Chapter 14

A Common Approach to Foster Prevention and Recovery of Forest Fires in Mediterranean Europe

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Additional information is available at the end of the chapter

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Abstract

Most countries of Mediterranean Europe are strongly affected by forest fires, with major socio-economic and environmental impacts that can spread over several regions and countries. A transnational approach allows creating synergies regarding resource sharing and problem-solving strategies. The access to high quality and up-to-date information is critical to improve fire hazard mitigation measures and promote comparable appraisals between different regions. Several collaborative initiatives have been implemented in Europe to foster research and service development, focusing on common issues amongst countries. The PREFER project was one of these initiatives, with the purpose of contributing to protect human communities and forests from fire hazard, by providing cartographic products through the implementation of a new systematic framework. The participation of end users, such as civil protection organizations and forest services, covering the Euro-Mediterranean region, was crucial to ensure the operational application of the mapping products. Fuel classification, daily fire hazard indices, vulnerability assessment and damage severity levels were some of the mapping applications developed for several test areas in Mediterranean Europe. This chapter illustrates the potential enhancements for forest fire management offered by this framework, bearing in mind the benefits of applying shared and harmonized approaches for common issues.

Keywords: forest fires, Mediterranean Europe, common framework, collaboration, prevention, mitigation

1. Introduction

The European Mediterranean region is systematically affected by uncontrolled forest fires, which pervasively threaten most of the vegetated land and cause extensive environmental damage, with significant economic impacts [1–6]. In Mediterranean Europe, an average of ca. 60,000 fires burn over 400,000 ha of wildland and forest areas every year [7]. The countries in the southwestern part, namely Portugal, Spain, France, Italy and Greece, are the most affected by fires [8]. These countries share similar environmental conditions, which can explain such high fire incidence: the coincidence of the driest with the hottest season and the occurrence of wet and dry weather extremes throughout the year; the coexistence of urban settlements, infrastructure networks and vegetated areas (forest, agricultural and uncultivated areas) in a complex, dense and intimately interconnected patchwork; the diminished control on traditional practices involving fires as an instrument for land management and the changes in land use verified in recent decades [2, 9–16]. Portugal is the most affected country with regard to number of fires, whereas Spain generally records the highest burned area, despite annual variations (**Figure 1**).

Additionally, climate effects are expected to become even stronger in the upcoming decades, according to the most recent fire danger projections [17–20], highlighting the high sensitivity of the Mediterranean area to projected climatic change in terms of fire activity [21–24]. In this context, forest fires can pose serious threats to human communities and the environment. The investment in recent years in suppression policies and the deployment of more efficient and sophisticated techniques for detection and firefighting, despite the noteworthy improvements in early detection and extinction of fires, cannot counteract entirely the effects of repeated and simultaneous fire events or very high intensity fires [25–30]. Fostering a significant improvement in effectiveness and timeliness of prevention measures, in association with appropriate recovery actions and their proper integration in the overall fire management cycle, is, therefore, the most suitable way to mitigate efficiently the damages potentially caused by forest fires in the European Mediterranean region.

1.1. Common approaches for shared problems

At the European level, it is recognized that the prevention of natural and man-made disasters focusing on a common approach is more effective than separate national approaches [31], by linking actors and policies and promoting technical and knowledge development applicable to transnational situations. In the last 20 years, the European Commission and

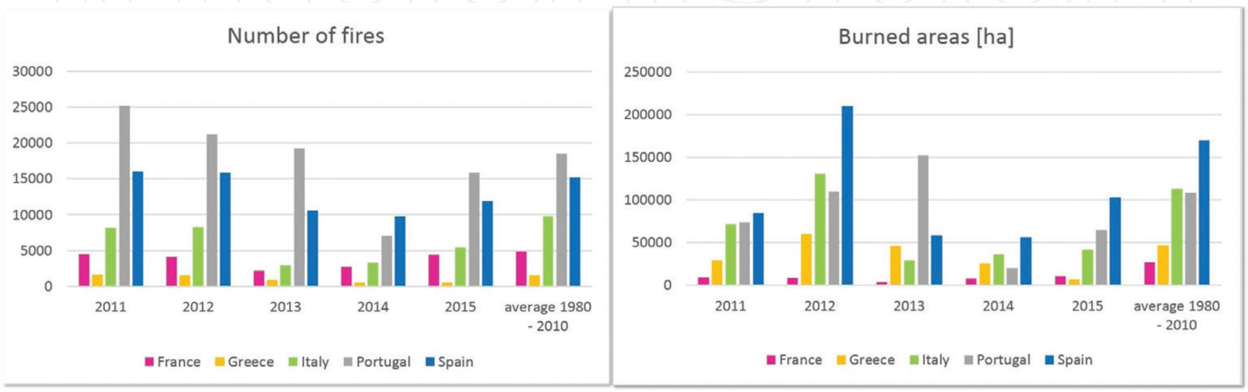

Figure 1. Distribution of the number of fires and burned areas (in ha) between 2011 and 2015 for the countries in Southern Europe most affected by forest fires, compared with the mean value of the previous 30 years.

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the EU countries have worked together to establish common forest fire management and monitoring approaches, as is the case of the European Forest Fire Information System [32, 33], although geographic differences, diverse traditions, differing resources and interest with regard to fire issues have delayed this process [33]. Other initiatives have been implemented to promote collaboration in fire research in Europe, integrated in hazard and risk assessment studies at different levels, benefiting from synergies with regard to resource-sharing and problem-solving strategies for mutual concerns, such as the projects FIRE PARADOX [28], FIRESMART and MOVE [34].

This chapter presents the outcomes of one of these initiatives, the PREFER project (Space-based Information Support for Prevention and Recovery of Forest Fires Emergency in the MediteRranean Area) [35], which was developed to respond to the pragmatic need of protecting European forests and communities from fire hazard, capitalizing on the experience gained in the last decade by the participating institutions. The project was based on the development of a shared framework applicable to European Mediterranean countries, to deliver timely and high-quality cartographic products, suitable for decision-making at different levels within the fire management process.

1.2. Geographic coverage

The target geographic area of the PREFER project was composed of the European territories located in the Mediterranean area where fire occurrence is particularly relevant. To test and demonstrate the products and services developed, five pilot areas were selected based on the availability of data required to develop the products, the interest of end users, the biophysical and social conditions of these areas and their fire occurrence history (**Figure 2**).

