The European Forest Fire Information System: A European strategy towards forest fire management

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Abstract

Natural fires are an integral part of Mediterranean ecosystems. However, in Europe, the extensive use of natural and forest regions as recreational areas has increased the number of human caused fires. Additionally, the decrease of rural population and abandonment of agricultural regions has led to the build up of fire fuels on these areas and the consequent increase in the number and the damage of forest fires. On average, fires in Europe burn 0.5 million hectares of forest areas every year. Although the number of fires has been steadily increasing in the last decade, the area burnt by fires has not increased. This increase in the number of fires has been accompanied by a decrease in the mean burnt area due to the improvements in infrastructure and means to extinguish them. Traditionally, fire fighting was carried out by local administrations, which extinguished fires in the surrounding areas. However, as limited and expensive resources became available, these were often administered by the National forest fire services. This scaling factor has evolved with time and national forest fire risks maps are currently available in many European countries. However, the regional (supra-national) evaluation of forest fire risk was a task that was not tackled until recently by the European Union. This was probably due to the lack of regional datasets for the estimation of forest fire risk and the lack of regional information of forest fires that would necessarily be used for the calibration and validation of fire risk indices. The European Commission (EC) Civil Protection Unit, at the EC Directorate for Environment, aware of the strong impact of forest fires in Europe, established a research group at the EC – Joint Research Centre (JRC) to work specifically on developing and implementing methods for the evaluation of forest fire risk at the European scale. This group has been working closely with the national forest fire administrations towards the development a European Forest Fire Information System (EFFIS) that will provide up-to-date and harmonized information to all the services in charge of forest fire prevention and management. EFFIS, which is available at http://natural-hazards.jrc.it/fires, includes a system for the delivery of forest fire risk forecast during peak of the fire campaign (6 months), and the yearly evaluation of fire damages through the analysis of satellite imagery.

Introduction

The public awareness on the issue of natural hazards is increasing every day. The European Union (EU) and international organizations have realized that there are means to reduce or minimize the damage caused by natural disasters. The first step in this direction is the characterization of areas subject to suffer damages. This involves the use of analytical tools to infer the risk of natural or human induced hazards.

In particular, in the case of forest fires, the EU has suffered in the last years enormous losses in terms of human life and environmental damage. Forest fires are the result of strong tensions in landscape use and management. High population density in suburban or tourist areas increase the risk of fires due to negligence or accident. Rural exodus and extensification of agriculture and livestock breeding increases agricultural and pastoral burning in order to contain natural re-afforestation. Economically not very profitable, the Mediterranean forests are often used as recreation areas. In addition, forests are often crossed by electricity cables, railways and roads networks that increase the risk of fires. These reasons may explain partially the increasing trend of the number of forest fires in the last years. The growth of cities in their neighbor natural areas has also increased the number of fires in the urban-forest interface.

Although forest fires are a global concern, indicators of forest fire risk are normally developed at the local or national levels. Until recently no mechanisms existed to estimate the risk of forest fires at the EU scale. This was due to the lack of regional data sets for the estimation of fire risk and to the lack of regional information of forest fires that would necessarily be used for the calibration and validation of the proposed fire risk indices.
Experts on forest fires know by experience that the distribution of forest fire events is not random. Particularly, in the Mediterranean region fires tend to occur where they have historically taken place. Despite of this, the impact of recurrent forest fires on the EU Mediterranean region has never been evaluated because of the lack of a harmonized cartography of forest fires on this region.

Aware of this problem, the European Commission (EC) and the Standing Forestry Committee decided in 1990 to set-up a Community forest-fire information system in order to monitor the forest fire phenomena at EU level. European data sets on fire occurrence are derived from data collected on the ground by the forest fire and civil protection services of the Member States. Thus these data come from the aggregation of heterogeneous local and national databases in which data are collected in different ways with very diverse methods. Although the EU data permit observing some insights of the fire phenomenon, they do not permit a harmonized assessment of forest fire damage. Figure 1 presents the trend in the number of forest fires in the five EU Mediterranean countries during the last two decades, from 1980 to 2000.

