaction among H, E and V. Consequently, "Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability and capacity of the exposed elements to any particular hazard to estimate the

quantitative risks associated with that hazard in the area of interest". Based on the above, **Disaster risk** is understood as "The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity".

Capacity is also part of the risk equation since is defined as "The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience", and "may include infrastructure, institutions, human knowledge and skills, and collective attributes such as social relationships, leadership and management". The following categories are stated:

- **Coping capacity** is the ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters. The capacity to cope requires continuing awareness, resources and good management, both in normal times as well as during disasters or adverse conditions. Coping capacities contribute to the reduction of disaster risks.
- **Capacity assessment** is the process by which the capacity of a group, organization or society is reviewed against desired goals, where existing capacities are identified for maintenance or strengthening and capacity gaps are identified for further action.
- **Capacity development** is the process by which people, organizations and society systematically stimulate and develop their capacities over time to achieve social and economic goals. It is a concept that extends the term of capacity-building to encompass all aspects of creating and sustaining capacity growth over time. It involves learning and various types of training, but also continuous efforts to develop institutions, political awareness, financial resources, technology systems and the wider enabling environment.

Although capacity may influence in all risk factors, in this report it will be included within the level of Vulnerability, understanding it as "positive factors which increase the ability of people to cope with hazards".

Finally, **Resilience** is defined as "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management".

In terms of risk management, existing and potential risk reduction measures identified for each risk factor (HEV) may be allocated within a phase of the RMC and can share one or more **cross-sectoral component of risk management** used in RECIPE Project for risk analysis and commonly present in all Disaster Risk Reduction strategies (Table 1). For the exposure and vulnerability dimensions the following risk driver categories were established: Population, Infrastructure, Buildings, Critical facilities, Economic activities, and Environmental services[1].

[1] The environmental or ecosystem services are: "the benefits people obtain from ecosystems. These include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling. The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services". (https://www.millenniumassessment.org/documents/document.356.aspx.pdf)

Table 1. Cross-sectoral components of risk management (adapted from Plana et al. 2019)

Cross-sectoral component	Description
Risk assessment, mapping, and planning tools	Comprises the assessment of risk level (e.g. through modelling, mapping or qualitative surveys); identification of underlying causes of the driving hazard, exposure and vulnerability; and risk planning tools.
Risk governance and policy	The corresponding regulations and a public-private multi-actor governance framework for regional/national DRR strategies.
Risk culture and communication	Refers to actions promoting risk awareness and participation of exposed population in mitigating risk under the general framework of risk culture.
Technical measures	The corresponding mitigation measures at technical level.
Emergency management and response capacity	Considers all actions related to the protection of people, goods and environmental services, and the organisation of the emergency services during the event.
Recovery	Recovery and post-disaster management initiatives (e.g., from assessment of lessons learned to recovery plans).

From a methodological point of view, the risk analysis scheme conducted in RECIPE implies a sequence within the risk "building" process resulting from the combination of hazard, exposure, and vulnerability dimensions. In this sequence, if hazard mitigation measures are effective, natural hazard no longer has the capacity to impact on the exposed elements. If hazard cannot be neutralized (e.g., due to natural risk factors such as wind or rainfall intensity), only the absence of exposed elements may limit the risk. Finally, if neither hazard nor exposure can be neutralized to acceptable levels of risk, vulnerability of people and values at risk must be reduced by, for instance, increasing copying capacity.

Therefore, a proper identification of risk driver factors within each dimension should help to address disaster risk reduction in the most effective way. The understanding of risk process sequence facilitates to focus the Civil Protection systems since the general objective is to reduce the social vulnerability from the perspective of integrated risk management, by anticipating risk mitigation actions in the dimensions of exposure and hazard that may become more cost-efficient.

3. Method for integrated wildfire risk assessment and planning and stakeholders' engagement into risk mitigation strategies

3.1 Framing integrated prevention-preparedness-response-recovery approaches and inclusive stakeholders' engagement to deal with the increasing wildfire risk context in the Mediterranean landscapes

Wildfires is one of the major threats of Mediterranean landscapes. Common main risk factors drivers identified in Deliverable 2.1 (Hörl et al. 2020) are fuel (biomass) continuity (e.g., extension of wooded areas in abandoned crops and pastures) and availability (thin and dry vegetation), fire-prone weather conditions (i.e., increase of high fire risk index across the season) and, finally, a high level of exposition and vulnerability of goods and values (settlements and isolated houses, traffic infrastructures, strategic infrastructures, tourist resorts, disperse outdoor visitors, protection forest covers, natural parks, etc.) combined with a limited copying capacity in the case of high intensity wildfires and extreme wildfire behaviours, simultaneous and/or multi-emergency situations.

In the last decades, these wildfire risk driven factors are being exacerbated by two on going processes in parallel in many Mediterranean landscapes:

- The land use changes, which favours the connection between fuelled landscapes and houses and infrastructures (the so-called wild land urban interface or WUI).
- The climate change, which favours fire-prone weather (heat weaves, structural droughts) and related cascading effects on forest health (stressed trees affected by pest and diseases providing more dead biomass which burns easier).

Consequently, wildfire risk management must deal with a changing risk context where policies addressing fire ignition and spread risk, potential impact of high-intensity fires to exposed population and infrastructures, safety and efficient response capacity and recovery strategies to mitigate cascading wildfire risk effects meet. A more detailed analysis of risk factors shows how risk mitigation measures are, on one hand, distributed in different stages of Risk Management Cycle (from prevention to recovery) and, on the other, these measures involve different stakeholders both public and private, in both sense, as "providers" of risk mitigation (e.g., managed forest avoiding high intensity fire behaviours) and "beneficiaries" (e.g., less vulnerable urban developments or tourist resorts to wildfires' impact).

In terms of risk components, normally as higher is the hazard (H) more exposition (E) exists, and increased efforts to decrease Vulnerability (V) are needed. Reducing the H, less E is, and less V reduction is needed. This sequence is particularly relevant in the case of wildfires, where H is highly human influenced since fuelled landscapes are one of the main wildfire risk drivers, i.e., reducing fuels amount and modifying its distribution in the landscape permit to eliminate the presence of high intensity fires able to overcome suppression capacity and impact to the exposed elements. Moreover, fire-smart urban planning may also play a crucial role in reducing risk acting in the "building" process of creation of Exposition, e.g., promoting dissemination settlement housing model into forest fire-prone landscapes. Even when H and E cannot be reduced, building codes and norms can allow to reduce Vulnerability under consistent risk thresholds

adapted to each territory copying capacity. Therefore, resulting risk is the sum of actions increasing/reducing the H, E and V. Consequently, high levels of HEV may collapse the system and overwhelm the risk threshold socially assumed.

This cross-link between HEV factors can also be explained through the RMC stages. Prevention actions can help to reduce the H limiting high intensity wildfire risk behaviours that collapse the suppression capacity by managed forest, mosaic landscape or the ignition control. Within Prevention, by integration of wildfire risk into urban and spatial planning and standardized and compulsory building codes to be applied in the case of wildfire risk, E and V can be reduced. In terms of Preparedness, copying capacity (V) may be reinforced by defining Civil Protection protocols of confinement or evacuation in the case of wildfire, preparing the infrastructures of the territory to the application of those protocols (e.g., reducing fuels along the pre-selected roads to be used as evacuation infrastructure or to those sites selected for safety confinement) or developing early warning systems (EWA). In some regions such as in Catalonia, due to the high level of H (fuelled landscapes in high fire risk index periods), access control to natural areas is applied, seeking for the reduction of E of visitors in the case of wildfire (which will jeopardize suppression capacity as well), the reduction of H of ignitions, and the increase of copying capacity (V) by reducing the probability of simultaneous events (less ignition risk). Highly efficient Response allows to reduce the expansion of wildfires, especially when it is based on the knowledge of wildfire behaviour patterns (Costa et al. 2011). This approach permits to anticipate the wildfire movement before it happens and increase the suppression capacity by implementing fuel management in strategic areas that which serve to support the manoeuvres of Fire Service in the case of wildfire. These strategic areas, therefore, can be understood as infrastructures and resources to support fire suppression such as water points or equipment. At the same time, as more trained, efficient and equipped is the Fire Service, more copying capacity exist. Nevertheless, extreme wildfire events everywhere show how often the suppression capacity is overwhelmed in many countries, and how in that situation, a defensive strategy is basically adopted protecting lives and infrastructures limiting the capacity to control the fire spread in the forest.

Therefore, in high HEV context, Response if offering a limited capacity to reduce the risk. This helps to understand the deep cross-link that exist among risk factors and mitigation measures across the RMC in a similar sequence as in the case of HEV: As more Prevention actions are adopted, less efforts in Preparedness and Response are needed, and lower Recovery impacts may be expected. The following figure summarize two potential risk scenarios according to the risk mitigation measures adopted (or not), and the corresponding risk management strategy.

Consequently, in terms of risk management, there is a correlation among the level of the risk factors, the strategy to follow in the case of wildfire and its potential impact in the landscape. The assumption (or not) of risk reduction measures will influence how to manage the situation in the case of wildfire and the final impact of the event to citizens, infrastructures, and the ecosystem services of the landscapes. Indeed, not a unique risk scenario exists, and how to manage wildfire risk can be balanced according to the level of risk, together with each territory capacity and level of values at risk to be protected. What extreme wildfire events are showing in the Mediterranean is that in most cases, Response complemented by standard Prevention (fire breaks, ignition controls, etc) and Preparedness (civil protection plans) actions can face most of wildfires, but a small proportion burning in high intensity collapse the system and affects hundreds or thousands of hectares. This means that Response capacity, in those risk scenarios, should be complemented by additional Prevention and Preparedness actions able to reduce HEV factors. On that sense, predefined objectives should be stated according to the risk management strategy adopted, for instance, to ensure population safety but not being able to ensure forest protection versus looking both

objectives (when more resources and mitigation action will be needed). On that sense, since fuelled landscape become a Hazard factor, win-win strategies can be adopted through high intensity fire-resistant landscapes, promoting forest structures able to protect the values at risk. As was stated in the beginning, the increasing risk context due to the land and climate change is stressing the suppression centred strategies and make this need of better balance among HEV factors and RMC measures more and more urgent. Stakeholders' engagement within this risk management alternatives discussions should help to articulate the necessary contributions from individuals, private and public bodies, in a more synergic and cost-efficient, and policy-coherent manner to protect fuel-laden communities from firestorms.

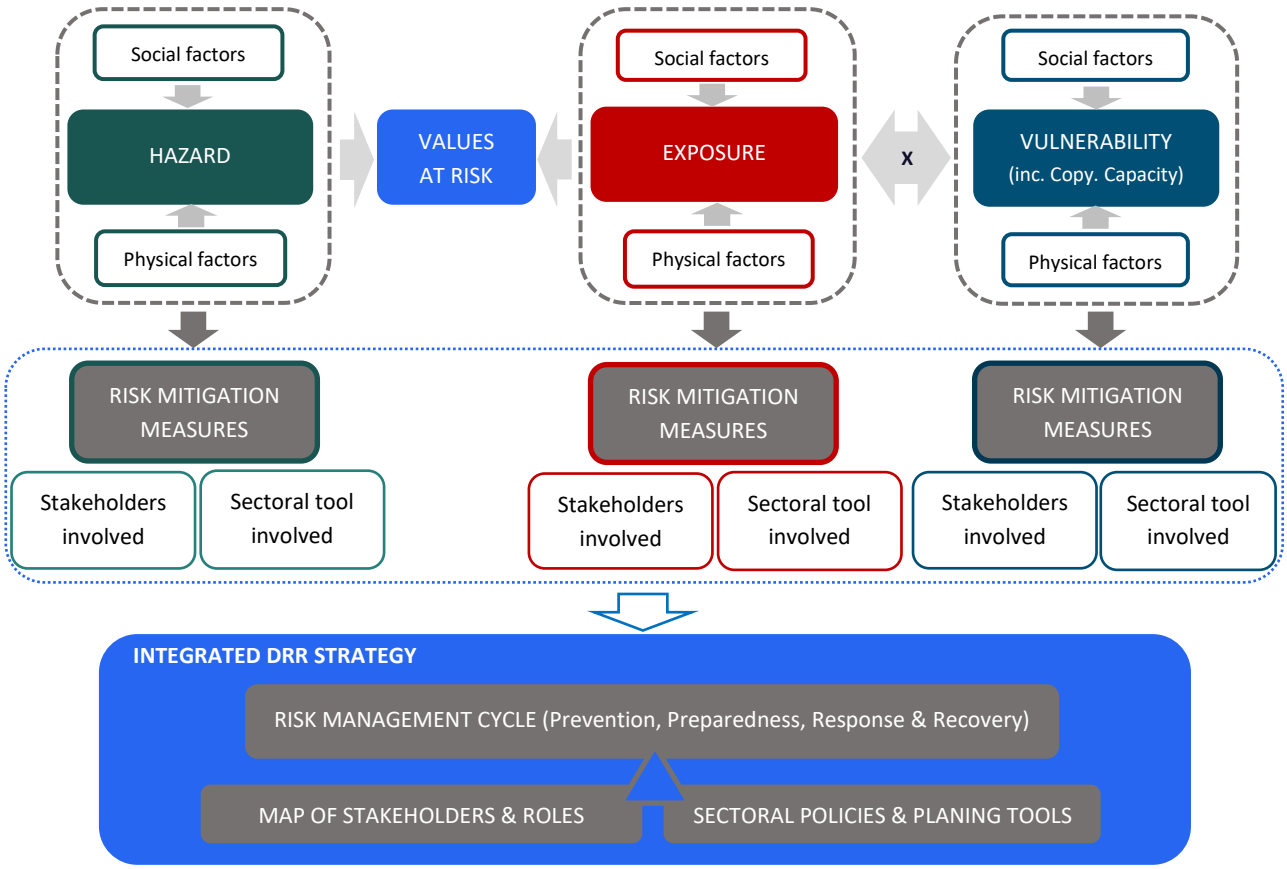
3.2 Methodological sequence for the integrated wildfire risk assessment and planning

The risk assessment and planning (RA&P) method developed follows a sequence of analysis able to promote more integrated, inclusive and balanced risk management approaches, with a specific focus on the increase the Civil Protection and copying capability of the system. To achieve these objectives, the protection of the exposed population, infrastructures and ecosystem service is centred according to the potential wildfire event impact, and risk management actions are defined and planned accordingly. Along the process, main components of HEV factors are identified. Subsequently, the corresponding risk mitigation measures are proposed, and the related stakeholders are identified (both, from the side of providers and beneficiaries of risk mitigation). And finally, defined risk scenarios and measures are transferred into planning tools in a coherent and consistent way. This process is complemented by the stakeholders' engagement into the risk analysis process, by explaining them the situation, promoting risk awareness, and allowing a risk scenarios alternative choosing process in the meanwhile a sense of risk management community is built, establishing the corresponding roles and contributions of the public and private actors involved.