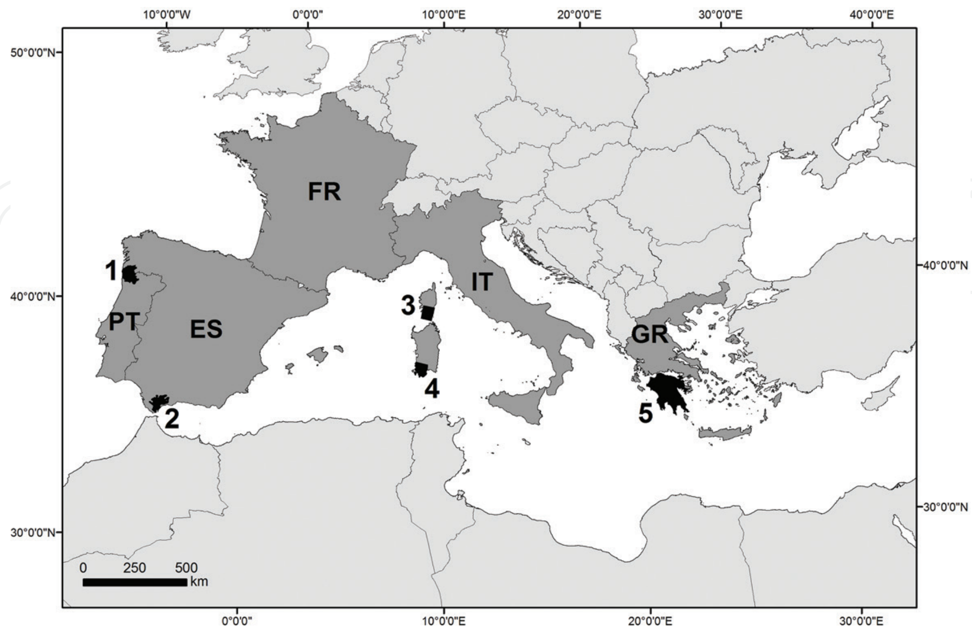

Figure 2. Geographic coverage of the PREFER project and location of the test areas in the participating countries. 1-Minho region, Portugal (PT); 2-Los Alcornocales, Andaluzia, Spain (ES); 3-SW Corsica, France (FR); 4-SW Sardinia, Italy (IT); 5-Peloponnese region, Greece (GR).

2. A common framework for forest fires in Mediterranean Europe: the PREFER project

The PREFER project ("Space-based Information Support for Prevention and REcovery of Forest Fires Emergency in the MediteRranean Area") was developed under the framework of the EU service Copernicus, between 2012 and 2015. PREFER was configured as an industry-driven/science-controlled initiative and the consortium was composed of eight partners from five most fire-affected countries in Southern Europe, among which research institutes and industries of technological development and security (**Table 1**). The main purpose of PREFER was to set up a common information communication technology (ICT) infrastructure to provide mapping tools and services, adapted to the needs of end users interested in different stages of forest fire management. To attain this goal, the project was driven by three main conditions as follows:

(1) The development of a common mapping framework regarding fire prevention and recovery, applicable to European Mediterranean countries.

(2) The creation of a service available at the operational level and useful for multiple users from different sectors and countries.

(3) The timely delivery of easily accessible cartographic tools based on harmonized, high-quality and up-to-date information.

2.1. A common framework for forest fire management

Although the peril of forest fires is a shared issue among the countries of the European Mediterranean region, there are differences in the way each country reacts, which are mirrored in the administrative structure and operational organization of each country or region. In most countries, specific regulatory conditions exist at the national level with regard to forest fire management. France, Greece, Italy, Portugal and Spain have corpus of laws with specific norms punishing fire crimes, and their regulations foresee administrative penalties towards burned surfaces or unmaintained vegetation. Specific regulations concerning the preparedness and prevention phase exist for all these countries, but this is not the case for the recovery phase (e.g. Italy). As such, fire prevention plans are foreseen by law and operational procedures include risk analysis; however, standard operational procedures of forest fire management are not established by any national legal framework. Fire management structures vary among countries, from the dispersed governmental organization of Spain and the regional autonomies [36] to the provincial structure of Italy and to the more centralized systems of France, Greece and Portugal [37, 38]. At the governmental level, resources and responsibilities on forest fire management can be spread over different departments (e.g. Portugal). Overall, preventive actions and recovery strategies are assigned to various actors and institutions that differ among countries, crossing local, regional or national management level. Among these, fire services, forest management and environmental protection services, civil protection agencies, environmental

Country	Consortium partners		Participating users
France	University of Strasbourg	UNISTRA SERTIT	• Service Départemental d'Incendie et de Secours de la Haute Corse • Office National des Fôrets, Direction Generale Corse
Greece	Center for Security Studies SATWAYS Ltd, Satcom & Telematics	KEMEA SATW	• General Secretariat for Civil Protection • Aristotle University of Thessaloniki • InterBalkan Environment Center (i-BEC) • National Centre for Scientific Research DEMOKRITOS
Italy	Università Degli Studi di Roma "La Sapienza" CGS SPA Compagnia Generale per lo Spazio Intelligence for Environment & Security	DIAEE GCS IESC	• Corpo Forestale e di Vigilanza Ambientale, Sardinia • Centro Nazionale di Meteorologia e Climatologia Aeronautica • Fire Brigades
Portugal	University of Coimbra	UCO	• Autoridade Nacional de Proteção Civil (ANPC) • Instituto de Conservação da Natureza e das Florestas (ICNF) • SEPNA, Guarda Nacional Republicana
Spain	GMV, Aerospace and Defence SA Unipersonal	GMV	• Agencia de Medio Ambiente y Agua de Andalucía

Table 1. Countries, consortium partners and end users who participated in the PREFER project.

organizations, volunteer associations and armed forces assume different tasks, although with common interests.

Under these circumstances, the involvement of multiple actors and institutions from the participating countries was essential to develop a framework applicable at the transboundary level, with systematic data collection and analysis, but flexible enough to allow for specific adjustments according to each country's characteristics and needs.

2.2. Creation of a service available at the operational level and useful for multiple users

Concerning forest fire emergency, the civil protection authority is usually the main organization dealing with the strategic planning and coordination of resources. However, they are not involved in operational activity at the same level in all countries. Owing to the obvious differences among countries, the PREFER project devoted a specific activity to involve a core group of users in the project activity. These end users represented a variety of organizations with a legal mandate for managing forest fires in their respective region or country, between the most affected countries in southern Mediterranean Europe. Among these, civil protection authorities, regional and national forest services, fire brigades and environmental protection agencies were involved (**Table 1**). The application of the cartographic tools at the operational level required the testing and demonstration of the resulting products in view of current implemented procedures. The end users provided feedback along the different stages of project development and helped defining a harmonized set of requirements to ensure the operational applicability of the products and tools developed.

2.3. Delivery of timely and easily accessible cartographic tools based on harmonized information

The access to high-quality and up-to-date information is a key issue to improve the effectiveness of fire damage mitigation, grounded on preventive measures and suitable recovery actions. The PREFER project made use of advanced technologies to ensure the consistent collection and analysis of data and the systematic delivery of mapping tools. Considering the relevance of transnational approaches within the European forest fire context and the need to obtain harmonized information to enable equivalent appraisals between regions and countries, the project design was based on the exploitation of remote sensing observations, in order to: (i) provide systematic and repeatable data and support the consistent creation, update and delivery of products and (ii) harmonize information used to manage forest fires and promote transnational cooperation across Mediterranean Europe.