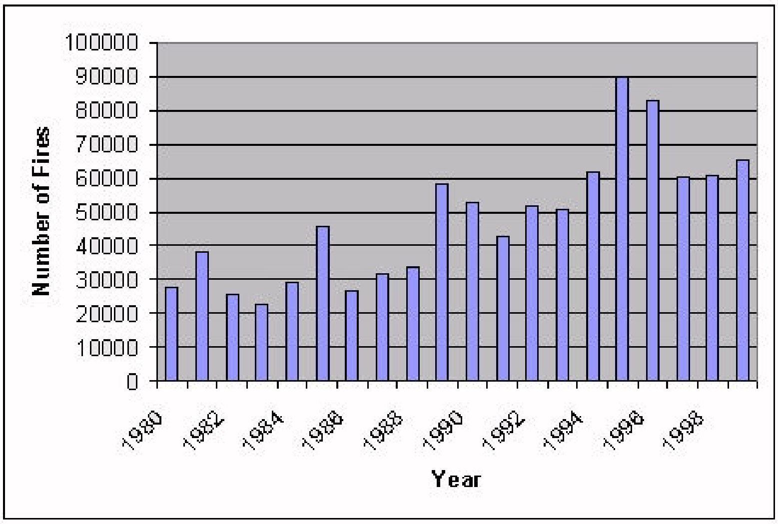


Figure 1.

The European Commission reinforced this action in 1997 by setting up a research group to work specifically on the development and implementation of advanced methods for the evaluation of forest fire risk and the estimation of burnt areas at the European scale. This group is since 1999 working as part of the Natural Hazards project of the EC DG Joint Research Centre. All these activities are coordinated through DG ENV to reach the final users in the Member States.
The forest fire activities of the Natural Hazards project comprise the different phases of fire monitoring. i.e. before, during and after the fire event. Only fire behavior, for which very detail local information is required, is not considered. On the prevention phase, the work has focused both on the development of systems to provide forest fire risk forecast based of existing fire risk indices, and on the development of new integrated forest fire risk indicators. Five types of forest fire risk indices, from long-term (static) risk indicators to short-term (dynamic) risk indicators have been implemented. All these indices permit the harmonized assessment of forest fire risk at the European scale. Thy may be used as tools for the assessment of risk situations in cases in which international cooperation in the field of civil protection is needed. In all cases, the indices were calibrated and validated using a five-year fire event dataset.

In addition to evaluating the fire risk, an activity to estimate the annual damage caused by forest fires in the south of the EU was established. This activity has produced the first cartography of forest fire damages in the south of the EU. In the year 2000, all the burned areas larger than 50 ha, which account for on average about 73 % of the total area burnt every year, were mapped using satellite imagery. Further, the analysis of which types of land cover classes were affected was performed. In order to centralize the existing information on forest fires in Europe, the EC General Directorate for Environment and the Joint Research Centre have initiated a collaboration for the creation of the so called European Forest Fire Information System EFFIS.

THE EUROPEAN FOREST FIRE INFORMATION SYSTEM

Information on forest fires in Europe is very scattered. This information is compiled by the local authorities and aggregated at the provincial or regional levels. The data is further aggregated at the national level to derive national statistics. In the case of European data, the national data suffer a further level of aggregation. In looking at the integrity of the data and the susceptibility of performing statistical analysis to draw conclusions regarding the fire situation in Europe, one must realize that the methods to collect the information are very diverse. In fact, the methods vary from region to region within each country, and from country to country. Moreover, the concept of forest fire differs from country to country because the definition of forested area is not unique for the EU Mediterranean countries.

Within the bounds of the forest protection framework ruled by Regulation (EEC) No. 2158/92, the Member States and the Commission agreed to create a Community information system on forest fires. The system consisted initially of the aggregated data provided by the relevant services in the Member States. It is foreseen that the structure of the system will evolve to include information derived with the use of new methods and advanced techniques. The system, as shown in figure 2, will integrate the existing information sources from the Member States of the EU, which provide data to the so-called "common core of information on forest fires", and the newly derived information by the Joint Research Centre. The system will be referred to as the European Forest Fire Information System.