Figure 1 shows the three steps RA&P sequence carried out in the integrated HEV-RMC method:

- **Step 1**: Per each value at riks in the territory, the HEV risk factors are identified, considering both physical and social aspects.
- **Step 2**: Accordingly, risk mitigation measures per each identified risk factor, stakeholders involved in each measure, as well as the corresponding sectoral policy and/or planning tool where to fit it are related. One stakeholder can be related to more than one risk mitigation measures.
- **Step 3**: In a final statge, risk mitigation measures are organised within the RMC, conforming and integrated approach where cross-links among prevention-prepardness-response and recovery actions are balanced and synergies are potentiated in a coherent policy frame, defining the roles and contributions of stakeholders.

Figure 1. Sequence of risk assessment and planning sequence towards integrated, balanced and synergic Disaster Risk Reduction strategies



Within step 1, three sub-stages as carried out and serve to organise the information for steps 2 and 3 as follow:

Step 1. Identification of HEV factors in the territory

1.1.- Description of the territory and its main features regarding wildfire risk (including the institutional frame)

1.2.- Sectorization of the territory in sub-units according to HEV factors for a consistent wildfire RA&P (if needed, depending on the size and diversity of the case study)

1.3.- Definition in detail each HEV factor per each sub-unit

Step 2. Identification of risk mitigation measures, related stakeholders and planning tools (following the sub-units' level according to steps 1.2 and 1.3)

Step 3. Organization of the risk planning within the RMC and definition of synergies and policy coherence

3.3 Integrated RA&P implementation in the pilot site of the municipality of El Bruc

The above-mentioned methodology was tested in the municipality of El Bruc. This chapter describes the implementation process and show examples of the results achieved.

With regards step 1, the **description of the territory** and its main features regarding wildfire risk (1.1) was based on the main **wildfire patterns** identified in the area and the potential wildfire environs that may impact on the values at risk in the territory. Within these values at risk, the protection of civilians (downtown, suburbs and visitors for recreation), infrastructures (highway, oil station, touristic resorts, etc.), as well as the natural heritage (considering the presence of the Natural Park of Montserrat) were the main priorities.

In this case, the expert knowledge from the Catalan Fire and Rescue Service (CFSR) as well as historic fires in the area serve to identify the main wildfire risk scenarios to be considered in the analysis. As much as known is the wildfire patterns in the area, more precise may be the risk scenarios definition. Therefore, fire service was contacted and involved in the analysis from the beginning which also serve to start engaging stakeholders in the process. Moreover, the analysis considered previous projects carried out in the area such as LIFE+Montserrat, in which the current municipality team was involved, with the aim to look for as much synergies as possible with current initiatives on the territory.

Together with the wildfire patterns, a special focus was done also to the Land Use Changes drivers in the area due to the high influence of fuels distribution in the HEV distribution. On that sense, the landscape of El Bruc shows a typically Mediterranean changing dynamic with:

- a recent regression of the cultivated and grazed area (especially sheep and goats),
- the consequent expansion of forests only offset by the presence of forest fires,
- the also increase of the urban surface (settlements and infrastructures) which and due to the previous points, often implies an increase of the urban-forest interface and, finally,
- an increase in the diffuse recreational use and tourist infrastructures (itineraries, viewpoints, car parks, etc.) in the natural area.

At this stage, the **institutional frame** is analysed where the existing risk management plans and tools are identified. A documentary review of the most relevant plans was conducted (e.g., the municipality civil protection plan, fire prevention plan, urban plan, but also the emergency plan of the Natural Park of Montserrat or the Emergency Plan or the Special emergency plan for accidents of dangerous freight transport of Catalonia since it affects a road close to Montserrat Parc suburb).

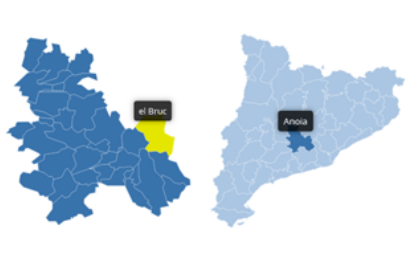
In parallel, the **map of actors** related to each RMC stages is carried out (more than 20 actors were identified). At this stage, the collaboration of the municipality is fundamental to reach the necessary sensitiveness in the analysis of the institutional frame and map of actors.

Once the case study is framed, in a next step several field visits were conducted to achieve a more accurate understanding of the HEV factors. The visits were done together with the staff of the municipality and the local Association of Forest Defence, officers of General Directorate of Civil Protection (DGPC) and CFSR as well, which also serve to strengthen the involvement of stakeholders in the main purposes of the analysis of addressing an integrated wildfire risk management (WFRM) approach. Meeting them on the field, serves indirectly to understand each other perspective and, in the case of emergency bodies, share its own operational requirements. Local stakeholders such as shepherds in the area where also visited.

Figure 5. Examples of the summary table featuring the municipally of El Bruc, including the current planning tools (shorted list) related to wildfire risk valid in the area and the corresponding links, the analysis of the historic fires and the LUC in the area

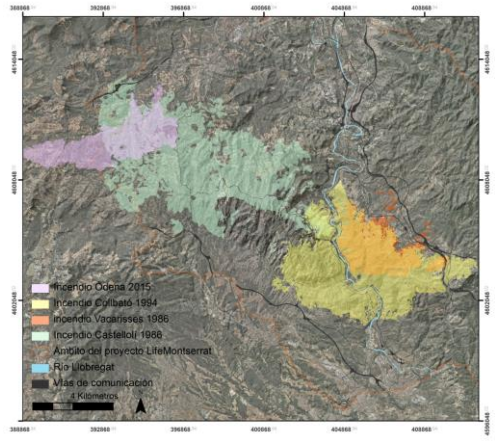
Caracterització del municipi de El Bruc i el risc d'incendis forestals

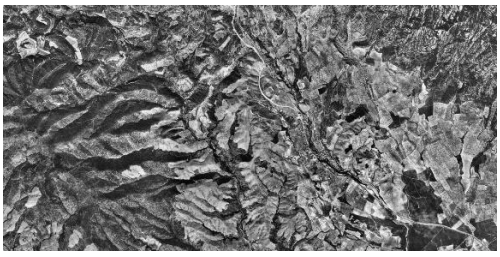
Municipi	El Bruc	Comarca	Anoia	Província	Barcelona	Àmbit funcional territorial	Penedès



Altitud*	489m	Població (2020)*	2.110	Superficie*	47,20 km²	Densitat*	44,7 hab./km²		
Sup. forestal**	4.188ha (arbrades: 1.426)	Sup. agrícola útil*	277ha	Terres llaurades	270ha (herbacis 122ha, fruiters 6ha, vinya 48ha, olivera 93ha)	Pastures permanents	7ha		

Consideracions i documents en relació al risc d'incendi forestal vigents				Font
Mapa Municipal de Perill	Alta	Mapa Municipal de Vulnerabilitat	Molt Alta	Pla INFOCAT
Pertinença al Sector de Risc del Perímetre de Protecció Prioritària per a la prevenció d'incendis B1 Montserrat (17.274ha totals, 12.924ha forestals, 4.350ha no forestals)				Pla INFOCAT DACC
Document únic de protecció civil municipal (DUPROCIM). El Bruc (2017)				Ajuntament del Bruc
Pla Municipal de Prevenció d'Incendis Forestals (PPI) (2020-2026)				Ajuntament del Bruc
Pla de prevenció en urbanitzacions (PPU) Montserrat Parc (2012)				(ddp:29/04/2021)
Pla de Prevenció d'Incendis Forestals a les urbanitzacions i nuclis de població (PPU) Nuclí Urbà (2020)				(ddp:29/04/2021)
PEMONT: Procediments de resposta per a emergències a Montserrat (PEMONT) (2009)				DI
Cartografia operativa d'emergències de la muntanya de Montserrat				DI
Actuacions estratègiques per la prevenció d'incendis. Informes Projecte Life Montserrat				Projecte Life Montserrat
Altres documents rellevants				Font
Regulació del pas de trànsit rodat al Peudemont de Montserrat (2018)				Acta Ple Municipal 21/03/18
Pla de Gestió i Desenvolupament del Parc Rural de Montserrat (2019)				Diputació de Barcelona Web PRM
Planejament urbanístic - Normes subsidiàries de planejament (NNSS) per a la regulació del sòl no urbanitzable (darrera modificació de 2021, text refós) - Pla especial del Catàleg de masies i cases rurals en sòl no urbanitzable (text refós) Per altra banda, l'avanç del POUM ha estat revocat en un ple municipal l'any 2021				Ajuntament del Bruc
Informe tècnic ambiental El Bruc (Oficina Tècnica de Planificació i Anàlisi Territorial-DIBA 2016): Valoració de la Infraestructura Verda i els Serveis Ecosistèmics del municipi				Ajuntament del Bruc
Pla especial de Roques Blanques, Sant Salvador de les Espases (Montserrat)				DVPDT
Pla especial del Parc Natural de la Muntanya de Montserrat (1988) RESOLUCIÓ PRE/70/2016, de 15 de gener, per la qual es fa públic un acord de la Comissió Executiva del Patronat de la Muntanya de Montserrat sobre la pràctica d'activitats esportives, activitats col·lectives i normes de comportament i ús dins l'espai natural protegit de Montserrat.				Patronat de la Muntanya de Montserrat





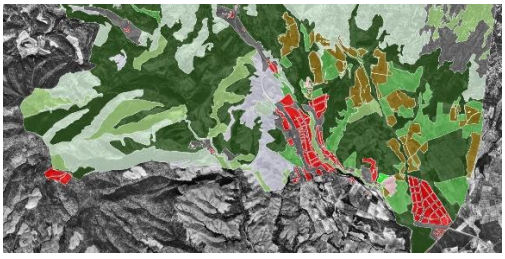
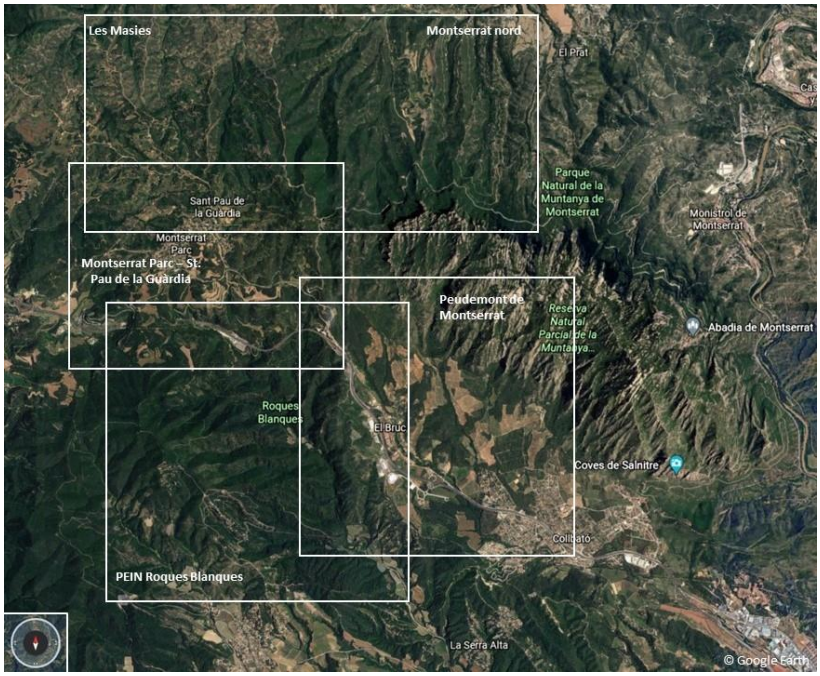


Figure 6. Visiting a grazing area promoted by LIFE+Montserrat to prevent large wildfires in the downhill of Montserrat Parc suburb, and the fuel treatment area promoted by the Natural Park in the entrance's paths for hikers and climbers, which suppose a tricky issue in terms of exposition of visitors to wildfires

According to the main HEV factors identified, the territory in this case was divided in 4 sectors with specific particularities in terms of risk management, values at risk but also social aspects about the risk community sense. For instance, Roques Blanques area is a massif with almost continuous forest. In the south of the Natural Park of Monserrat sector, the so-called Montserrat foothills, is where the downtown is situated, together with some annexed suburbs (wildland urban interfaces) and an interesting agroforestry mosaic that plays a crucial role in reducing HEV. Therefore, each sector has a justification from risk analysis and management perspective and, in some cases, social aspects are determinant. For instance, the neighbourhood feeling in the inhabitants of the North sector linked to a typical rural disseminated settlement in farms, justify do not mix with the isolated suburb of Montserrat Parc with a specific social dynamic. In Montserrat Parc is where the risk awareness exercise was conducted (Chapter 4).