2.3.1. Satellite remote sensing

Remote sensing offers useful tools for fire monitoring and damage assessment to support fire management in a cost-effective way. In comparison to other methods of information gathering, satellite remote sensing provides some advantages, such as (i) large area coverage; (ii) frequent and repetitive coverage of the area of interest, even if this area is remote or difficult to access; (iii) easy data acquisition at different scales and resolutions; (iv) provides spatially continuous data, avoiding thus the need for interpolation which always degrades the original information to some extent; (v) one single image can be interpreted for different purposes and applications; (vi) quantitative measurements of ground features are obtained using radiometrically calibrated sensors and (vii) enables the implementation of a systematic approach and allows for monitoring of dynamic processes.

Currently, several remote sensing satellites provide imagery suitable for forest fire research and fire monitoring operations; from land cover/use maps to burned area and fire danger estimations, nowadays users can access several global, pan-European products for use in the field of fire preparedness and post-fire vegetation recovery. Several initiatives also exist to generate Earth observation (EO) data according to predetermined standards and to optimize the access of the users' community to geoinformation products derived from remote platforms; among these are as follows: the Global Fire Monitoring Center (GFMC, http://www.fire.uni-freiburg de),

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the fire mapping and monitoring theme of the GOFC/GOLD (Global Observations of Forest and Land Cover Dynamics, http://gofc-fire.umd.edu), the CEOS (Committee on Earth Observation Satellites) and several missions of NASA (National Aeronautics and Space Administration, http://www.nasa.gov).

The PREFER project was particularly associated with the European Programme Copernicus (http://www.copernicus.eu/), formerly known as GMES (Global Monitoring for Environment and Security). The goal of Copernicus is to develop operational information services on a global scale in support of environment and security policy needs, to provide the user community with accurate, timely and easily accessible information collected from Earth observing satellites and *in-situ* sensors. The thematic areas more relevant for PREFER were the land and the emergency management, and the project aimed to ensure complementarity of its products with those delivered by the other Copernicus services. Therefore, the potential synergies between different services, initiatives and current space missions were integrated in the design of the project. As well, the future EO space missions, particularly Sentinel [39], were examined to ensure the long-term sustainability of the project's services, the availability of cost-effective remote sensing data, and to identify potential gaps of future missions with respect to the users' requirements.

The information retrieved from satellite images was used in various ways, according to the type of cartographic product developed, the needs and requirements of end users and the local characteristics of forest fires. In the participating countries, no specific legal framework exists regarding the use of space-based information in the domain of forest monitoring and forest fire management. This is why most countries do not retain a central Earth Observation database and they do not use official forest fuel type or other maps provided at the national level and based on EO data. The exception is found in Spain, where the situation differs between autonomous regions.

3. Service portfolio and cartographic tools

The approach implemented enabled the creation of a regional service for the systematic provision and update of operational products suitable for use in different European Mediterranean countries. The PREFER portfolio included services providing information concerning the preparedness/prevention phase and recovery/reconstruction phase (**Table 2**). Each of these services focused on a particular aspect of the forest fire cycle, following the next specific criteria:

- The products developed were based on the exploitation of data from the Copernicus space infrastructure, taking advantage of the readily available space-borne observation data;
- The procedure of product development had to optimize the integration of different data types from a variety of sources, such as earth observation, digital terrain models, socio-economic data, meteorological data and *in-situ* data;
- The procedure developed had to be applicable in different countries of the Mediterranean region, in a systematic and sustainable way;
- The products had to be distributed by an interoperable service provision infrastructure (based on OGC/INSPIRE) that could allow easy access to the information.

Product	Description	Resolution	Refresh rate	Input EO data current (and future)
Preparedness/prevention service phase				
Fuel map	Classification map of forest fuel complexes	5–30 m	Yearly	OLI/Landsat8, Rapid-Eye
Fuel reduction map	Identification of the areas where the prevention procedure based on fuel reduction is advisable	5–20 m	Yearly	OLI/Landsat8 (Sentinel-2)
Prescribed fire map	Spatio-temporal map of the areas where prescribed fire would be useful and safe to apply	250 m	Daily	OLI/Landsat8 (Sentinel-2)
Daily fire hazard map	Fire danger index, indicating the proneness of a vegetated area to support a fire	250 m	Daily	MODIS/Terra & Aqua (Sentinel-3)
Seasonal fire hazard map	High resolution hazard index	250 m	Bi-weekly	MODIS/Terra & Aqua
Vulnerability map & economic value	Relative measure of the maximum potential for loss in the case of fire. Estimation of economic losses	100 m	Yearly	(OLI/Landsat8)
Seasonal risk map	The probability of occurrence of a fire event that can cause losses	100 m	Bi-weekly	MODIS/Terra & Aqua
Recovery/reconstruction service phase				
Post-fire vegetation recovery map	Identification of areas previously damaged by fire event where regrowth of vegetation took place	Min 1 ha	Every 16 days	OLI/Landsat8 (Sentinel-2)
Damage severity map	Degree of damage based on vegetation status after a fire event	30 m, BA >10 ha	On request	OLI/Landsat8 (Sentinel-2)
3D Fire vegetation volume loss map	2D and 3D fire impact monitoring maps, to identify areas with increased risk of flash flooding and debris and to highlight areas prone to soil erosion	10 m	On request	SPOT, Pleiades, Sentinel-1
Soil erosion susceptibility map		30 m	On request	SPOT, Pléiades, Sentinel-1, OLI/ Landsat8
Burned scar map HR	Burned scar perimeters, at scale 1/10,000–1/50,000	Min. 1 ha	Every 16 days	OLI/Landsat8, Cosmo-SkyMed, Sentinel-1, (2)
Burned scar map VHR optical	Burned scar perimeters at cadastral scale (1/1.000–1/4.000)	Min. 0.25 ha	On request	Ikonos, Quickbird, Worldview & other

Table 2. Service portfolio and brief description of each cartographic product.

The information based on satellite images, combined with data from other sources according to the type of product developed, can improve forest management with regard to fire prevention and the prompt assessment of damages for planning recovery activities at a transboundary level. To illustrate this goal, details on some of the products and mapping tools developed, as well as the results obtained and their usage in view of fire management activities in the different countries, are presented. PREFER products aimed at enhancing forest fire management across Mediterranean Europe, and helping to meet the overall objective of improving the preparedness and responsiveness of national authorities in relation to wildfires, reducing the vulnerability of people, property and the environment to the adverse impacts of fire hazard.

3.1. Preparedness/prevention service phase

In Mediterranean Europe, over 90% of fires are due to human activities, either intentional or accidental, and therefore are mainly unpredictable and require strong awareness actions. Notwithstanding, particular environmental and biophysical conditions, such as vegetation, meteorological/climatic features and topography, influence fire propagation and the severity of damages caused by a fire [4, 6, 40–43]. The cartographic tools developed for this phase were, therefore, inspired on the possibility to measure these biophysical conditions and to foresee the behaviour of a fire in case an ignition occurs, as well as on the estimation of the potential damages a fire could cause, with the overall purpose of identifying suitable prevention and hazard mitigation strategies.