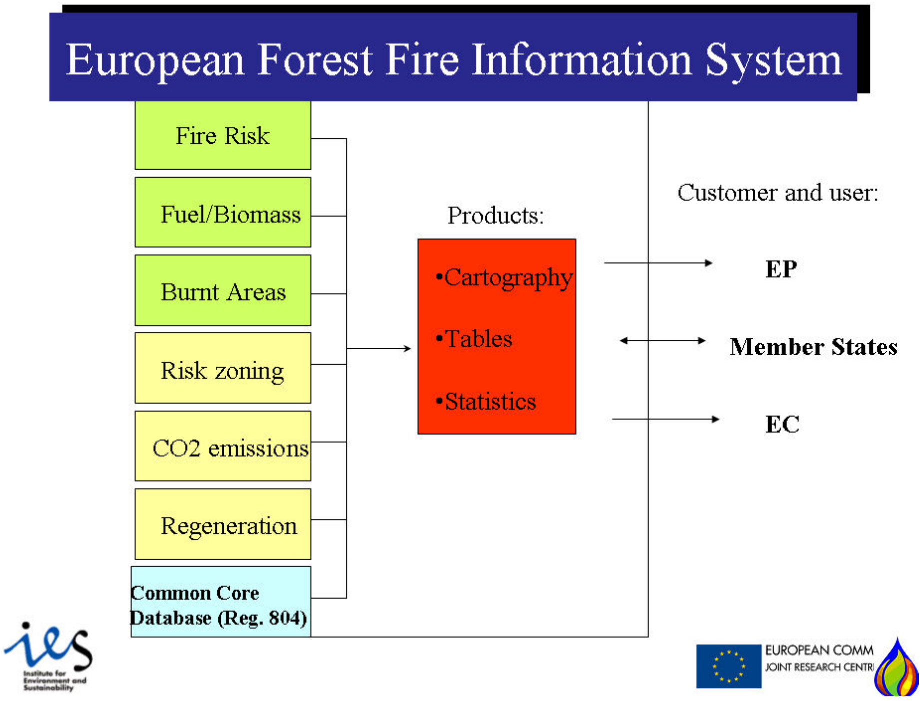


Figure 2.

It has been decided to establish the integrated system at Joint Research Centre in Ispra. The system, as well as the information to be entered, will be coordinated by the EC Directorate General of Environment, and will be accessible to all the representatives of the civil protection and forest fire services of the EU Member States. For the year 2000, the system has already incorporated the harmonized information of forest fire risk in Southern Europe and the mapping of burnt areas for those fires larger than 50 ha in this region. Figure 2 shows how, in addition to the "common core database on forest fires", two subsystems feed the EFFIS. These are the European Forest Fire Risk Forecast System (EFFRFS) and the European Forest Fire Damage Assessment System (EFFDAS). These subsystems will be described in the sections ahead.

The european forest fire risk forecasting system

As mentioned above, the EFFRFS has been designed for computing several types of forest fire risk indices varying from dynamic indices to long-term indices. Once the indices are computed, they are distributed to the civil protection and forest fire services via Internet. Forest fire risk is influenced by many variables. These variables have a wide range of spatial and temporal variability. According to this variability forest fire risk can be classified into long-term prediction and short-term prediction (Vorissis, D. 1999). The methods as well as the applications of the derived fire risk maps varies with this time frame. Long term prediction is provided by indices that are referred to as static or long-term. Short time prediction is provided by the so-called dynamic indices. Long-term fire risk prediction is intended for long term planning, which may serve to characterized regions as subject to high or low risk of fires. On the other hand, short-term prediction is more related to fire fighting and extinction and it can be seen as a decision support mechanism for the allocation of forest fighting resources by operational fire fighting centers.

Even though variables that influence fire risk are usually evaluated regionally, the computation of forest fire risks was until recently performed at a local scale. This was mainly due to the intrinsic infrastructure that deals with forest fire prevention and extinction. The JRC started in 1997 the development of applications that take into account the regional variability of the factors that influence fire risk. This action crystallized in 1999 in the forest fire activities of the Natural Hazards project. Regional (pan-European) approaches to evaluate long-term as dynamic forest fire risk are currently in place. The computation of these indices, as opposed to those computed at the national or local level, will enable the regional evaluation of forest fire risk. The use of harmonized regional forest fire indices will make possible the inter-comparison of risks for different areas of Europe, which is not possible nowadays (San Miguel-Ayanz *et al*. 2001, Bovio and Camia , 1999).