In the next step (1.3), the definition in detail of each HEV factor is carried out per each sub-unit or sector. Firstly, a general description of the sector is done, including biophysical and social attributes. Consequently, the identification of factors of H and values of the territory at risk (Exposed and Vulnerable) is done, giving a code to each one separately and representing them in a map.

Figure 7. Sectors of risk considered in the case study



In terms of H, main wildfire situations are correlated with the wildfire patterns in the territory and validated with the CFRS. Wildfire situations are analysed in a comprehensive way, including those related to large wildfire event and environ, running from far away and impacting in the area (with the presence of secondary fires at long distance for instance. Big green arrows in the figure below). Nevertheless, in this case, also other small fires with high potential, such as does fires starting in the suburbs driven with south wind which easily can reach the Natural Park (where accessibility is highly limited, and fire will spread easily) were also considered (small green arrows). Once those scenarios are defined, EV factors are identified accordingly. In a next step, the corresponding risk mitigation measures in each case are defined.

Figure 8. Example of identification of HEV factors in the South Montserrat Park sector

Based on the above, in Step 2, **risk mitigation measures, related stakeholders and planning tools** are identified and explained. Measures are described through figures and tables, following the corresponding codes, and linking them to the specific HEV factor and the corresponding RMC stage.

In the definition of the risk mitigation measures the **sequence among HEV factors** in terms of risk management is implemented. In consequence, mitigation measures are balanced according to the level of risk, "starting" for those able to reduce the H, after, looking for the options to reduce E and, finally, how to tackle V reduction. By this way, the trade-offs among HEV risk reduction measures are stablished, giving visibility in a very practical way to the consequences of acting, or not, and establishing the alternative risk reduction pathways in each case. For instance, in the case of the potential impact of wildfire in the popular restaurant of la Vinya Nova cannot be reduce (Vn in the previous figure. More than 500 people can easily meet for lunch in a normal weekend), subsequent measures to prepare and adapt the place as a safe confinement area should be implemented (in this case, for instance, complemented with a protocol of early warning with the owners to do an effective confinement, since normally first reaction of people will be to leave the area).

Figure 9. Example of the table (shorted) of risk mitigation measures per each sector (HEV factor, RMC phase, related stakeholders planning tools)

Taula 12. Definició dels factors de risc d'incendis forestals i les mesures de mitigació al sector del Peudemont de Montserrat

Factors de PERILL (P)	CODI	MESURES MITIGACIÓ	RMC	ACTORS	DOC&INIC
Ignicions	Pi1	Franja perimetral en urbanitzacions, aparcaments dissuasius i àrees lleure	PREV	ADF, Ajuntament, Propietaris i veïns de les urbanitzacions i habitatges aïllats, Fundació Catalunya La Pedrera (Can Massana)	PPU_Nu, PPU_BR, PPI, DUPROCIM, COE
	Pi2	Control aparcaments i d'activitats en zones d'interfase els dies de més ric	PREP	ADF, Ajuntament, Associació de Propietaris i Veïns del Bruc Residencial, Veïns i propietaris en urbanitzacions, Agents Rurals, Mossos d'esquadra	PPI, DUPROCIM
	...	...	...	...	...
Ambient de foc_GIF	Paf1	Ampliar àrees estratègiques de gestió a la carena de les Creus Verdes - Es_GIF2.	PREV	ADF, Administració forestal, Patronat PN, DIBA, Associació de Propietaris Forestals del Entorns de Montserrat, Pastors de Foc de Montserrat, UT GRAF (cremes controlades)	PPP, PPI, IOF, PEMON, NN.SS-POUM
	Paf2	Manteniment i ampliació del mosaic agrícola - priorització zones estratègiques - Es_GIF1-2	PREV	Administració forestal, Associació de Propietaris Forestals del Entorns de Montserrat, Associació de productors de Peudemont de Montserrat, Associació del Parc Rural de Montserrat	PPP, PPI, PEMON, NN.SS-POUM
	...	...	...	...	...
Factors EV_VALOR EN RISC	**CODI**	**MESURES MITIGACIÓ (E i V)**	**RMC**	**ACTORS**	**DOC&INIC**
UrbanitzacióBruc Residencial UrBR	UrBRE1	Implementació Paf1-3 (Carena de les Creus, Serrat de Muixerugues, eix conreus Torrent del Castell, alineacions Roques Blanques - Vall de St. Cristòfol, Es_GIF1-2)	PREV	Paf1-3	Paf1-3
	UrBRV1	Pi1 (ample addicional sector N - Torrent del Castell i parcel·les interiors + vessant sud A2)	PREV	Pi1	PPU_BR, DUPROCIM, NN.SS-POUM
	...	...	...	...	...
Vinya Nova, aparcament i rodalies Vn	VnE1	Implementació Paf1-3 (Carena de les Creus, Serrat de Muixerugues, alineacions Roques Blanques - Vall de St. Cristòfol) - Es_GIF1-2	PREV	Paf1-3	Paf1-3
	VnV1	Aplicació de tractaments forestals de reforç i condicionament pista a BR per emergències, manteniment xarxa de conreus propers del peudemont	PREV	ADF, Administració forestal, Patronat PN, DIBA, Associació de Propietaris Forestals del Entorns de Montserrat, Associació del Parc Rural de Montserrat	DUPROCIM, PPI, PPP, SS.NN-POUM
...	...	...	...	...	

In the same sense, risk mitigation measures are defined according to the level of hazard, for example, adapting the place for safe confinement in case of short distance wildfire risk scenario (see Es_IF1 in the previous figure) and preparing the place and protocols for safe evacuation (with time enough) in the case of sever wildfire risk scenario (see Es_GIF1 and 2). Consequently, measures are balanced according to the level of HEV and the response capacity in a consistent way and the territory can better be prepared according to those pre-defined risk scenarios. Moreover, this approach also serves to easily show to the local actors in a comprehensive way the different alternatives and consequences per each risk situation, and up to what extend the risk can be reduced in a proactive way investing more in the prevention/preparedness stages of the RMC.

Figure 10. Example of figure representing the values at risk and the risk mitigation measures in the South Montserrat Park sector

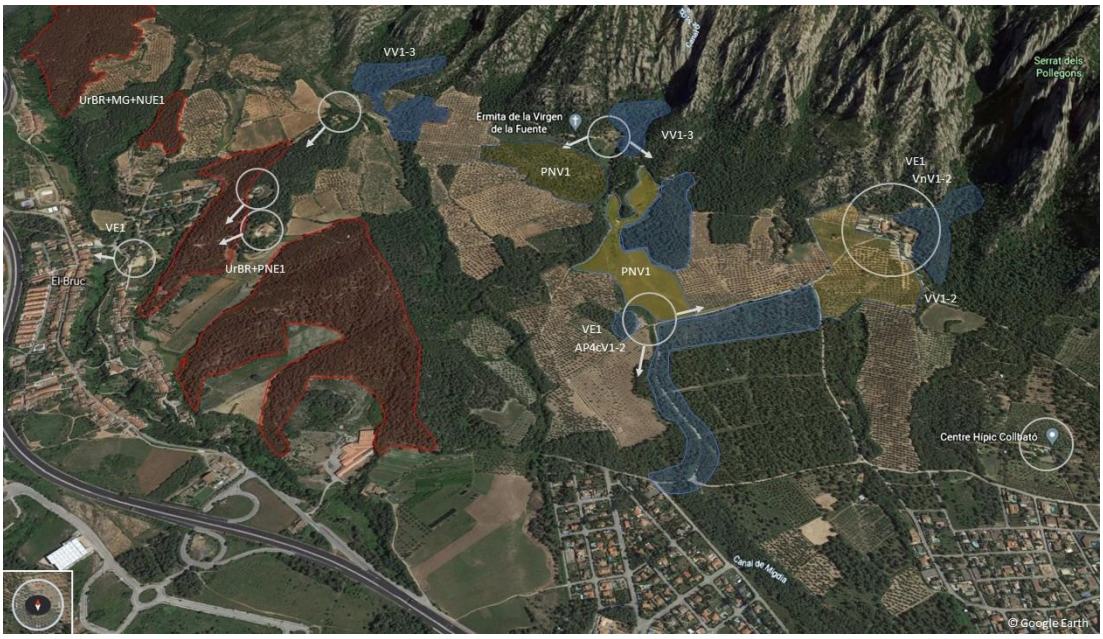
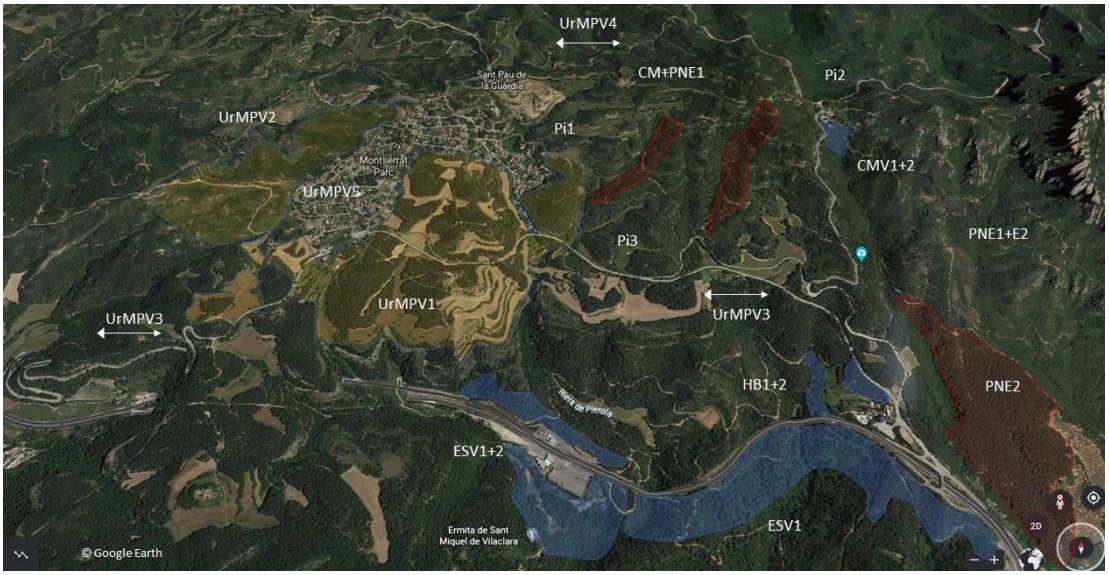


Figure 11. Other example of figure representing the values at risk and the risk mitigation measures in Montserrat Parc sector



Per each sector, a final chapter of **policy coherence** is done (Step 3), establishing the links and synergies among the proposed risk mitigation measures with the institutional frame and the map of actors of the territory. From this perspective, some of the recommendations in the case study were as follow:

- Integration into the urban planning tools and the corresponding sectoral policies those crop and managed wooded lands which are strategic for the reduction of wildfire spread capacity, looking for incentives to support them as a Civil Protection infrastructure (mapping them into urban, fire prevention and CP plans for instance).
- To establish the necessary coordination with the neighbouring municipalities since risk mitigation measures can be situated out of the municipality border. In this case, two main kinds of measures where identified; Measures related to evacuation/confinement infrastructures: Measures related to fuel treatment according to the wildfire pattern. That information should be transferred and included to the corresponding local urban, fire prevention and CP plans and sectoral policies of the surrounding municipalities, which may also be used to build a fire community sense in the territory (including them in the analysis and discussing the results and alternatives of risk management).
- The proactive inclusion of private actors in the Civil Protection plan. For instance, the tourist sector may play a first early warning role with the clients (e.g. restaurants), managing the pre-defined confinement or evacuation protocols.
- Establish the legal mechanisms to do the most efficient use of resources for risk reduction (normally very limited). For instance, transferring money from fuel treatments to reduce vulnerability (perimeter strip in WUI) to those activities able to reduce exposition (fuel treatments in adjacent areas through grazing, forestry and cropland activities).
- Make visible the trade-off among HEV factors to involve the corresponding actors in the mitigation measures, creating the necessary operational, legal and financial measures to compensate the risk "generated" as well as the risk "reduced" among them.
- Based the risk reduction tools and plans in the pre-defined and validated risk scenarios as a common baseline for all the bodies with competences in the risk management. This should help to deploy in the most efficient way the different kind of measures in the corresponding sectoral plan (wildfire prevention plan, civil protection plan, suppression, etc.) within a common multi-agency risk reduction strategy. This implies to move forwards in shared information systems and platforms, carry out RA&P process in a participatory way, address the risk mitigation measures according to pre-defined risk scenarios agreed with the territory and manage the necessary drills in these scenarios to train the most efficient response in case of emergency.