3.1.1. Fuel map

Forest fuel types can be defined as an identifiable association of fuel elements of distinctive species, form, size arrangement and continuity, which will exhibit particular fire behaviour under defined burning (meteorological) conditions [44]. Fuels vary broadly in spatial distribution, type, physical characteristics, load (amount) available for combustion, their contribution to fire potential and effect on fire behaviour.

The fuel type mapping method implemented in PREFER combined Geographic Information Systems (GIS) methods with remote sensing technology. GIS techniques were applied to integrate different static vegetation-related geospatial layers, while remote sensing aimed at capturing those dynamic aspects of vegetation, which relate to its phenology and thus require more frequent monitoring. Evolving from the results of previous projects, namely FUELMAP and ArcFUEL, the method applied within the PREFER project meant a step further, since it allowed for a more realistic updating that accounts for season, the clear-cuttings, reforestation and afforestation labours, as well as for urban sprawl, and burned areas. Additionally, in comparison with previous approaches in which the fuel load was a fixed number derived from standard fuel classifications (for example, see Ref. [45]), in PREFER the fuel load was included through a dynamic proxy, the fraction of vegetation cover (FVC) [46–48] computed as a function of the normalized difference vegetation index (NDVI). The forest fuel type product depicted forest fuel complexes in some test areas and classified them according to the assessed capacity of these complexes to support fire occurrence and contribute to fire potential. The fuel types were presented in categories, according to specific characteristics of the vegetation, such as density, arrangement and physical parameters related to fire behaviour (such as potential flame length and rate of spread) and then input into the following phases of the processing chain, that is, fire risk and behaviour modelling on the one hand and prescribed fires and vulnerability modelling, on the other hand. Adaptations at national and subnational levels were carried out when needed, using the best available local data sources to increase the fuel map precision while keeping its compatibility with the pan-European scale.

Figure 3 shows the fuel maps produced for the test sites in Italy (Sardinia) and Spain (Andalusia). The distribution of fuel types in these sites is very different; in Sardinia, non-wildland fuels (growing areas and other non-wild vegetation) and shrubs predominate and forests are interspersed with shrub lands dispersed by the NW and SE sides of the test site. Conversely in Cádiz, dense and open forests occupy a larger area, which can be a result of the classification as a natural protected area (Natural Park).

Fuel maps constitute a very important tool of fire management and are used by multiple institutions for allocating resources, planning prevention activities and developing fuel management programs. These mapping tools are also useful for civil protection authorities, since fire propagation modelling, based on fuel classification, serves to design evacuation plans for endangered population. A European fuel classification scheme enables equivalent evaluation between countries and regions, promotes the strategic implementation of pan-European approaches and a more efficient use of resources and effective preparedness.

3.1.2. Fuel reduction map

The reduction of fuel load accumulation is a common practice [49–52] to decrease hazard levels, through the use of several prevention practices such as: (i) manual or mechanical modification and removal of natural fuels, including cutting, crushing or stacking; (ii) other treatments such as application of herbicides, introduction of biological controls or pasturage; (iii) prescribed burning technique, with the deliberate use of fire in a given area and well-defined environmental conditions.

This product was found on the need to plan suitable programs for reducing fuel loads to reduce fire danger. The fuel reduction map was based on the identification of the territorial units with a higher probability of being affected by a fire and on the factors that favour

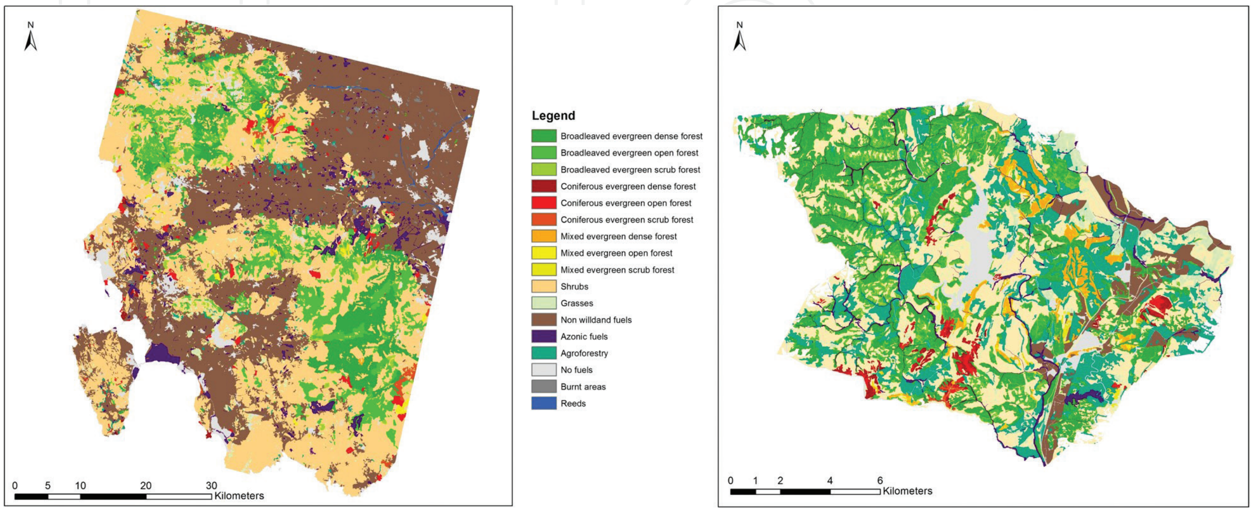

Figure 3. Fuel maps created for the test sites of Italy (left) and Spain (right).

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fire spread, with the subsequent computation of a fire propagation probability (FPP). The methodology takes into account geospatial elements, representing the territorial factors that may affect the onset of fires and their propagation. Four types of factors were considered: (i) topographic (altitude, slope, aspect); (ii) environmental (fuel type, climatic conditions); (iii) land use (urban areas, agricultural areas, roads, natural parks, forests) and (iv) fire incidence (burned areas of, at least, the last 5 years).

The combination of all these parameters provided a type of landscape classification, where each class represents a particular combination of these parameters which were defined as homogeneous territorial classes (HTC). The FPP was then obtained for each HTC, following the formula:

$$FFP = \frac{\sum_{k=1}^{N_i} Cb_{ik}}{TC_i^{\text{tot}}} \tag{1}$$

where Cb_{ik} is the burned surface of the k_i-th fire within the HTC$_i$-th (Ha), T is the time range (8 years), N_i is the number of fires in the time range T in the type$_i$-th, C_i^{tot} is the area of the HTC$_i$-th.

The FPP values were reclassified in five classes expressing the geospatial hazard (GSH), which indicates the priority level for fuel load reduction (**Table 3**). The final output is a cartographic product (**Figure 4**) showing the areas where fuel load reduction measures should be carried out in order to mitigate potential fire effects.