The following forest fire risks are being developed:

1. Long-term (static) indices
   1.1. Probability of fire occurrence
   1.2. Likely damage

2. Dynamic indices
   2.1. Meteorological fire risk
   2.2. Vegetation stress fire risk

3. Fire Potential Index

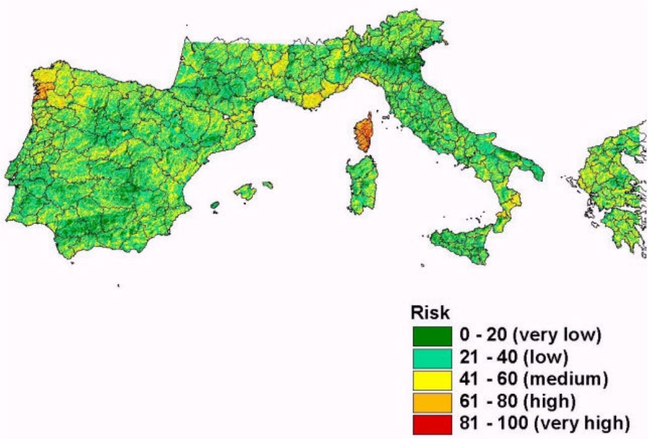
The periodicity with which each index is computed depends on the variability of the factors that it takes into account. The lapse of time for updating a fire risk index goes from a year (long-term indices) to a day. Up to three day forecast is produced for those indices that are computed from meteorological variables.

Long-term Indices

Long term fire risk indices are computed from variables that do not change in a short lapse of time. Consequently, these maps are updated with a yearly (or longer) frequency. Two types of long-term indices are being developed. The first one provides the probability of fire occurrence, while the second one indicates the likelihood of damage to a forested area in terms of economic or environmental losses.

Probability of fire occurrence

Forest fire risk is derived through empirical and statistical methods to provide two different outputs. In the first (*empirical*) approach three types of variables were used for the estimation of the probability of fire occurrence: fuel types, topography, and socio-economic factors. Previous studies have shown the relationship between these variables and forest fire occurrence. This index intends to evaluate the probability of fire ignition, rather than the propagation of the fire. Fire propagation is more related to the dynamic indices that are presented in the sections ahead. Aspect was included in the model as representative of the topographic conditions that may influence fire ignition. Aspect is related to the type and condition of the available fuels for ignition. Since the influence of socio-economic factors (human factor) is difficult to model, fire recurrence was introduced in the model as a surrogate of these factors. Fire statistics for southern Europe show that the probability of fire occurrence is higher in those areas that have historically suffer a high rate of fire incidence. Figure 3 presents this first type of long-term fire risk index for southern Europe.

Figure 3. 

In a second (*statistical*) approach, multivariate statistical methods were used to derive a long-term index that would provide the probability of fire ignition according to the estimated annual mean of fires per square kilometer. This index takes into account physiographic and socio-economic variables obtained from comprehensive European databases of GISCO and EUROSTATS.

Likely damage
There are natural areas that are of particular interest. This may be due to many different reasons, from the purely economic value of the timber to the unique environmental qualities of the area. The aim of the likely damage index is to provide a method to highlight areas that should be strongly protected from forest fires. In the Mediterranean region of Europe the highest quality of most forested areas is their environmental value. Timber production is usually a secondary asset of these forests. An added condition of these forests is the intrinsic difficulty for regeneration due to the lack of rain and the fragility of soils. Due to the slow regeneration of the forests, burnt areas are subject to erosion by autumn rains, just after the peak of the fire season in the summer.
The likely damage was estimated by assigning to each cell a vulnerability degree. The following variables were taken into account in the computation of the index: (1) potential erosion, (2) rareness and fragility, and (3) human lives and property at risk.
The two types of long-term indices (probability of fire and likely damage) could be integrated into a single index. This so-called integrated long-term index would identify areas that are jointly subject to suffer forest damage and high potential losses. The index would help forest fire services locate those areas to which the highest level of protection should be given.

Dynamic indices

Dynamic indices are short-term indices that assess the probability of fire ignition and spread. These factors may be derived directly from meteorological variables, or indirectly by the effect that these variables have on vegetation. Indices that are computed from meteorological variables are referred to as meteorological fire risk indices. On the other hand, the indices that evaluate the status of the vegetation are the so-called vegetation stress fire risk indices.