Moreover, the classification of each risk mitigation measure allows to compile and compare them across risk sectors. In the final step 3, all measurers can easily be organised following the RMC stages. The **organization of the measures following the common phases of risk management** gives the advantage to **engage stakeholders** at very operational level, defining in the process practical questions such as; **What are the measures**: **Which is my role**, and: **to Which planning tool this measures should fit.**

At the end of this process, synergies among risk mitigation measures and actors are better identified and strengthened, enhancing the policy coherence and cost-efficiency of the IWRM strategy in the territory with the pro-active participation of the stakeholders from the beginning.

3.4 Lessons learned, main achievements and further developments

The tested methodology has shown relevant insights that can help to better address integrated wildfire risk management with a special focus on Civil Protection. The comprehensive approach of the method helps to meet several cross-sectoral components of risk management (Table 1) in a unique process, from those referred to *Risk assessment, mapping, and planning tools*, the *Technical measures*, but also the *Risk governance and policy* and the promotion of enhanced *Risk culture and communication*. Moreover, within the method, the requirements for an efficient *Emergency management and response capacity* may easily fit within the fire prevention plans, being able to make the most efficient use of the commonly limited resource to manage risk at local level.

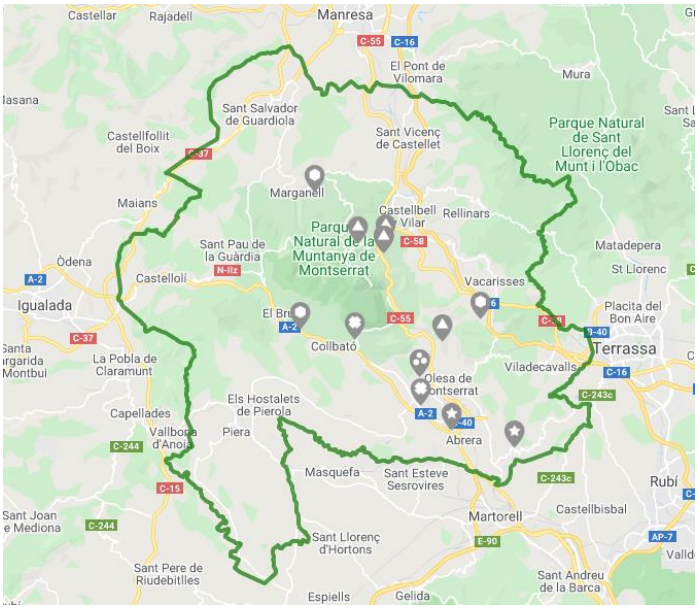
In terms of scale, the biophysical approach through the wildfires patterns at landscape allows to integrate in the analysis the potential impact of high intensity wildfires environs. In fact, in the case study area, the suburb Montserrat Parc was evacuated preventively at risk of wildfire impact in 2015 (which finally did not reach the area). This landscape overview is, subsequently, downscaled at local level, but also integrates in the analysis possible measures beyond the administrative limits of the municipality, enhancing a more systemic approach both at spatial and institutional level.

During the pilot site implementation, some **key findings** can be summarized as follow:

- To achieve an accurate HEV factors definition is fundamental to base it in main and consistent risk scenarios in the area. The proper knowledge of wildfire patterns in the territory is a powerful tool to define those risk scenarios. This may help to balance potential risk mitigation measures in a more efficient way, adapting accordingly the prevention (typically, the Fire Prevention Plan at municipality level), preparedness (the corresponding Civil Protection plan at municipality level) and response tools (cartography, strategies, resources, etc.). This also permits to involve in a more consistent way the territory stakeholders, based in pre-defined risk situations and pathways that can be easily understood (inspired in past events, novel knowledge shared, maps and figures, etc.). Over this understanding about wildfire patterns, corresponding requirements from emergency management or spatial planning should be overlapped, motivating a multi-agency shared RA&P process. On the contrary, if the information is not accessible or shared, risk mitigation measures from the different competences (in some case, very segmented, at institutional but also physical levels) are disconnected, resources are used in an inefficient way, and it is not possible to move forward to integrated WFRM strategies.
- The map of actors needs to be enough wide to be able to integrate all stakeholders related with IWRM and HEV drivers' factors perspective. At the same time, the zoom should be large enough to include those actors/initiatives affecting the dynamics of the targeted territory analysed (in this case, the municipality of El Bruc) is embedded. The neighbouring municipalities will have a special role since some risk mitigation measures may be situated at their territories.
- Presenting the process from the beginning to the municipality and getting the pro-active engagement of the mayor and the staff is fundamental to reach the necessary level of sensitiveness of the analysis. The local knowledge about the stakeholders and about the dynamics of the territory, the concrete availability and validity of the planning tools, etc., offer a fundamental resource where to base the corresponding risk mitigation measures in a consistent way from the local perspective. The municipality (as main beneficiary of the RA&P process) may also help to mobilise the participation/collaboration of the public bodies in charge of risk management, which competences are usually segmented across several administrations (local, subregional, regional) or even in different departments in the same administration.

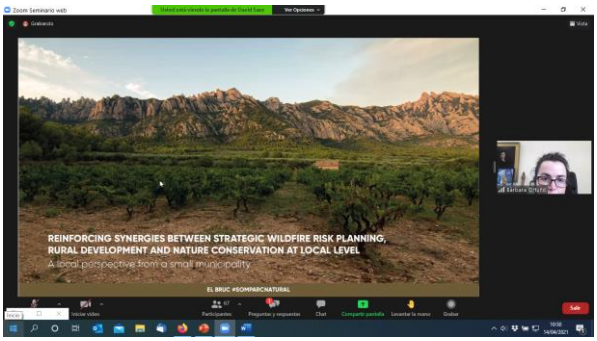
The municipality also plays a fundamental role in reaching and including private actors during the analysis process. On that sense, the level of leadership of the municipality may influences this engagement capacity.

Figure 12. Left: Montserrat Rural Park area. Right: Local olive oil tasting fest organized by the municipality of El Bruc



The case study area below to the [Rural Park of Montserrat](), which offers an excellent frame where to build synergies with regards fuels and land management risk mitigation actions. Mosaic landscape surrounding the Natural Park of Montserrat may be understood as a green infrastructure protecting the NP from wildfire impacts. This is a very relevant issue, considering the local visitors and the thousands of tourists that every summer are visiting the NP.

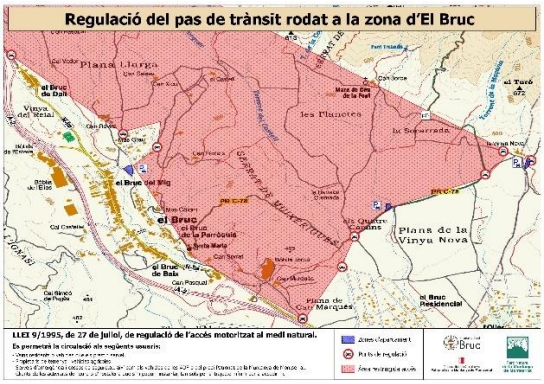
Figure 13. Images from dissemination actions related to the case study



The mayor was very interested in the pilot site from the beginning, disseminating the RECIPE project pilot site in meetings, local magazines and in the municipality website. We also invite her in workshops and visited the pilot site with the students of Pyrolife project interviewing local stakeholders such as the chief of the CFRS in the area.

- Moreover, along the risk analysis and planning process, the corresponding public and private stakeholders can be easily reached, involving them in the discussions, showing and contrasting the results, balancing the different risk scenarios according to the intensity and level of achievement of the risk mitigation measures, and establishing the corresponding specific collaborations and protocols. Therefore, RA&P process is used, not only to make the best efficient use of external/local resources for the Civil Protection and risk reduction of the territory, but also for promoting risk awareness and culture, to develop a risk community sense and engage exposed population and economic sectors in the DRR strategy in a pro-active way. For instance, making the local population aware about how olive oil and other crops in the area are "protecting" from the wildfire impact the suburbs and the Natural Park, and how wildfire risk will be enhanced in the case those crops are lost (and subsequently, identifying the Farmers Association of Montserrat Foothills as a key stakeholder within the local DRR strategy).
- The pilot site and the dialogue carried out with the actors also showed how much improvements may be achieved just connecting concepts and information from the different fields of expertise. For instance, during the field visit was stated that one of the new parking areas created to regulate the access to the Natural Park did not have any fuel management around, generating a new ignition risk area. In some way, solving a problem of access, the same municipality created a new wildfire risk situation. After two weeks from the visit, we were informed that fuel perimeter trip was carried out once they were aware of the situation thanks to the visit. This is not a complex proposal to manage wildfire risk, just it works thanks to connect knowledge and information.

Figure 14. Map of the access regulation, and the perimetral trip carried out after the visit in the Quatre Camins parking



In terms of **further steps**, once the pilot site was carried, it was stated that different public entities showed interest in the methodology developed. The RA&P approach developed has the potential to be inserted within the existing tools and plans of risk management, offering a novel integrated process able to join efforts and resources from different agencies involved in wildfire prevention, Civil Protection and wildfire suppression towards a common and shared risk management strategy.

On the other hand, the RA&P process and results could be easily embedded in the official tools and norms related to wildfire risk (including urban, rural development and touristic policies), and could offer a more cost-efficient way to address risk mitigation (connecting the economy of risk mitigation with the economy of the territory), while engaging stakeholders in a very practical and operational way meanwhile risk community sense is developed.

Nevertheless, to be able to carry out this kind of analysis, specific technical and financial support to small and medium size municipalities should be deployed since normally they have limited resources (and/or skills). The pilot site has demonstrated the crucial role of local authorities in the implementation of risk reduction measures and the territory stakeholders' engagement. For this reason, the necessary tools and resources provided should be able to articulate and put in place integrated WFRM strategies across and with the local authorities.

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- Cristian López, Councilor of Territory, El Bruc, and representatives of the Forest Defence Association
- Asier Larrañaga, officer of the Catalan Fire and Rescue Service
- Agnés Centelles, Oscar Gordillo, General Directorate of Civil Protection (in charge of the official drill exercise of a wildfire impacting in Montserrat Parc conducted in July 2021 where we were CTFC was invited to participate and share our case study)
- Marc Arcarons, shepherd and promoter of the initiative "Sheperd of Fire of Montserrat"

Final note: The extended version of the analysis is available in the RECIPE project website in Catalan language.

4. Enhancing Wildfire Risk Awareness among Society Exposed to Risk

The risk of large forest fires in the municipality of El Bruc has increased considerably in the recent decades for two different reasons. The first is the abandonment of the territory, which has meant that rural population that was responsible for managing it through extensive livestock, vineyards and olive trees, left in search of other economic opportunities. The second reason is the growing influence of climate change, which is already causing a progressive increase in temperatures, as well as prolonged droughts that stress vegetation and make it more fire prone.

To the factors of abandonment and climate change, we must add a very important component: land use change with the building of urban areas in high fire risk zones near forested land, known as Wildland Urban Interphase (WUI).

Considering the need to improve the communication of fire risk and the need to raise awareness among the population most exposed and vulnerable to fire risk, in the case of El Bruc it has been considered important to enhance awareness about the importance of being prepared for the different situations that may arise in the event of a forest fire:

- Understand the risk of the municipality.
- Understand simple measures to be undertaken to reduce the risk.

In this sense, work has been done on two different scales and target groups (Table 2).

Table 2. Work scales and target audience of risk awareness activities

Municipal School of El Bruc	With the students of 3rd and 4th grade of primary school, a one-day activity has been carried out to work on the issue of forest fires, from fire as a natural element to the problem of forest fires and forest management as a key element of risk reduction.
Montserrat Parc Urbanization	Activity carried out between the different bodies and organizations involved in risk management, to communicate the risk of fire and possible measures to the neighbours of the urbanization.

Both activities are detailed in the following sections.

4.1 Risk Awareness for primary school students

On April 15th, 2021, the MeFiTu activity (The Mediterranean Forest, Fire and You) was carried out with the students of 3rd and 4th grade of El Bruc school with the aim of transferring the necessary knowledge to see fires with a critical point of view, fire as an essential element for the human-beings, the problem of forest fires and forest management as a key element of risk reduction.

4.1.1. Why risk awareness for kids is necessary?

Since its origins, forest fires have shaped our landscape and our biodiversity. But the management model that has dominated the last 50 years has led us to think that fire should not be tolerated.

Over the years, it has been found that zero risk does not exist: no matter how much investment is made in suppression, there will be some fires that cannot be controlled and suppressed immediately and that will become large forest fires.

Faced with this situation we must be prepared: what can we do as citizens? The workshop seeks to increase awareness of the risk of the children living in areas that may be affected by forest fires, such as the municipality of El Bruc, as well as the need to get involved.

Working on risk with children is considered key for two reasons:

- Speech multiplier effect. Each child can transmit the knowledge acquired at home and to other friends outside the school.
- Children, despite having little impact today, are the adults of the future.