3.1.3. Daily fire hazard index map

The daily fire hazard map provided a medium spatial resolution fire danger index, through a dimensionless number indicating the proneness of a vegetated area to burn or to support a fire. This product was based on the evidence of a strong relationship between fire and the fuel characteristics (vegetation type, density and humidity content), topographic features (slope, altitude and solar aspect angle) and meteorological conditions (rainfall, wind direction and speed, air humidity, surface and air temperature) [43, 53–56]. The resulting maps represent a normalized index with values from low (0) to very high hazard (100), subsequently classified in six hazard levels (**Figure 5**). Every day, three maps are produced for the required area, showing the spatial distribution of fire hazard levels for the present day and the two following days.

The daily hazard levels are strongly dependent on weather and fuel conditions, which are highly variable on a daily basis. This dynamic index is a valuable tool also for allocating fire suppression and emergency resources for a short timeframe, during the main fire season (usually summertime) in Mediterranean countries. The computation of this product has been active beyond the duration of the project and it has been applied in additional areas, by request of local users (**Figure 6**), which confirms its applicability within the Mediterranean region.

3.1.4. Seasonal fire hazard map

The strong influence of anthropic factors on forest fire distribution in the context of Mediterranean Europe requires the integration of the human factor in fire hazard definition, besides the

FPP values	Geospatial hazard	FR classes
>0.1	5	Very high
0.01–0.1	4	High
0.01–0.001	3	Moderate
0.001–0.0001	2	Low
<0.0001	1	Very low
0	0	Null

Table 3. Geospatial hazard and fuel reduction (FR) classes according to fire propagation probability (FPP) values.

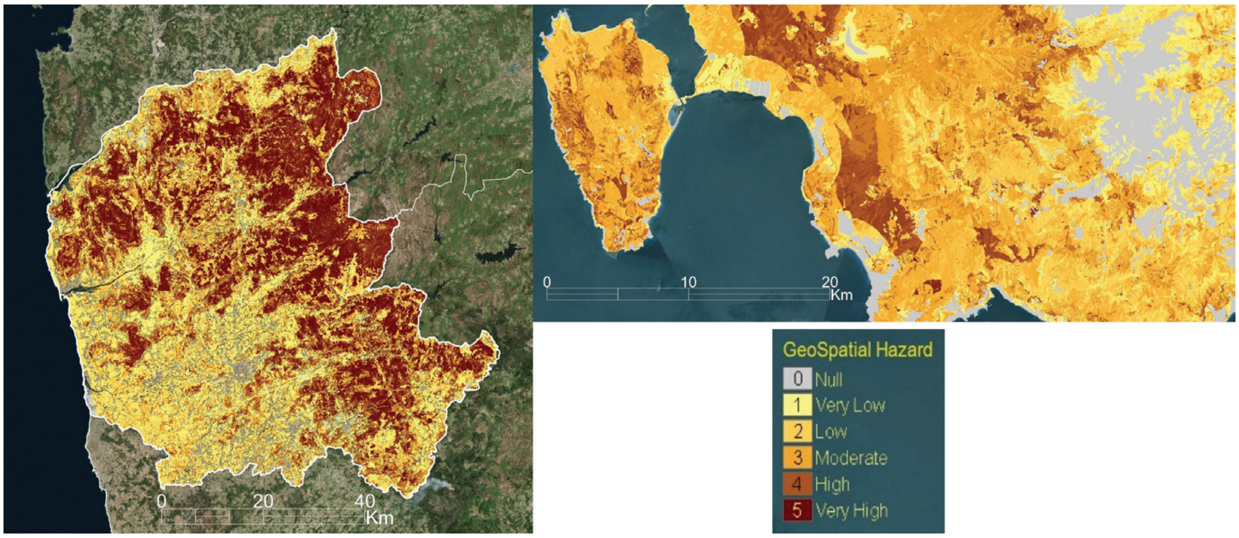

Figure 4. Fuel reduction maps computed for the test sites of Minho region, Portugal and SW Sardinia, Italy, in 2015. Darker areas are expected to be more prone to fire. The map can be computed for areas with different sizes and at several scales.

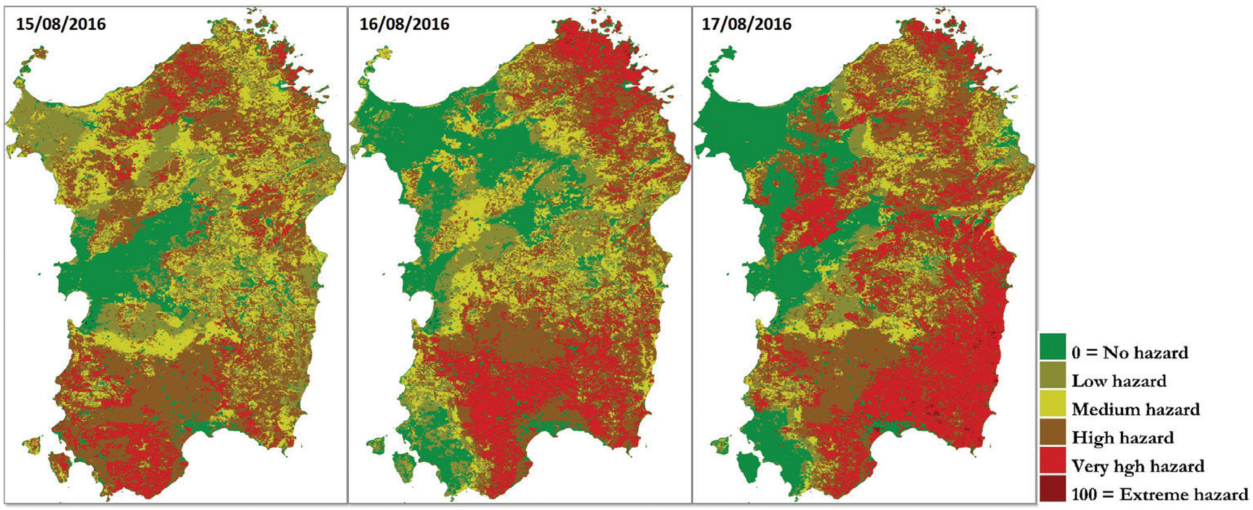

Figure 5. Daily hazard index maps computed for the Sardinia region in August 2016. The maps produced on the August 15, 2016 depict the situation for that day and provide the prediction of fire hazard levels for the next 2 days (August 16–17, 2016).