Meteorological fire risk
Several meteorological forest fire risk indices are computed. There is not a consensus on which meteorological fire risk performs best for the whole Mediterranean region, although several studies show that the Canadian Fire Weather Index is well suited for the estimation of fire risk for the region (Sol, 1999). Accordingly, the activities of the Natural Hazards project include the computation of several indices that are operationally used in southern Europe.

All of them were initially computed from data collected from a network of meteorological stations covering Europe. Although the data are collected at the station level, they are further interpolated to a 50 km by 50 km grid. At present, these indices are computed from forecast data, and fire risk indices are produced as forecasts for one, two and three days. Six indices are being computed:

- **Behave** (Rothermel et al. 1986; Van Wagner and Pickett, 1987) based on estimation of the moisture content of fine dead fuel,
- **The Canadian Fire Weather Index (FWI)** (Van Wagner and Pickett, 1987) made up of six normalized indices that indicate the daily variation of fuel water content, initial rate of propagation, and quantity of fuel and expected intensity of the flame front,
- **Portuguese index** (Gonçalves and Lourenço, 1990) assesses atmospheric conditions in the proximity of the fuel layer,
- **Spanish ICONA method** measures probability of ignition (ICONA, 1993) based on litter and fine dead fuels moisture content,
- **Sol Numerical Risk** (Drouet and Sol 1993; Sol , 1990) related to ignition and propagation ,
- **Italian Fire Danger Index** (Palmieri et al. 1993) derived from Mc Arthur's model.

European statistics on forest fire data are used for the calibration and validation of these indices. All the indices are computed for southern Europe, however individual civil protection agencies can download the indices for its own territory. Figure 4 shows an example of the Canadian FWI computed for Europe.

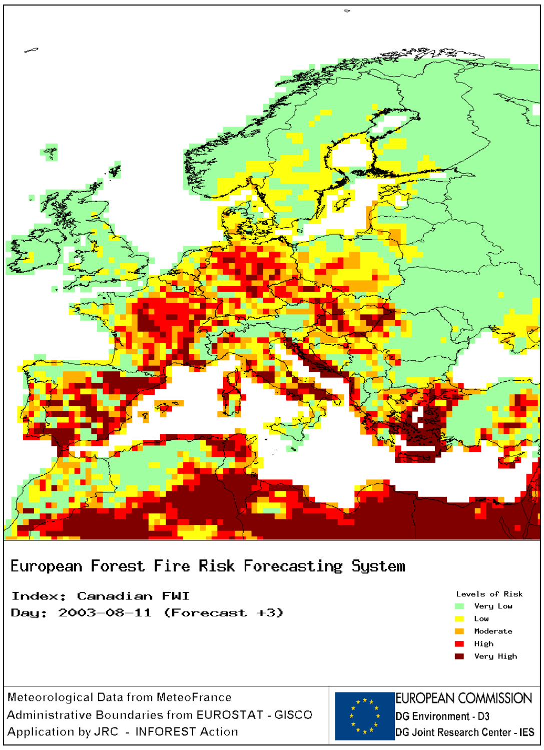


Figure 4.

Vegetation stress fire risk

Vegetation stress is derived using remotely sensed data. The part of the solar radiation that is reflected by vegetation is related to the vegetation status. When there is a stress due to either water or nutrient shortage, this is noticeable by changes in vegetation reflectance. Vegetation indices are mathematical formulae that combine the reflectance of vegetation in several wavelengths of the solar spectrum. These indices are used to derived vegetation stress, which is further correlated to the probability of fire ignition and propagation. The use of remote sensing methods permits retrieving spatial information for a fairly large region with a limited cost.

Vegetation indices are derived from satellite data acquired from the NOAA AVHRR sensor for the computation of vegetation stress fire risk indices. The "normalized difference vegetation index" or NDVI is used for this purpose. It is assumed that the hydric stress caused by summer drought will cause a decrease in the NDVI. This effect will be noticeable as an increase in the absolute value of the cumulative slope of the NDVI curve (Illera et al. 1996). This index is only computed over forestry and agro-forestry areas of Europe to avoid abnormal fluctuations of the NDVI due to other land uses. Figure 5 presents the index computed for a given day over the study area.