4.1.2. Expected results

The workshop MeFiTu seeks that the students at the school of El Bruc understand, in an experimental way:

- That zero risk does not exist, and you have to learn to live with fire.
- That the fire has always been here and that has helped to shape the landscape.
- That the management model requires investing in prevention (sustainable forest management), but also in self-protection.

The student and the fire become the focus of the workshop, as it is in the reality of our landscape, and the student gets to achieve a new perspective that will enable taking smart future decisions on the territory, through their own experiences with the forest fires.

4.1.3. The activity

Heather's MeFiTu consisted of four parts developed throughout the day (Table 3).

Table 3. Program of the activity carried out in the municipal school of El Bruc

Activity	Timetable	Place	Activity Description	Material
Audiovisual	09:00 – 10:00	Classroom	Audiovisual presentation by the trainers of the Pau Costa Foundation. The related concepts are worked on forest fires and their problems.	Presentation, classroom and projector.
Paper trees workshop	10:00 – 10:30	Classroom	Preparation of paper and cardboard trees. Creation of two scenarios of paper forests.	Paper, cardboard, adhesive tape and wire.
Controlled burning	10:30 – 11:15	Schoolyard	Interactive workshop on burning two scenarios: a managed forest and an unmanaged forest.	Surface of 1x2 meters and lighter.
Field Output	11:15 – 16:30	Vineyards, olive groves and forests near the school.	Field trip to visit areas of the municipality interesting for the management of forest fires.	

Presentation

The wolf Mefitu, the symbol of the project, is the animation axis of the presentation, the students hear the importance of the discovery of fire and its management in the evolution of humankind. They see daily situations where controlled fire have a role, and as an uncontrolled fire the example of forest fires is given. It is important also to put the focus on their causes and its relation to landscape changes, minimization of its effects and reducing the vulnerability of our forests. The concept of forest management is introduced, and the forest cycle is explained.

Paper trees workshop

Students make paper trees using easy techniques. With these trees, two forest scenarios are built. The first one represents an unmanaged forest (full of trees, bushes and grass) while the second scenario simulates a managed forest.

Story with controlled burning of the models

A story with puppets is explained. Through the story, children can understand that the fire easily burns the unmanaged forest, while the managed forest is barely impacted by the fire.

Figure 15. Model of an unmanaged forest before being burned

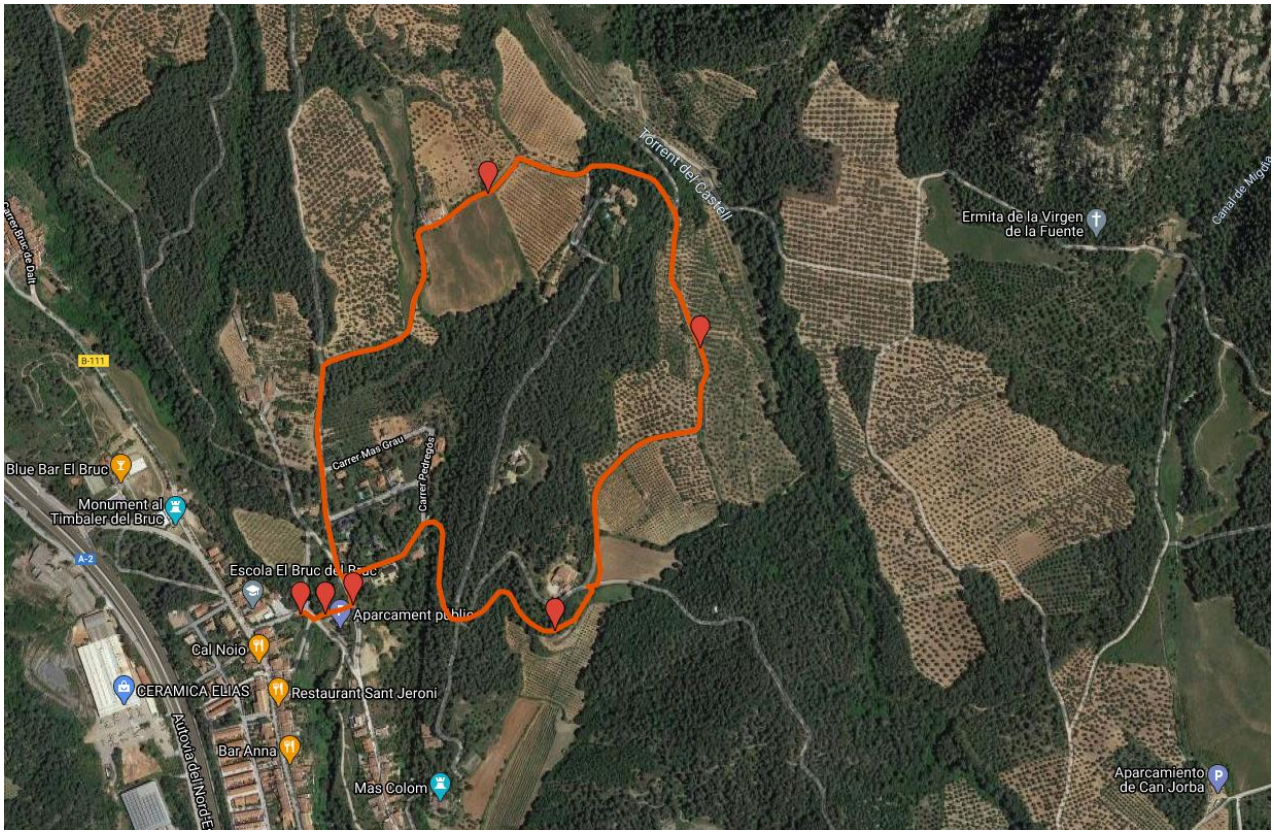
Field visit

An area of interest close to the school was visited, in this case, an area of WUI and fields of vineyards and olive trees as an example of land management based on activities of the primary sector.

At the same time, the children were able to see the operation of an ADF engine and learn about the tasks carried out by this volunteer body.

Figure 16. Left: Local ADF talk. Right: Field visit to the olive groves

Figure 17. Route of the field visit. It is possible to see the interphase areas and the vineyards and olive groves



4.1.4. Impact of risk awareness on children

The students of the Bruc school were asked the following questions before and after carrying out the activities:

1.- Before
   1.- What do we know about forest fires?
   2.- What doubts do we have?
   3.- What would we like to know?
2.- After
   1.- What have we learned?
   2.- What was more surprising?
   3.- On what do we have doubts about?

Before

Before carrying out the activities, the students showed a lot of knowledge about the forest fires issue. The municipality has suffered several large fires in the recent decades and children, despite not having experienced them in first person, have heard of them and it is something that causes a great impact on them.

Apart from the historical fires, another action in which the municipality has been involved and that has facilitated the knowledge of children in relation to forest fires is the LIFE Montserrat project, a European project that promoted the management of the Natural Park in strategic fire prevention areas.

Previous knowledge of children includes aspects such as the importance of firebreaks during emergency management, the importance of firefighters and resources to deal with fires, their danger when they take place near inhabited areas, the meteorological variables that influence fire propagation (temperature, wind and rain). Two aspects that they identified, and which demonstrate the high knowledge of fires were the accumulation of vegetation as an exacerbator of the risk and recognition of the danger of smoke for the health of the neighbors.

The most frequent doubts were related to the use of firefighting equipment and resources (hoses, helicopters, Personal Protective Equipment, etc.), the highest risk season and methods firefighters use to put out fires. They also showed a lot of interest in knowing details about the 2015 Òdena fire, which affected the municipality of El Bruc and was about to impact the urbanization of Montserrat Parc. Looking at the most common doubts, it is clear the impact that suppression bodies have on children's imagination.

When asked about things that they wanted to learn about fires, the students at the School showed willingness to learn about aspects that aggravate forest fires, such as droughts, high temperatures or climate change. They also showed interest in knowing the operation of the emergency, so, the management that exists by the emergency forces from the time the fire is detected until it is extinguished.

After

At the end of the activity, the curiosity shown by the students at the beginning of the day was confirmed. Despite having a high degree of knowledge of the problems of fires considering their short age, it was seen that at the end of the day they highlighted other aspects such as the importance of forest management, in addition to seeing fire as a natural element that has positively influenced ecosystems and the humankind

Children learned relevant aspects such as:

- Strategies that forest species have to sprout or germinate after a fire and how they have evolved thanks to fire disturbance.
- Basic aspects of fire propagation. For example, that the fire propagates faster uphill than downhill.
- The primary sector as a key factor for forest management of El Bruc. The importance of herds, vineyards and olive trees.
- Basic self-protection measures of their homes.
- Fire as a natural disturbance.
- The existence of ignitions due to natural causes, mainly lightning.

The factors that surprised the most are mainly related to details of the speech and the explanations that are made during the day. For example, some students stressed that they were surprised that there were pinecones that explode with fire, the ability of lightning to generate a fire days after it had occurred or the evolution of fires in accordance with socioeconomic changes in recent years.

Finally, after the activities, students continued to show doubts in aspects of the operational picture of firefighters.

4.2 Risk Awareness for WUI Communities

In parallel with the strategic wildfire risk analysis, community awareness is considered a crucial aspect considering the population exposed as a proactive stakeholder in fire risk reduction strategies. That is why the pilot case has served to adapt the successful participation approaches developed in other countries (for example, Firewise USA® in the United States or Safer Together in Australia), to the regional study conditions.

The activity was carried out through a Wildfire Preparedness Day, which is an international day that was originated in the USA. It is usually celebrated worldwide on the first weekend of May and seeks to communicate the problem of forest fires in WUI areas.

Recently, Preparedness Days have begun to be held in Europe in places such as Tuscany and Madrid. In Catalonia, the first Preparedness Day took place in 2018 in the town of Vacarisses and in 2019 in Begur.

Organizing a Preparedness Day involves mobilizing for a day different actor in the management of fire risk (Firefighters, ADF, Civil Protection, Rural Agents, City Council, etc.) in order to promote the preparation of citizens. The actions to be carried out during this day can be very varied: door to door to explain the risk of fire and measures to consider, informative talks, field visits, environmental education activities for children, tastings of local products that promote landscape management, etc. In short, it is about involving the population to end up encouraging them to take self-protection measures.

In the case of El Bruc, the door-to-door methodology was adopted for its ability to reach people directly exposed to risk.

4.2.1. Activity organisation

The door to door took place on October 27th, 2021, in the urbanization of Montserrat Parc an urbanized area very exposed to the risk of fire, particularly those that are reinforced by the dry and warm winds of the west.

Figure 18. Urbanization of Montserrat Parc where the door-to-door activity was carried out

To carry out the door to door, we had the collaboration of different emergency management bodies of Catalonia and other entities involved in risk management: Firefighters of the Generalitat (CFRS), Civil Protection, Diputació de Barcelona and Mossos d'Esquadra.

Four mixed groups (mix of organizations) were formed with the aim of seeking interaction and impact on neighbours. Each group had a number of streets assigned to avoid duplications and houses without getting there. Before starting the door to door, an initial briefing was held to agree on key messages and distribute the communicative material. Basically, it was agreed to spread a very simple message with the main objective of understanding the fire risk of the municipality and simple self-protection measures.

The material of each group consisted of:

- A brochure (see below) specifically designed and adapted to the urbanization of Montserrat Parc that was distributed in each house.
- A car air freshener designed by the Diputació de Barcelona to promote fire prevention.
- A book of the DG ECHO EU funded eFIRECOM project (coordinated by CTFC and participated by PCF) with false myths about forest fires.
- A sheet with frequently asked questions to prepare door-to-door staff for possible questions from neighbours. Mainly, the questions emphasized legal aspects of self-protection in interphase areas according to Catalan regulations.
- A map of the urbanization with the streets assigned to each group.
- Sheet to point out relevant comments of the neighbours.

Figure 19. Leaflet delivered

The activity was carried out in the urbanization of Montserrat Parc. For approximately two and a half hours, the different teams were distributed through the urbanization to inform, through door to door, about the measures of prevention of forest fires and preparation that the neighbours must carry out in their home and in the surroundings of the urbanization. Residents were advised that El Bruc is in a particularly high-risk zone, and that, despite the fire season is on summer, there may be fires any time of the year if the appropriate conditions occur. Printed information is delivered to the neighbours so that they can consult it.

Figure 20. Door-to-door activity. The participants explained the risk of fire in the urbanization. Colleagues from Instituto Superior de Agronomia (ISA) from Portugal could participate in the exercise in a learning Exchange visit organized by CTFC

The activity ended with a final debriefing where the participants of the door to door exposed the lessons learned and the main conclusions after talking to the neighbours of the urbanization.

4.2.2. Impact of risk awareness on exposed communities

In total, almost 300 houses were reached, to which 35% could be established conversation. At 65% where no one was there, the information material was also left in the mailbox.

In general, the residents of the urbanization showed a high awareness of the problem of forest fires. A fairly common comment that stood out above the rest was the memory of the large wildfires that has suffered the urbanization, mainly Montserrat 1984 and Òdena 2015. The first hit Montserrat Parc, but after more than 35 years, many residents did not remember it or did not have it in mind. By contrast, the recent fire of 2015 did have a great impact on the population that still lingers. Many of the residents saw the flames nearby and had to be evacuated, even though the fire eventually took another direction and did not impact on Montserrat Parc.