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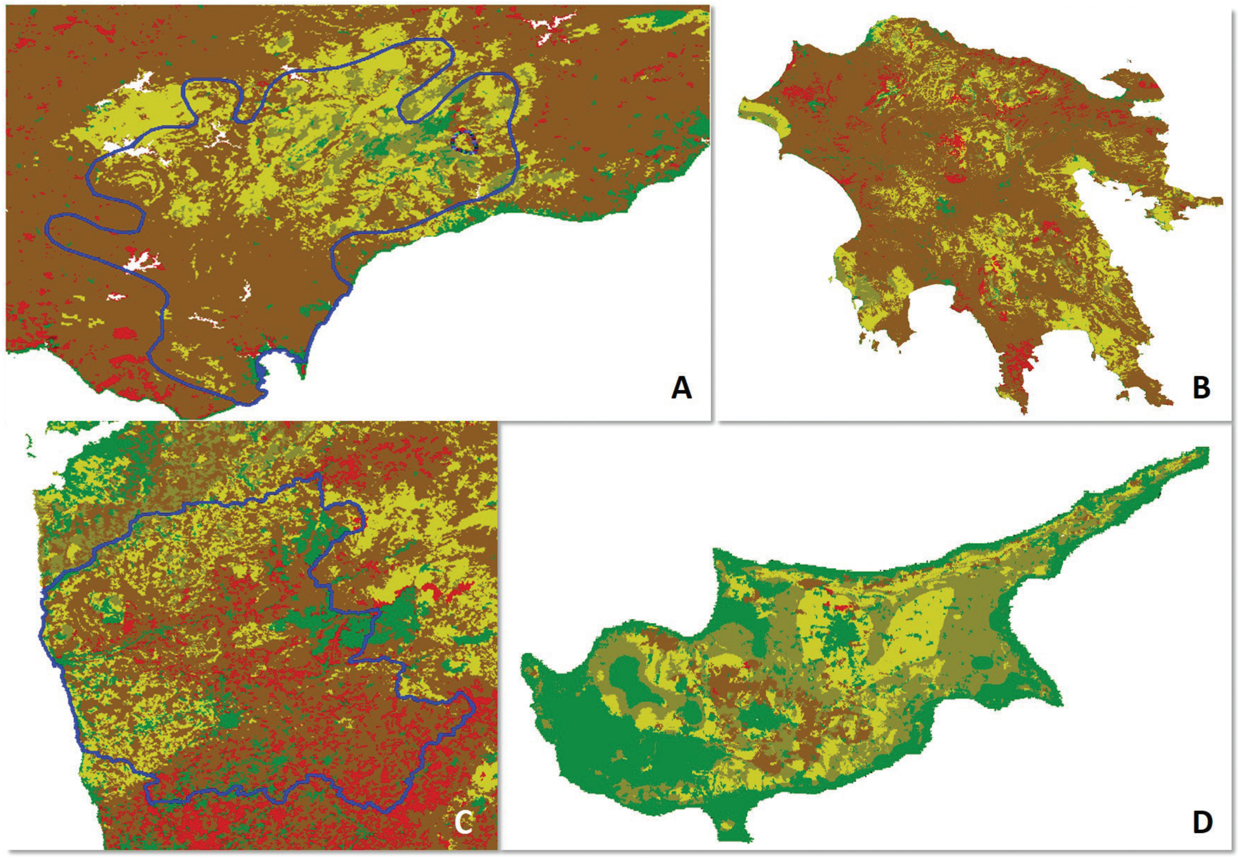

Figure 6. Daily hazard index maps computed for other test sites for the August 15, 2016, at different scales: (A) Spain, (B) Greece, (C) Portugal, (D) Cyprus island, requested later by the local Civil Protection.

biophysical and variable weather conditions. The seasonal fire hazard product had the objective to combine both human and meteorological factors to create a new index able to represent these different aspects of fire hazard, based on the integration of the following information: (i) natural factors that take into account the morphological characteristics distinguishable in static (such as slope, aspect and climatic zone) and dynamic data, related to vegetation stress (e.g. normalized difference vegetation index, NDVI), meteorological data, updated fuel map with burned areas and daily fire hazard index averaged over 15 days; (ii) human factors, considering the accessibility (urban areas and roads), the cultural factors (fire occurrences for the last 5–10 years, representing the security of a place) and the seasonal factors (current season fire trend with respect to the 5 previous years). This approach is based on the computation of homogeneous territorial classes according to the probability that a forest fire may occur, useful to manage prevention actions and firefighting activities and adjust the distribution of human resources and other means. Based on statistics of the previous years, in combination with the other included factors, the Portuguese test area had the highest proportion of spatial units classified as high and very high hazard, with a decreasing trend between June and September (**Figure 7**).

3.1.5. Vulnerability map

In a general sense, vulnerability means the potential for loss, which can affect different types of elements, either biophysical or anthropogenic [34, 57–59]. The vulnerability approach applied in PREFER was comprehensive, resulting from the combination of three different components:

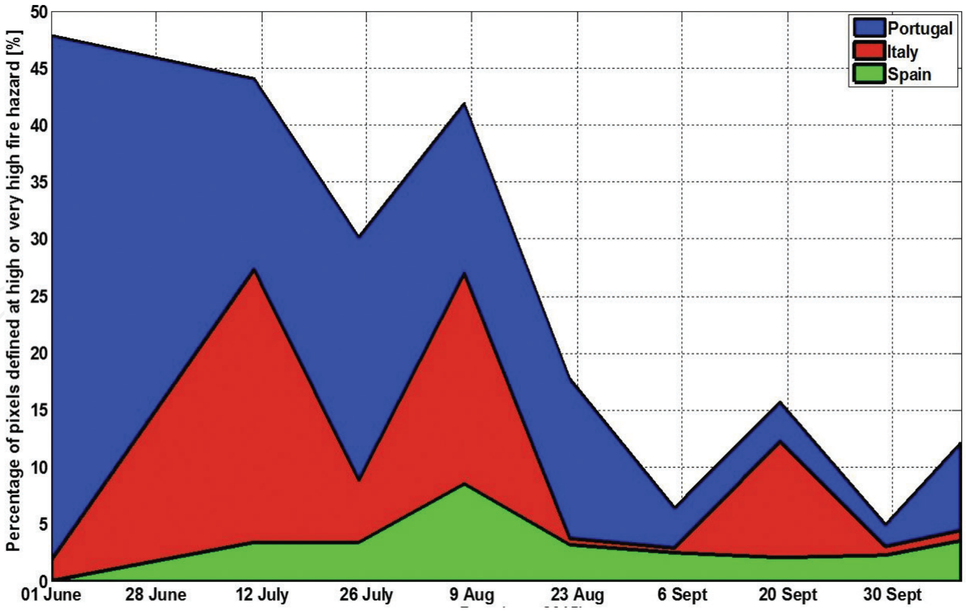

Figure 7. Variation of the area (% of pixels) classified at high or very high fire hazard during the 2015 summer season in three test areas.

exposure, sensitivity and coping capacity. Exposure represented the presence of people, property, systems or other elements in hazard zones that are, for that reason, subject to potential losses. Sensitivity characterized the conditions that influence the predisposition of the exposed elements to suffer a certain level and extension of damages. Coping capacity represented the circumstances that could reduce or, instead, amplify the ability of the elements to respond and recover from the impacts of a hazard, being related to the level of resilience of a community. Each of these components was first computed separately as an intermediate index, resulting from the combination of normalized variables that reflected multiple dimensions (socio-demographic, environmental, economic and institutional conditions). The vulnerability map resulted from the aggregation of the three intermediate components and represented a relative measure of the potential for loss, identifying the areas with higher likelihood to suffer losses in case a forest fire occurs.