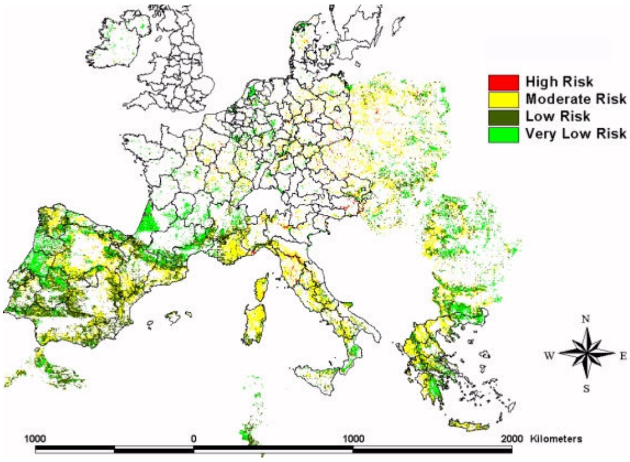


Figure 5.

Fire potential index
As mentioned above the risk of forest fires is influenced by many different variables, including dynamic and long-term ones. Thus, it is reasonable to think that the best forest fire risk index should somehow combine these different types of variables. Following this approach Burgan *et al.* (1998) developed the Fire Potential Index (FPI). The FPI takes into account dynamic variables such as the vegetation relative greenness and meteorological conditions, and long-term factors, such as the type and load of fuels on the ground. The FPI has been implemented in the U.S.A., and it has been successfully validated in California. The FPI is being adapted to European conditions within the Natural Hazards project. This task is performed in close collaboration with the developers of the FPI. Intrinsic European conditions forced some modifications into the model inputs, which make the resulting index slightly different from the original FPI.

This system will enable civil protection agencies to receive timely information of all the different forest fire risk indices. In addition, downloading of the data will be possible through a ftp site. This will enable the integration of forest fire risk data with any other type of spatial information. Figure 6 shows an example of the FPI computed in Europe in Agust 8, 2003.

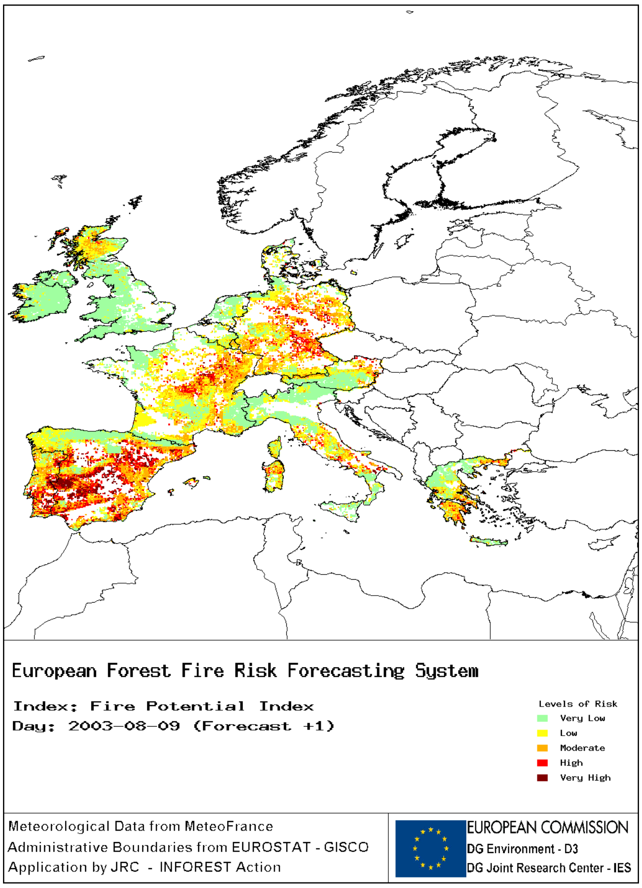


Figure 6.

THE EUROPEAN FOREST FIRE DAMAGE ASSESSMENT SYSTEM

Burnt area mapping and forest fire damage assessment are performed as a support activity for the European Commission Directorate General for Environment. First, burnt areas are identified and classified on satellite imagery, then the damage is assessed intersecting the maps of burnt areas with a land-use / land-cover database. The CORINE land-cover is used since it is the only land-use map with a harmonized legend for all the European countries.