During the activity, the impact of receiving a visit from different emergency bodies was also perceived. On the one hand, it is a fact that facilitates a first good reception by the resident, and on the other hand, it allows the message to be more rooted.

Preparedness Day has been seen as a first entrance with the population in order to generate impact. It has been observed how few households comply with fire prevention measures and for this reason it is clear the importance of continuing preparedness day with other days of awareness and co-creation of solutions with neighbours. For example: field visit to the urbanization and its surroundings to identify risk elements, day on forest fires, day to jointly carry out prevention actions, etc. It is for this reason that the involvement of both the city council and some neighbours who are able to stretch the community is considered essential.

In the USA, the identification and involvement of key neighbours, called ‘local champions’ has been very relevant in achieving a bottom-up perspective, where citizens exposed to risk gain awareness and take risk reduction measures. In Montserrat Parc this strategy has not been attempted, but after door to door it could be a next step: the identification of residents of the urbanization with desire and capacity to organize new activities.

The dissemination of simple messages has been considered as a strong point of the activity. The idea is not to enter into complex concepts or make people feel guilty for not complying with the necessary measures. We simply try to explain the risk and small measures or actions that must be considered. Therefore, the final objective is to encourage the reflection of the residents after the visit, so that it can be themselves who make the decision to act or not.

Finally, the fact of carrying out the activity in a community of first residences meant that, on the one hand, there was a better reception of the message by the citizens, and on the other hand, it facilitates the implementation of future actions now that the first one has been carried out. Similar door-to-door actions carried out in tourist areas with a high percentage of second homes have been seen as a weak spot for further monitoring. In this way, the need to design activities adapted to each audience specifically becomes evident.

4.4 Lessons learned and main achievements

As lessons learned to organize a Preparedness Day, the following is extracted:

- It is important that the neighbours have experienced a previous fire to be aware of their exposure to risk and to be more receptive to messages.
- The involvement of different organizations is considered key and the impact that the joint work of different emergency bodies causes in the neighbours is perceived.
- The involvement of the city council is of great relevance to facilitate that the activity takes place and to undertake future actions.
- It is clear the positive impact that the different uniforms of the emergency forces cause on the neighbours.
- Despite the knowledge of the risk that the inhabitants have, it is true that there are few households that strictly comply with the measures. It is necessary to follow up the community after the activity and continue implementing awareness strategies. Preparedness Day is a first step of many that can be taken to reduce exposure and vulnerability.
- The fact of doing the activity in a community of first residences is considered positive in order to be able to follow up on it in the future. Doing the same activity in second residences and touristic areas would hinder the dissemination and rooting of the message.
- It has been seen how a simple message reaches residents more easily. It is not necessary to enter into specific topics or complex concepts unless the neighbour show curiosity.
- The message must be simple and in a positive tone. It is important to make people feel comfortable and avoid a sense of guilt by not having self-protection measures taken. The objective must be to make people reflect after the conversation and get it to be the neighbour himself who decides to act (Bottom-up Perspective).

5. Prioritizing fuel management at wildland urban interfaces at the municipal scale in Portugal

5.1 DSS for wildfire management

Living with wildfire risk under a climate change context in a sustainable manner requires an integrated approach to risk, to optimize the synergies between prevention, preparedness, response, and recovery actions. This will offer a frame where the activities of the territory are embedded into the Risk Management Cycle from a cost-efficient and resilient community perspective. Decision support systems (DSS) are information systems used for better decision making, which are very useful in a context of wildfire management.

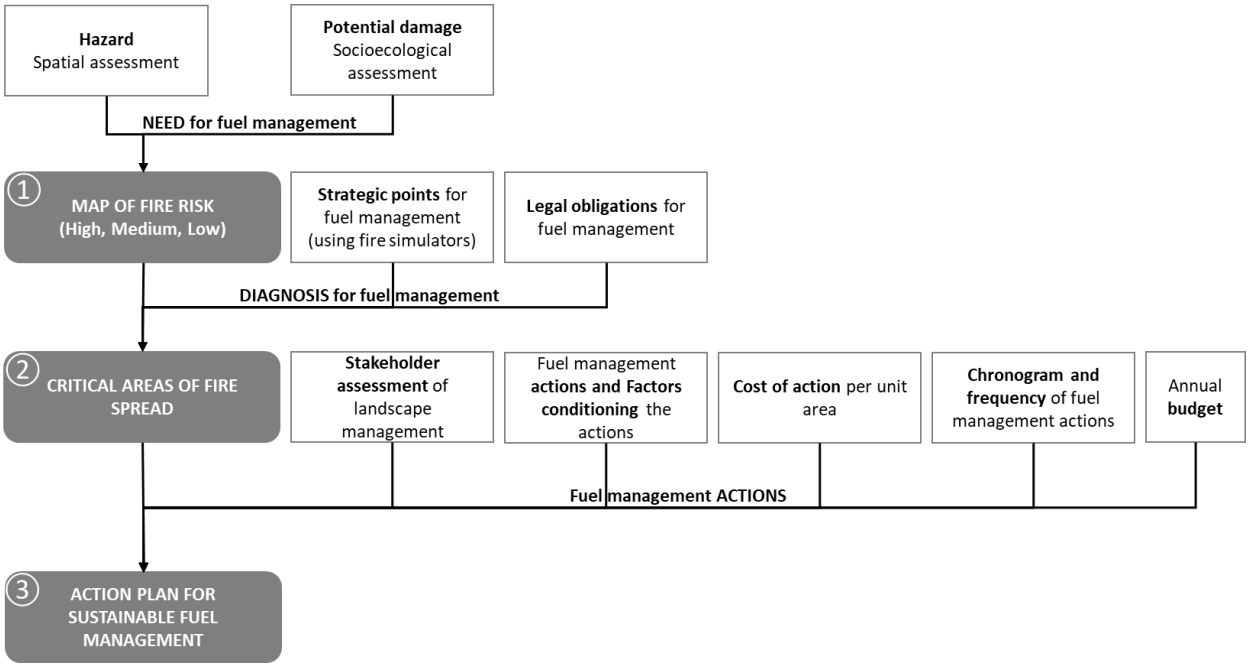
DSS can go from robust IT tools to simple roadmaps and guidelines. Regardless of their structure, DSSs gather, integrate, and analyze data from multiple sources and using different interfaces. DSSs specifically for wildfire management decision making were reviewed in detail by Xanthopoulos et al. (2002), Minas et al. (2012), Mavsar et al. (2013), Martell (2015), Pacheco et al. (2015), and Sakellariou et al. (2017). From those reviews, it was understood that wildfire DSSs strongly rely on simulation models of fire behavior, which allow for fire risk assessment and subsequent planning of preventive fuel treatments. The most widely used simulators of fire behavior are Behave Plus (Andrews, 2014), Farsite (Finney, 1998) and Flammap (Finney, 2006), and the three of them are based on Rothermel's fire spread model (1972), adapted by Albini (1976).

Nevertheless, the conceptual model of a DSS for fuel management that was recently designed within the PREVAIL project[2], shows a more holistic perspective than the previously reviewed DSSs. PREVAIL DSS considers the existing planning, management, and stakeholders' views, and combine them with landscape needs (Sequeira et al., 2021). The roadmap presented in figure 1 is the starting point to develop the RECIPE DSS module which will prioritize the areas to be intervene on the wildland urban interface.

Figure 21 shows the roadmap of PREVAIL DSS, whose approach is a good starting point to apply to a RECIPE DSS Module, which purpose is prioritizing fuel management at wildland urban interfaces (WUI) in Portugal.

[2] Prevention Action Increases Large Fire Response Preparedness, DG ECHO 2018 Call 826400-PREVAIL-UCPM-2018-PP-AG

Figure 21. Roadmap of PREVAIL socio-ecological Decision Support System for effective fuel management, adapted from (Sequeira et al., 2021)



5.2 The tool: RECIPE DSS Module for prioritizing fuel management at wildland urban interfaces in Portugal

In Portugal, each municipality defines a municipal plan to protect forests from fires (PMDFCI), for a 10-year period, according to a technical guide provided by the Institute for Nature Conservation and Forests (AFN-ICNF, 2012). Such technical guide follows all requirements established in the law of national planning to protect forests from fires (Decree-law nr. 124/2006, June 28), regional forest planning, and district planning to protect forests from fires. Every PMDFCI follows the 5 strategic axes of the 2006-2018 National planning (to increase resilience to forest fires; to reduce forest fire occurrences; to improve effectiveness of the initial attack and to improve fire management; to recover and restore ecosystems; and, to adopt a functional and effective structure) and is composed of 3 sections: Diagnosis, Action plan, and Municipal operational plan.

The action plan section includes determining fuel management bands according to the legislation (Table 4), which are of indiscriminate application if it is located on the surroundings of a forest and not always fit to all locations. The plan also defines critical areas to constantly surveil and inspect based, for example, on previous arson events and fire recurrent starting points that took place in the municipality.

Table 4. Fuel management bands description according to the Portuguese legislation (legal obligations for fuel management)

Description	Band width (m)
Constructions within rural areas (buildings, construction sites, warehouses, other construction buildings)	50
WUI areas (10 or more buildings spaced not more than 50 meters)	100
Camping sites and picnic sites	100
Forest road network	10
Gas transmission network	10
Very high voltage energy transmission network	10
Fuel management plot mosaics (agricultural land, inland water, rock outcrops, golf courses, wind farms)	-
Water points	30
High voltage energy transmission network	10

On the one hand, the area resulting from the application of the Portuguese legislation for fuel management is quite high in wildland urban interfaces, because of the high number of infrastructures to be considered in their design. On the other hand, due to the indiscriminate application of fuel management legislation, not all areas to be treated have the same priority of fuel treatment. Additionally, there is a legal deadline, which is defined annually, for the completion of fuel management before the beginning of the fire season. It means, not only that the high number of private owners that have plots within fuel management bands may likely have to be reminded of the mandatory character of the treatments, but also that authorities must inspect all plots and the respective fuel treatments performed.

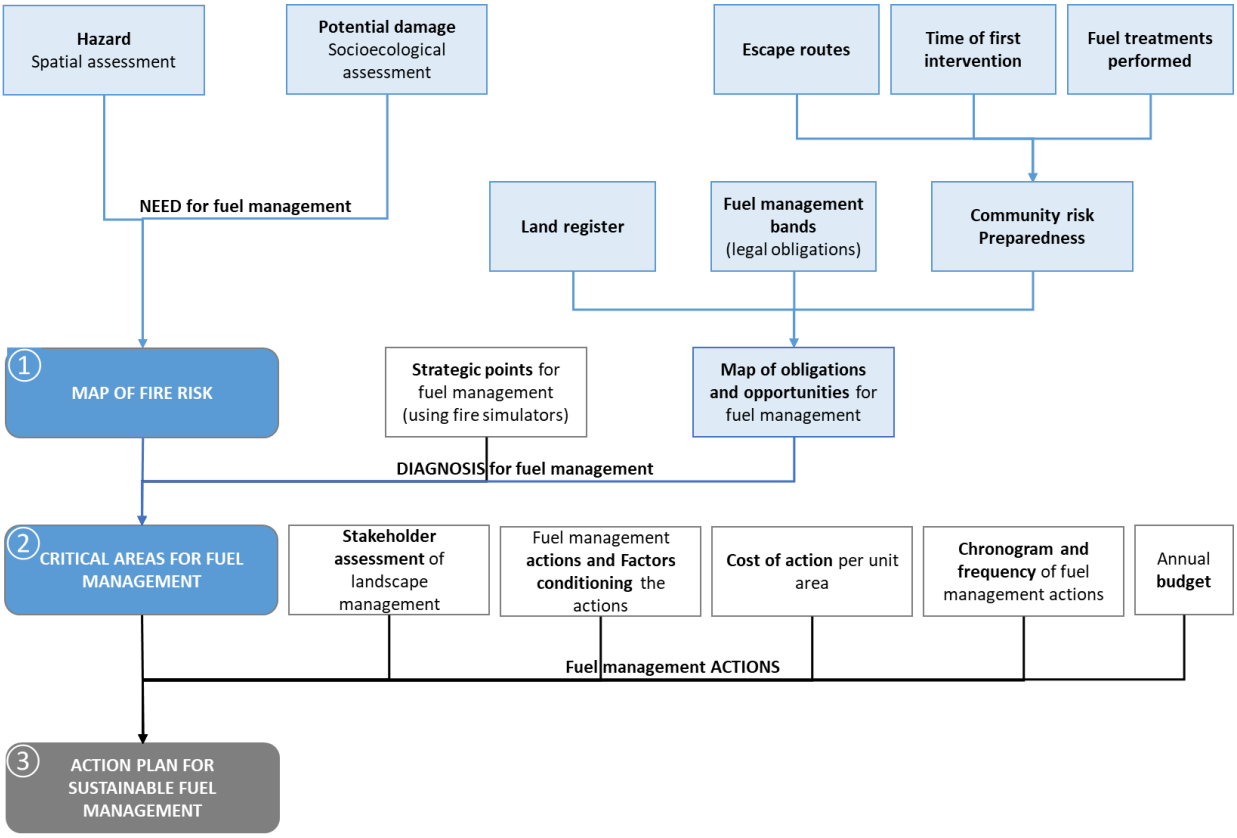
Considering the above, it would be useful if the municipalities develop a database of plots to be inspected annually according to fuel management priorities for fire prevention. Such database of plots will likely help to better targeting the authorities' intervention in the field.