The spatial patterns of forest fire vulnerability levels were uneven in the test sites (**Figure 8**). In Portugal, the northeastern (NE) part of Minho region showed higher vulnerability, due to the cumulative presence of population, infrastructures and fire-prone fuels, higher sensitivity derived from ageing population in that area and the presence of an internationally recognized protected area (Peneda-Gerês). Lower vulnerability levels largely coincide with the more urbanized areas, where fuel is nearly absent and institutional resources, such as fire stations, are concentrated. In the Italian test site, the lowest vulnerability levels are mainly concentrated in the NE part and seem to be closely related to fuel patterns; non-wildland fuels (which include agricultural land and are classified as less sensitive to fire) occupy about 37% of the test site and mostly occur in the northeastern side. Despite its complexity and challenging interpretation, vulnerability assessment is a relevant tool for fire prevention. In this case, the stepwise approach applied, with the creation of intermediate indices and the possibility to provide cartographic tools to end users for all the variables and components integrated,

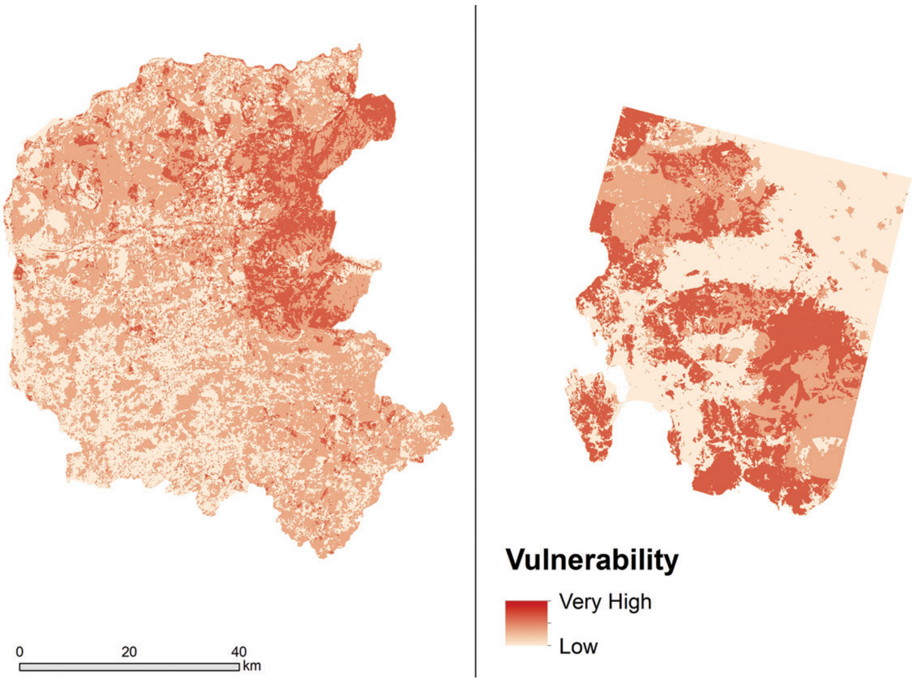

Figure 8. Vulnerability maps for the test sites of Portugal (left) and Italy (right).

facilitated the interpretation of the outputs and fostered their use in established procedures in the different countries. A common approach for vulnerability assessment enables comparable evaluations of exposed assets and coping capacity levels and promotes the implementation of mutual approaches to deal with lack of resilience.

3.2. Recovery/reconstruction service phase

The recovery phase products are strongly interconnected with each other. High spatial resolution (HR) burned perimeters are used to identify the areas where damage severity and post-fire vegetation recovery are evaluated. Post-event products are meant to improve the planning of the post-event intervention (recovery) by providing information on the level of damage caused by fires for vegetation and soil erosion, among other consequences. These products were computed based mainly on Landsat8 images [60, 61], acquired before and after the fire event, although the processing chain has been designed to use Sentinel-2 images when they become systematically available, ensuring the sustainability and further improvement of the cartographic tools at the disposal of multiple users.

3.2.1. Post-fire vegetation recovery map

The methodology for detecting and mapping burnt areas was based on the use of invariant or pseudo-invariant components of an image, called 'PRs' or permanent reflectors, to separate the variations which are due to intrinsic reflectance of the vegetation, from those caused by other external factors, such as sensor type, acquisition parameters or atmospheric conditions [61]. Preliminary detailed analysis of large sets of optical data was carried out to identify the pseudo-invariant targets to be used as PR, for burn scars mapping on the geographic area of interest, considering pre- and post-fire spectral signature changes in diverse land cover classes versus the associated PR reflectance spectra, as a function of time elapsed after fire. This process was necessary to define appropriate thresholding criteria for burn scar detection and mapping from HR optical data. The procedure was defined taking into consideration its possible application to any kind of satellite image having the required spectral channels (RED, near infrared (NIR) and short wave infrared (SWIR)). Hitherto, the mapping of burn scars was carried out on specific corine land cover (CLC) classes, namely permanent crops, agro-forestry areas, forests, scrub and/or herbaceous vegetation and sparsely vegetated areas, allowing to obtain a statistical analysis of fire impacts regarding affected land cover at the end of the fire season. **Table 4** shows the results of the burnt scars (BSs) for several test sites between 2014 and 2015. These areas showed different patterns of affected land cover. In France and Portugal test sites, scrub and/or herbaceous vegetation types were the most affected, whereas in Greece and Italy permanent crops were dominant in the burned perimeters. These differences between test areas can also be associated with firefighting resources efficiency, weather conditions or fire ignition causes, a relation that should be further explored.

3.2.2. Damage severity map

Maps with the level of damage in vegetation due to the fire were systematically computed on each burned area larger than 10 ha. The procedure downloaded automatically the burned areas for the test site (obtained within the PREFER project), retrieved two Landsat8 images, from before and after the fire, and computed three different indices: damage severity index (DSI), burn severity index (BSI) and differenced normalized burn ratio (dNBR) [60, 62, 63]. Validation was carried out with very high resolution pre-event images (RapidEye) and post-event field campaigns. The level of damage, as defined here, takes into account the biomass available in the burned pixel and high damage means that a long period is necessary for regeneration of the vegetation affected by the fire, for example, a wooded area completely burned that would require

Test sites		**FR**	**GR**	**IT**	**PT**
Temp. interval		**September 14, 2014–October 19, 2015**	**October 1, 2014–September 18, 2015**	**September 14, 2014–September 17, 2015**	**September 27, 2014–September 30, 2015**
Total N. of BS		62	92	58	1465
Total BS area (ha)		488	737	366	21,616
N. BS < 3 ha (%)		48	**77**	**71**	49
N. BS > 3 ha (%)		52	23	29	51
CLC of the BS (%)	22	29	**64**	**41**	4
	244	0	0	2	<0.2
	31	26	5	5	17
	32	**42**	29	52	**71**
	333	3	2	0	7

Note: Bold values highlight the highest values for the the percentage of fires smaller than 3 ha (77% in Greece and 71% in Italy) and the prevalent type of vegetation burned in each area.

Table 4. Results of the burnt scars (BS) for several test sites between 2014 and 2015.