Two types of algorithms were developed to derive the perimeter of burnt areas in medium and high spatial resolution imagery. These generic algorithms can be applicable to other types of imagery such as the EOS-MODIS or the ENVISAT-MERIS as they become available.

The first algorithm uses the burnt index (San-Miguel-Ayanz, et al. 1998) to segregate burnt areas within vegetated areas of the image. The BI is an orthogonal transformation of three spectral bands in the range on the green, red and infrared (NIR) parts of the spectrum. These bands are common to the most used satellite data such as SPOT HRV, Landsat Thematic Mapper, RESURS MSU-E, IRS-1C LISS-III. They are/or will be present in medium spatial resolution spectrometers such as NASA EOS-MODIS or the ESA ENVISAT-MERIS. The BI performs reasonable well in the absence of the green band. In this situation the orthogonal transformation is limited to the red and the NIR. This is the case of applying the BI to data from the IRS-1 WiFS sensor. The algorithm uses a pre-fire image in which vegetated areas are mapped. These areas are further investigated on the post-fire image on which burnt areas are clearly classified by the BI. The sequential process of this method is presented in Figure 7.

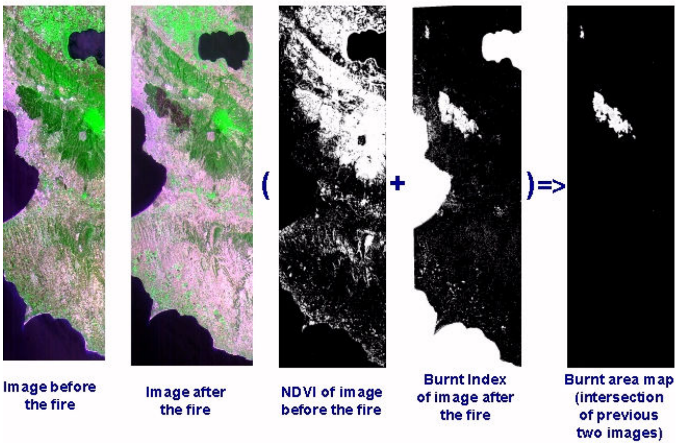


Figure 7.

The second type of classifiers are non-parametric cluster algorithms, which are based on the direct or indirect estimation of gradients in the histograms. These algorithms are based on the search of local modes on the histograms of the image bands. Some of these local modes would correspond in the present application to burnt areas. These are isolated from other classes by the intrinsic spectral and spatial characteristics of burnt areas (San-Miguel-Ayanz et al. 1998).
In order to improve the discriminative power of the algorithm, the classification process is carried out on sub-images. Burnt areas present within these sub-images present a greater relative proportion of pixels, which facilitates locating the local mode on the histogram. The way in which pixels are grouped around their spectral means is presented in Figure 8.

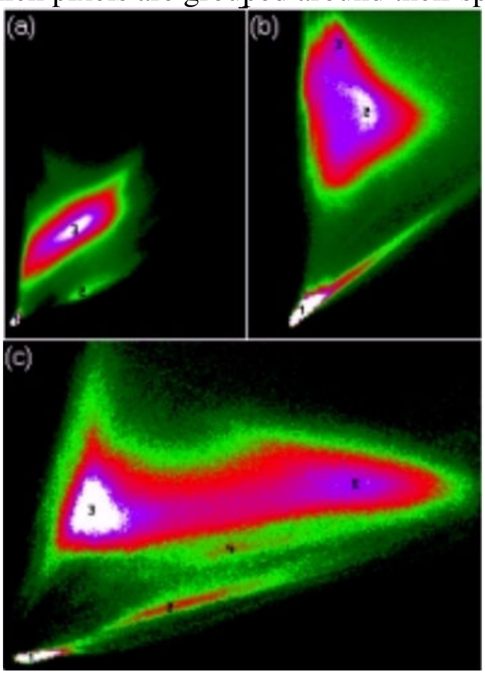
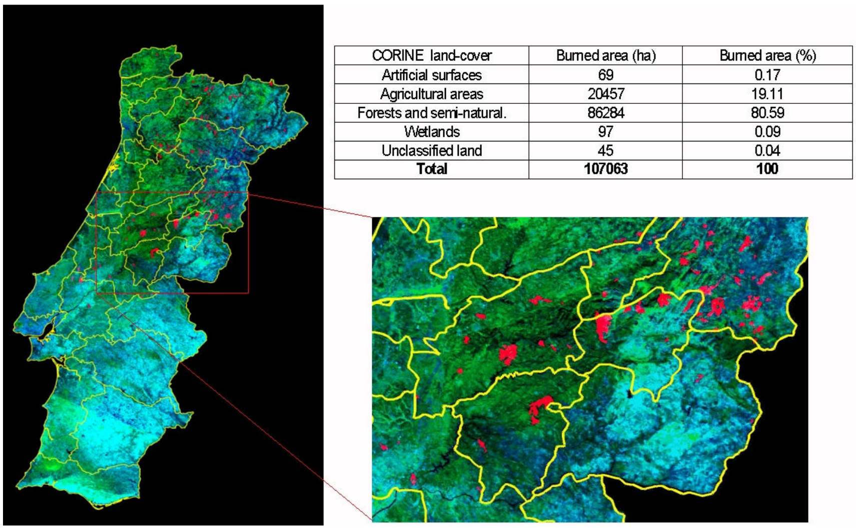