RECIPE DSS Module is focused on defining critical areas for fuel management, within the fuel management bands, based on the priority for fuel management to prevent wildfires. RECIPE DSS Module emphasizes both civil protection needs and communities-on-site needs, from a technical point of view. The resulting database is a map and a detailed list of plots ranked by priority for fuel management. It is helpful both for property owners to annually get to know fuel treatment priorities of their plot, and for authorities to plan the inspections according to assign priorities for fuel treatments.

In summary, RECIPE DSS Module allows for a phased in civil protection intervention, ensuring the adequate implementation of current fuel management legislation, optimizing civil protection operations during wildfire occurrences, and increasing the effectiveness of operations in the prevention phase of the disaster risk management cycle. Moreover, RECIPE DSS Module aims at increasing communities' preparedness, by means of showing them and educate them about vulnerabilities of their property.

From a technical point of view, RECIPE DSS Module intends at being as simple as possible in order to be applicable by all municipalities. It aims at defining a very clear and easy-to-replicate methodology for identifying areas with priority of fuel management treatments and respective inspection. RECIPE DSS Module is inserted (in blue boxes) in the roadmap of PREVAIL (Figure 21) as it is shown in Figure 22.

Figure 22. RECIPE DSS Module for prioritizing fuel management at WUI (in blue), inserted in PREVAIL DSS for fuel management



Priority will be given to (1) areas that show lower community risk preparedness (community risk preparedness considers the existence of escape routes in case of fire, the time needed for a fire brigade to reach the site, and the location of fuel treatments recently performed; and (2) areas that present a higher fire risk, considering territorial hazard and potential damage.

Materials used are available in every municipality in Portugal as it is mandatory to produce the PMDFCI. The process is based on a simple binary matrix, where value 1 stands for "need to prioritize", and value 0 "no need to prioritize". This binary classification is to be applied to every box of the module (shapefile raster or polygon format), according to Table 5, and then combined following Figure 22, using sums and/or intersection operations.

Table 5. General binary classification

Objective	Topic		Value = 1	Value = 0
Map of obligations and opportunities for fuel management	Legal obligations for fuel management		If the fuel management band if of 1st, 2nd, or 3rd order	If the fuel management band is not of 1st, 2nd, or 3rd order
	Community risk preparedness	Time of first intervention	If the distance from fire station is ≥ 20 minutes	If the distance from fire station is < 20 minutes
		Fuel treatments performed	If no fuel treatments were performed in the past 4 years	If at least 1 fuel treatment was performed in the past 4 years

		Escape routes	If it is a no-exit road or If it is a one-way road or If the road in bad conditions	If it is, at least, a two-way road or If there are 2 roads in opposite directions
Map of fire risk	Hazard		In a classification 1 to 5: If hazard is 4 or 5	In a classification 1 to 5: If hazard is not 4 or 5
	Potential damage	Ecological	If there are ecological features	If there no ecological features
		Social	If there are social features in a 100 meters buffer	If there are no social features in a 100 meters buffer

Next section introduces a case study for the municipality of Mafra, in Portugal.

5.3 The tool used in the pilot site (Municipality of Mafra)

To apply the methodology defined in the RECIPE Module, it is only necessary to obtain the base information presented in Table 6. All shapefiles in the table are necessary for the preparation of the PMDFCI and, as such, they already belong to the municipality's database.

Table 6. Material needed to apply the RECIPE Module

	Topic	*Shapefile (Portuguese)*	Format	Fonte
1	Administrative boundaries	Carta Administrativa Oficial de Portugal (CAOP)	Vector polygon	National Geographic Institute
2	Mandatory fuel management bands	Faixas de gestão de combustível com classificação Rede_DFCI	Vector polygon	Municipality
3	Land register	Cadastro	Vector polygon	Municipality
4	Forest road network	Rede Viária Florestal com identificação da classificação DFCI	Vector line	Municipality
5	Land clearings register	Data das limpezas de terrenos efectuadas nos últimos anos	Vector polygon	Municipality
6	Firefighting, Time of first intervention	Distância, em minutos, ao quartel de bombeiros	Vector polygon	Municipality
7	Potential ecological damage	Habitats, RedeNatura2000, Fauna	Vector polygon	Municipality
8	Potential social damage	Infraestruturas criticas	Vector point	Municipality
9	Hazard	Mapa de perigosidade, elaborada no âmbito do PMDFCI	Vector polygon	Municipality

5.3.1 Method – Preparing materials

Preparation of the material implies simplifying and standardizing the database, so that it is possible to apply the binary classification. For each shapefile, preparation operations are presented, as well as the binary classification to be applied according to Table 2. The software used in these operations was ESRI's ArcGIS 10.7.1, but they are easily adaptable to QGIS open-source software.

- Shapefile Land register: Creation of a field with a Unique Registration Code for each parcel (IDCADASTRO), since each parcel is uniquely identified when combining the Building Number, Section Name, and Parish Name.

Note: Binary classification does not apply to the Land register shapefile.

- Shapefile Mandatory fuel management bands: Only fuel bands classified under the Forest Fire Defense Network (DFCI) as being 1st, 2nd or 3rd order will be used. As such, these 3 orders are selected and the dissolve tool is applied, in order to result only in the area of interest.

- Shapefile Firefighting, Time of first intervention: This shapefile contains a field with the distance to the fire station, so it doesn't require preparation.

For the binary classification, a "CLASSTPI" field is created and the value "1" (maximum priority to perform fuel management and inspection of activities) is applied if the distance to the fire station in minutes is greater than 20 minutes and, the value "0" (minimum priority) applies if the distance is equal to or less than 20 minutes.

- Shapefile Land clearings register: Creation of a field with the date of the last clearing performed (ULTIMALIMP), since the current field that contains this information is a text field with various formats and unnecessary information.

For the most recent years, it only requires selecting by attributes using the year under analysis. However, for years prior to 2018, in which there was probably more than one cleaning, it is necessary to ensure that the "ULTIMALIMP" field has no value yet, and fill in with the corresponding year.

As for the binary classification: a "CLASSLIMP" field is created and, since the data used in this case study is from 2020, the value "1" is applied (maximum priority to perform fuel management and inspection of activities) if in the last 4 years (period defined by the municipality) no fuel clearing has been carried out, i.e., if the last clearing was carried out in 2017; the value "0" (minimum priority) applies if at least 1 fuel clearing has been carried out in the last 4 years.

- Shapefile Forest road network: Creation of a field with the buffer width that must be applied to convert the line vector shapefile into polygon vector shapefile. According to the Municipal Plan for Forest Fire Defense (PMDFCI), it is mandatory to manage fuel in a width of 10 meters for each side of the forest road network, i.e., in total it will be 20 meters in width added to the width of the road.

As for the binary classification: the field “CLASSRVF” is created, and the attribution of the binary classification depends on the classification attributed by the municipality within the PMDFCI scope. The value "1" (maximum priority to carry out fuel management and inspection of activities) applies if the DFCI classification = 2, and with a width of less than 6 meters, or if the DFCI classification = 3. On the other hand, it applies value "0" (minimum priority) if the DFCI classification = 2, and with a width greater than or equal to 6 meters, or if the DFCI classification = 1.

- Shapefile Hazard: This shapefile comes directly from the PMDFCI and does not require any preparation. For the binary classification, a field "CLASSPERIG" is created and the value "1" (maximum priority to perform fuel management and inspection of activities) is applied if the hazard is equal to or greater than 4 and, it applies the value "0" (minimum priority) if the hazard is less than 4.

- Potential damage: Unlike hazard, which directly uses the hazard map divided into 5 classes prepared within the scope of the PMDFCI, the potential damage (ecological and social) will be re-elaborated since the PMDFCI places more emphasis on land use land cover and not on critical infrastructures. Therefore, it is necessary to combine the various shapefiles related to ecology and critical infrastructure, as exemplified below.

- Potential ecological damage: Creation of the shapefile, through a combination of all shapefiles belonging to this theme, in the case of Mafra, Shapefile RedeNatura2000 and Shapefile Fauna.

For the binary classification, the “CLASSECO” field is created and the value 1 (maximum priority to perform fuel management and inspection of activities) is applied to the entire shapefile.

- Potential social damage: Creation of the shapefile, through a combination of all shapefiles belonging to the critical infrastructure theme, which in the case of Mafra is *Shapefile Social equipment*, *Shapefile Health equipment*, *Shapefile School equipment*, *Shapefile Services*, *Shapefile Pharmacies*, *Shapefile Culture*, and *Shapefile Social action*. After combining the shapefiles, and following the legal fuel management obligations in Portugal, the buffer tool with 100 meters is applied.

For the binary classification, the “CLASSIC” field is created and the value 1 (maximum priority to perform fuel management and inspection of activities) is applied to the entire shapefile.

5.3.2 Method – Generating the outputs

Map of legal obligations and fuel management opportunities

According to the RECIPE DSS (see Figure 22), the legal obligations and fuel management opportunities in the 1st, 2nd, or 3rd order management bands result from the intersection of the community fire risk preparedness shapefile and the shapefile of land register.

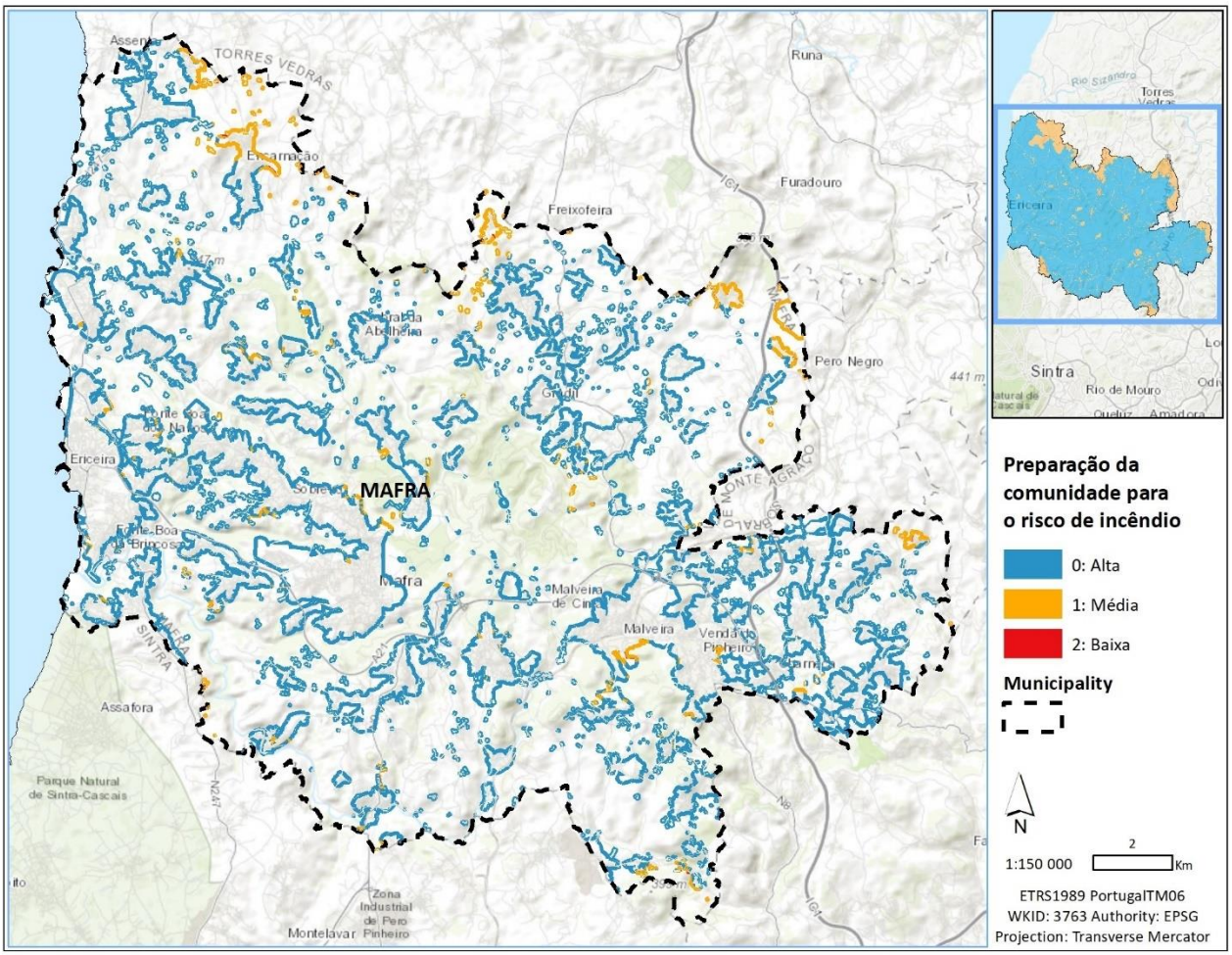
Community's preparation for the risk of fire results from the combination of priorities related to the time of the first intervention, the land clearings carried out, and the existence of escape routes. The method involves dissolving, individually, the 3 shapefiles (time of the first intervention, land clearings register, and escape routes) and, later, joining the resulting 3 shapefiles. The final ranking consists of the sum of the

binary rankings of the 3 previous shapefiles. Then, the obtained shapefile (Community Risk Preparedness) and the CadastroMafra shapefile are combined, by intersection. Finally, through a clip, the map of legal obligations and fuel management opportunities in the area of interest is obtained, i.e., only within the 1st, 2nd or 3rd order fuel management bands.