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several years to recover. On the contrary, the regeneration period of grasslands and shrublands is between 1 and 3 years, thus the damage severity on this type of vegetation is always lower. Based on this evaluation regarding damage level by vegetation type, the three indices gave rather different results [62] and the DSI seemed to provide better estimations, since a lower number of burned pixels in grasslands was considered high or very high damage (**Figure 9**).

In 2015, this procedure was applied to 173 burned perimeters in the test area of Portugal (**Figure 10**), showing higher damage levels in the north. Damage severity maps allow evaluating the

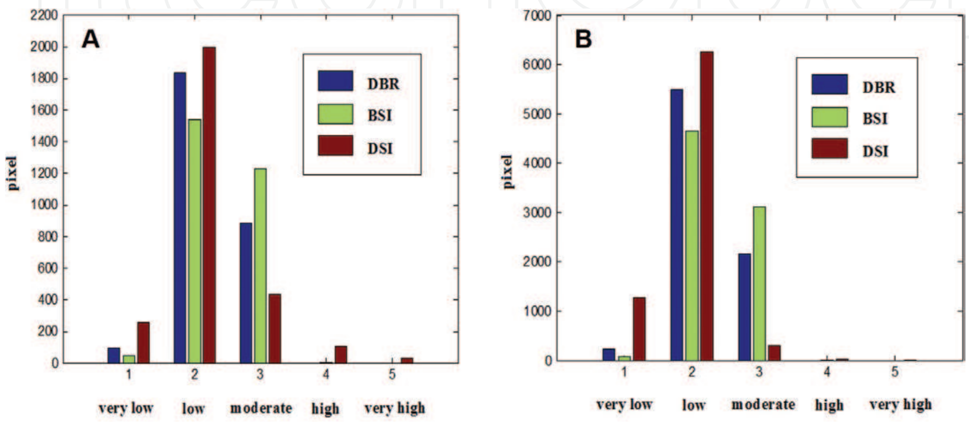

Figure 9. Distribution of the damage severity levels of burned (A) grassland areas and (B) woodland areas in Portugal (>10 ha).

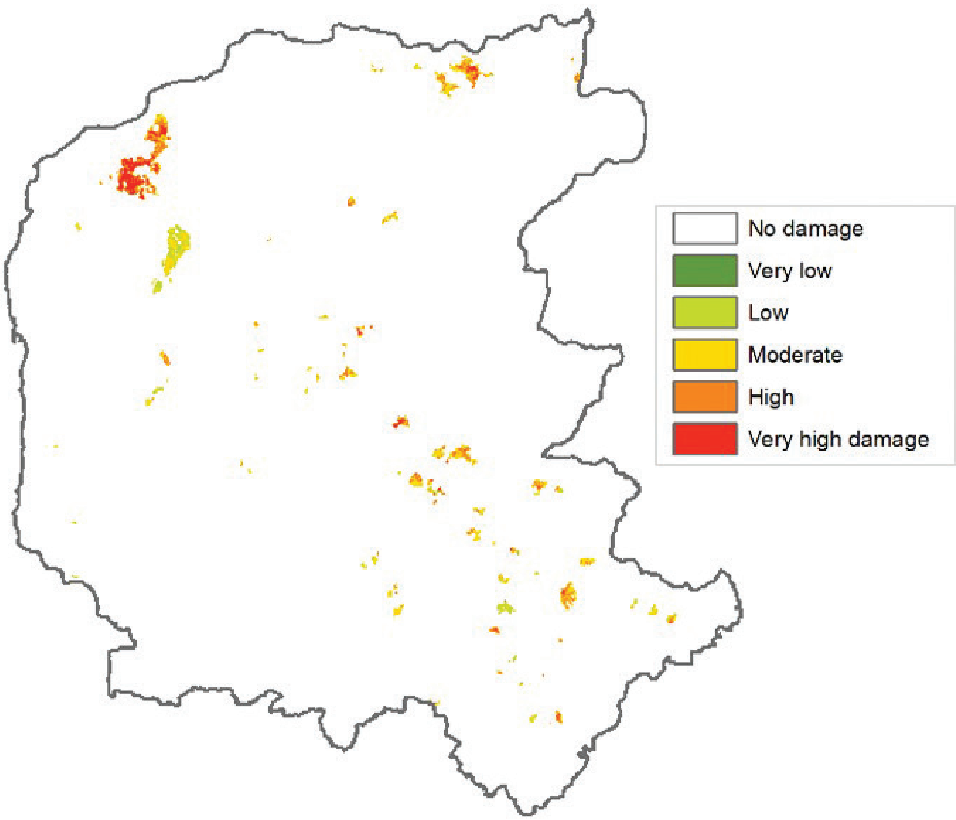

Figure 10. Distribution of the damage severity levels in Minho region, Portugal, in 2015.

incidence of fires at local, regional or national scales and help identifying areas where artificial plantation should be considered for reforestation of burned areas.

4. Concluding remarks

The forest fire context in Mediterranean Europe is characterized by a high incidence of fires causing substantial damages, with strong seasonal variability. The efficient mitigation of fire damages requires additional investment in the early phases of the fire management cycle, such as planning and resource allocation, since further improvements in firefighting and suppression above a certain threshold are associated with unsustainable costs. Despite regional and national differences, the European Mediterranean countries share common issues, for which equivalent appraisals are beneficial in view of facilitating knowledge-transfer and synergy at the transnational level. Fostering significant improvements in effectiveness and timeliness of prevention measures remains the most cost-effective strategy, which can be enhanced by sharing scientific knowledge, operational expertise and technical resources among countries with common challenges and environmental issues.

The PREFER project contributed to this direction, as an international initiative focused on the development of services for supporting fire management tasks, driven by cutting-edge technologies and state-of-the-art scientific results. The project has set up a regional online service, able to process and distribute to end-users spatial information to support forest fire management and intended to stimulate further coordination between countries to promote cooperation and operational deployment.

Relying upon an improvement in quality, quantity, scale and timeliness of mapping, and being complementary to services provided by other institutions, the project searched for efficiency improvements in preventing ignitions and supporting the planning of response and recovery strategies of burned areas. A common framework for product development was applied, ensuring comparability, sharing of best practices and reinforcing cooperation between institutions and countries, without precluding the possibility for adjustments on the procedures, by introducing further regional knowledge and level of detail, depending on the conditions of the area, data availability and user needs. Moreover, the framework was designed to allow for the integration of new or improved satellite images and other data when they become systematically available, ensuring the sustainability and further upgrading of the cartographic tools. The availability of a synoptic view of fire management procedures and the provision of a pan-European portfolio of products, based on similar requirements and usable by multiple users, are important tools to provide quantitative criteria to help prioritising the management of resources. An important aftermath of the project lies on the possibility to apply the knowledge and technical resources developed to other areas in the Mediterranean region, fostering collaboration between institutions and improving the transnational cooperation to increase resilience of the population and the environment to forest fires by providing valuable tools, at the disposal of the authorities in charge of forest fire management in the Mediterranean region.

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