Figure 8.

One direct application of the proposed algorithm is the mapping of burnt areas from a point located within it. The algorithm spreads searching for spectrally similar pixels until it finds the boundary between burnt and non-burnt surfaces. The result of the classification of the images covering Portugal with the non-supervised and non-parametric algorithm is shown in Figure 9. This methodology will be applied in conjunction with fire detection algorithms for mapping burnt areas across the Mediterranean basin.

Once the perimeter of the burnt area is identified on the satellite image, the next step is the evaluation of the forest fire damage. This is performed in a GIS environment by intersecting the classified image with a landcover database. The process involves the geocoding of the image (warping) to the map projection of the landcover map. Warping is performed until sub-pixel registration between the two data layers is achieved.

In order to standardize the way in which forest fire damage is evaluated in Europe, the European CORINE landcover database (CORINE Landcover – Technical Guide, 1994) is used as the base landcover layer. This harmonized methodology across Europe permits the comparison of damages among countries, which would not be possible if each country used a different landcover database. We should note that the definition of forest is different for the five EU countries in the Mediterranean basin.



CORINE land-cover	Burned area (ha)	Burned area (%)
Artificial surfaces	69	0.17
Agricultural areas	20457	19.11
Forests and semi-natural.	86284	80.59
Wetlands	97	0.09
Unclassified land	45	0.04
Total	**107063**	**100**

Figure 9.

The evaluation of forest fire damage in Portugal in the year 2000 is presented in Figure 9. A detail of the image with the mapped burnt areas is presented on the sub-image. The intersection of the maps of burnt areas with the CORINE land-cover database results in a table, as that presented in Figure 9. This table shows the area affected by the fire in the different cover types. The total estimated burnt area was 107063 hectares, of which 80.59% were forest and semi-natural areas. The same methodology was applied to map burnt areas and estimates in the rest of the Mediterranean countries. The results for the whole Mediterranean region can be found in the European Commission report for the year 2000 (European Commission, 2001).

As mentioned above the EFFDAS was developed to estimate fire damages for the whole Mediterranean basin. The cartography of the damage area can be provided shortly after the fire event. The information derived using this system would not only help forest fire services but it will provide harmonized information on fire damage across the member states. As mentioned before, in the EU forest fire damage information is at present collected at regional level within each country, the aggregated at national level and the further aggregated at European level. The diverse definition of burnt and non-burnt areas, as well as the different definitions of forests among the different countries makes this data compilation somewhat heterogeneous.

CONCLUSIONS

The use of new technologies such as remote sensing and telecommunications have permitted advances in forest fire monitoring. The collaboration of several European Commission institutions such as DG ENV and DG JRC with the relevant Member States has permitted a unified approach to the evaluation of forest fire risk and fire damages in Europe.

The existing EFFIS is the core of an advanced system for forest fire information that will permit the interaction of the national services and EC services for the establishment of an up-to-date database on forest fires in Europe. It is foreseen that new modules will be added to EFFIS, particularly in the field of risk zoning after forest fires to prevent landslides, soil erosion and soil loss, biomass estimation, and estimation of the contribution of forest fire to CO2 emissions into the atmosphere.

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