The resulting legend will be 0 to 3, with the higher, the less prepared the community is for the risk of fire.

In the case of Mafra, the preparedness of the community for the risk of fire is between 0 (High) and 2 (Low), with no class 3 (Very low) (Figure 23).

Figure 23. Map of legal obligations and fuel management opportunities in the municipality of Mafra, and in the fuel management ranges



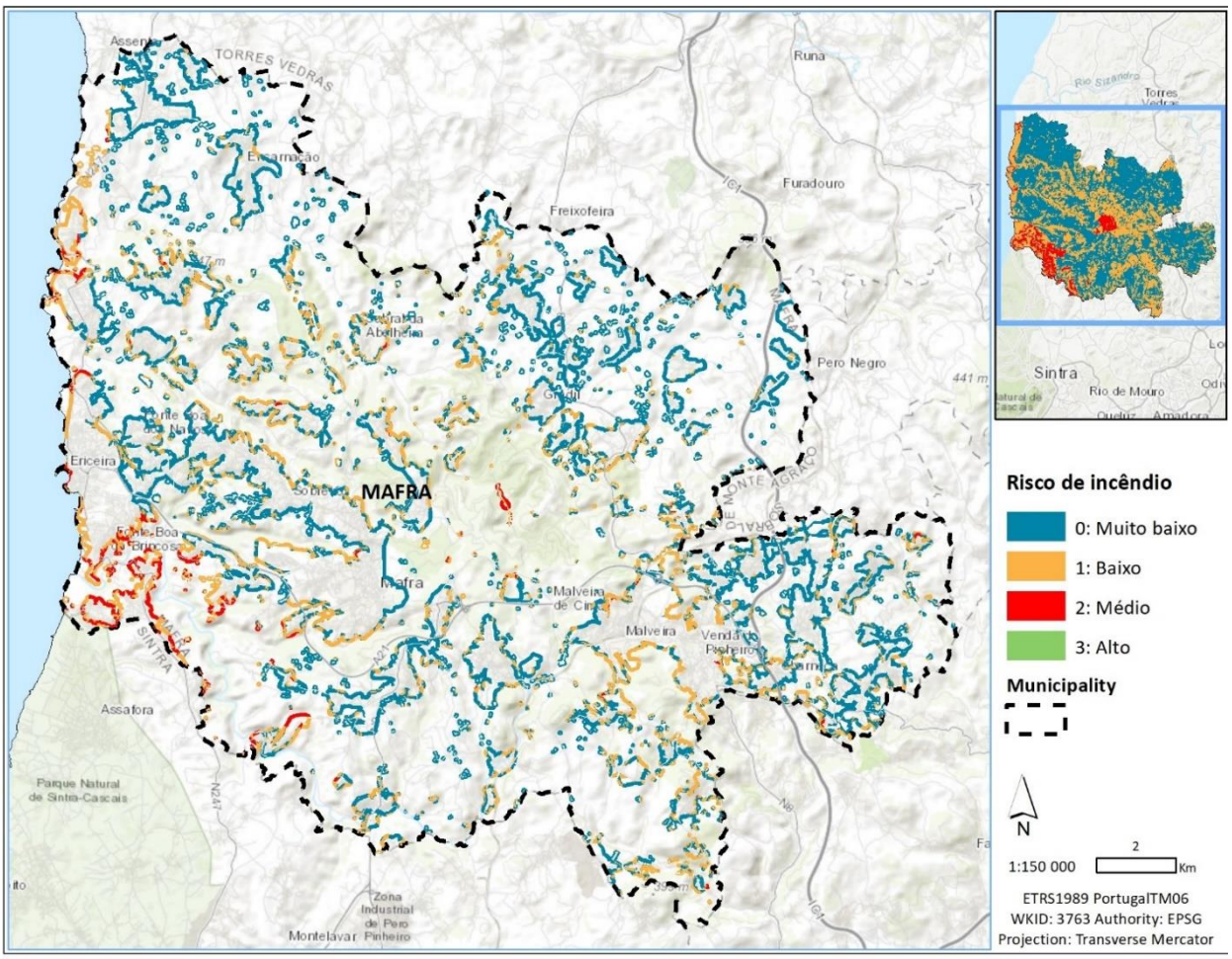
Map of Fire risk

Fire risk is obtained by combining structural hazard with potential damage (see Figure 22).

First, the potential damage is calculated through the union of the Mafra eco and social shapefiles, and later the sum of the binary classifications of the 2 shapefiles. Second, a union is performed between potential damage and hazard. Finally, the final classification is obtained through the sum of the 2 previous binary classifications.

The resulting legend will be 0 to 4, the higher the higher the risk of fire. In the case of Mafra, the risk of fire is between 0 (Very low) and 3 (High), and class 4 (Very High) does not exist (Figure 24).

Figure 24. Fire risk map in the municipality of Mafra, and in the fuel management ranges



Map of Critical areas for fuel management and inspection

The critical areas for fuel management and respective inspection are obtained by the intersection of the Map of legal obligations and opportunities for fuel management and the Map of Fire risk (see Figure 22), and the final classification results from the sum of the legend values of these maps. Then, the tool is applied to individualize the cadastral plots, which, due to previous operations, are segmented. Simultaneously, each plot is ranked with the highest priority value obtained previously, i.e., if a plot was divided and the various parts had different priority rankings, it is important that the final rank of the plot is the highest of these

rankings. In this way, the priority assumed for the plot will be the maximum of all parts of the plot. Finally, plots with an area of less than 100m2 are classified as “0 (Non-priority)”, regardless of their final classification, due to their small size. The limit area, which in this case is 100m2, will have to be defined by each municipality.

The result is a map (Figure 25) and the corresponding table (Figure 26) that will be used in planning the activities of the municipality.

Figure 25. Map of critical areas for fuel management and inspection in the municipality of Mafra

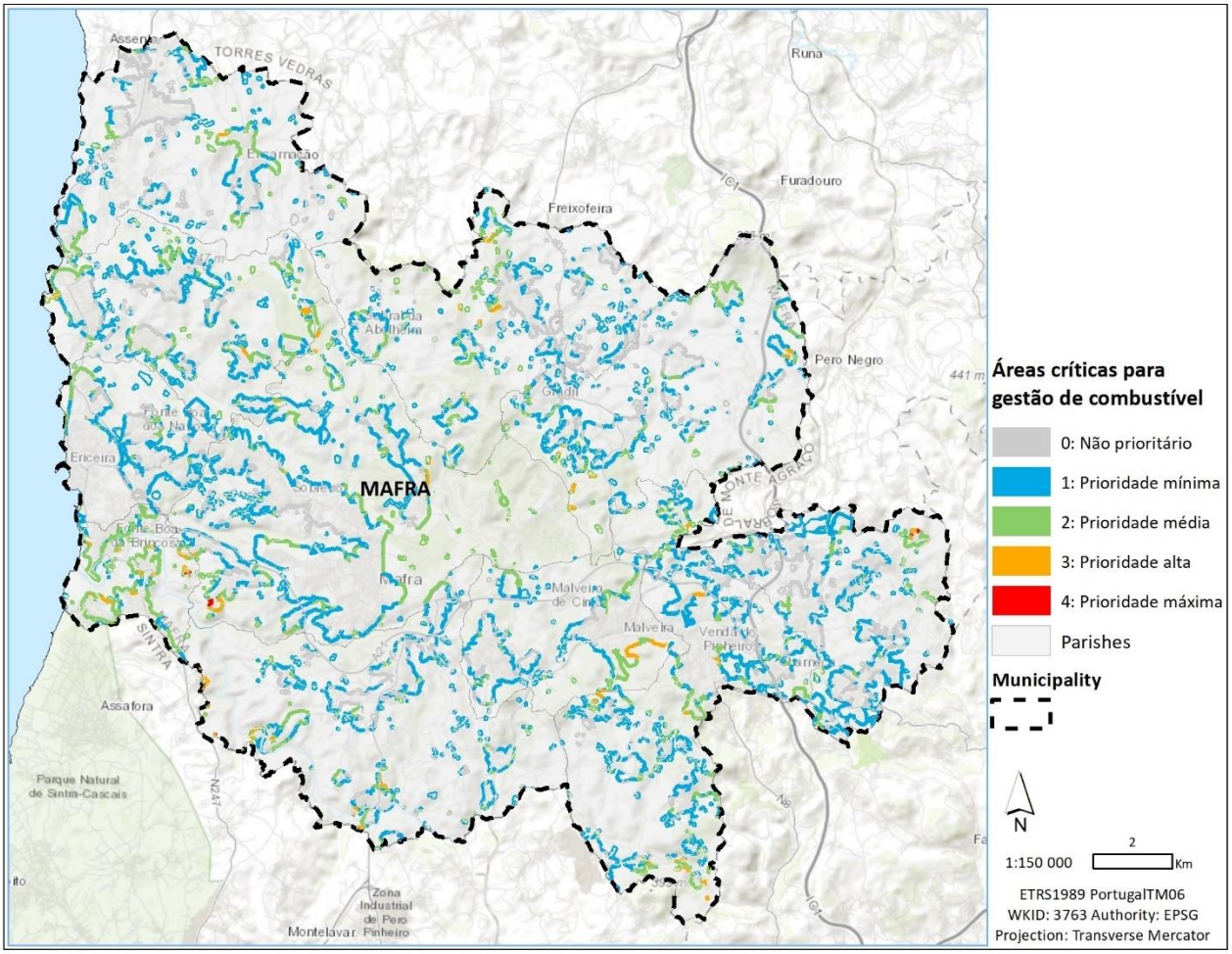


Figure 26. Table of legal obligations and fuel management opportunities in the municipality of Mafra, and in the fuel management ranges

	A	B	C	D	E
1	IDCADASTRO	PRIORIDADE DE LIMPEZA (sem limite de área)	AREA (M2)	LIMITE LIMPEZA (100M2)	PRIORIDADE DE LIMPEZA (com limite de área)
2	1-A-AZUEIRA	1	3359,13	Superior	1
3	1-A-CARVOEIRA	1	17548,05	Superior	1
4	1-A-GRADIL	1	2785,11	Superior	1
5	1-A-MALVEIRA	1	6700,62	Superior	1
6	1-A-SOBRAL DA ABELHEIRA	0	15089,54	Superior	0
7	1-B-AZUEIRA	2	5536,63	Superior	2
8	1-B-CARVOEIRA	2	11537,99	Superior	2
9	1-B-MILHARADO	2	5381,06	Superior	2
10	1-B-SANTO ISIDORO	2	9290,34	Superior	2
11	1-C-CARVOEIRA	1	666,74	Superior	1
12	1-C-GRADIL	1	658,20	Superior	1
13	1-C-MALVEIRA	1	1158,39	Superior	1
14	1-C-SANTO ISIDORO	2	1718,70	Superior	2
15	1-D-AZUEIRA	0	4186,70	Superior	0
16	1-D-CARVOEIRA	2	24761,44	Superior	2
17	1-D-CHELEIROS	1	3050,23	Superior	1
18	1-D-ENXARA DO BISPO	2	34449,48	Superior	2
19	1-D-GRADIL	1	301,47	Superior	1
20	1-D-MALVEIRA	2	126,23	Superior	2
21	1-D-SANTO ESTEVBO DAS GALOS	1	1123,85	Superior	1
22	1-D-VILA FRANCA DO ROSGRIO	1	3307,05	Superior	1
23	1-E-CARVOEIRA	2	3806,75	Superior	2
24	1-E-ENCARNA	1	4826,64	Superior	1
25	1-E-ENXARA DO BISPO	1	6404,52	Superior	1
26	1-E-SANTO ISIDORO	1	14061,11	Superior	1

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5.4 Lessons learned, main achievements and further developments

Mafra has a total of 30.974 plots in register, with different property owners. Approx. 44% of the total plots (5579 ha) are located in fuel management bands where fuel management is mandatory for property owners, as it is for authorities to inspect it. After the use of the RECIPE module, approx. 1279 ha, corresponding to 5070 plots, are classified as “non-priority for fuel management for fire prevention”. This corresponds to an optimization of inspection resources and community awareness, since these activities will be targeted to other higher priority plots, such as the 227 plots that have top (4) and high (3) priority after the application of the RECIPE Module.

The methodology presented to obtain the map and the database of all the plots that each year will have priority for carrying out fuel management activities, as well as priority for inspection, was positively validated by the civil protection of Mafra. Thus, its usefulness and ease of application are proven. In order to enrich the results obtained, in the next steps, a method will be established that will produce a list of plots with fuel management priority without taking into account the year in which the property was last treated. Thus, we will be able to have a map with data on all plots that (1) must always be kept clean of fuel, (2) must be treated 3 times every 10 years, and (3) must be treated 1 to 2 times in 10 years.

6. Recommendations for the eu scalability of the support tool

The above described guidelines can be adapted to other scenarios across Europe. The processes described are most suitable to be implemented at a local or regional level. It will be useful to consider the points stated on the “Lessons learned main achievements and further developments” sub-chapters.

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