BURNED LAND MAPPING AND POST-FIRE EFFECTS

Michael A. Karteris

Laboratory of Forest Management and Remote Sensing
Department of Forestry and Natural Environment
Aristotelian University, Box 248, Thessaloniki 540 06, Greece

Tel.: +30-31-998951 FAX: +30-31-998897

E-Mail: karteris@olymp.ccf.auth.gr

INTRODUCTION

Mediterranean forest ecosystems are quite limited. Part of the total land surface is covered by productive and potentially productive forests, sclerophyllus shrublands called maquis and grasslands. The forests, especially those growing in the lower zone, are open communities possessing a dominant tree layer (usually of pine species) with a well developed understory woody and herbaceous vegetation.

All these ecosystems are under continuous natural and human based disturbances, which influence their quantitative and qualitative condition. Forest fires are of major concern, because they are considered to be the most important factor (at least for the Mediterranean basin) of creating this condition.

Protection and conservation of these ecosystems constitutes the main environmental goal of the natural resources managers. To accomplish the above, rational planning and management strategies should be developed, which will take into consideration political, social, economic, biotic and abiotic influences and constraints. However, these factors create a seasonally dynamic system. This requires a thorough understanding not only of the pre-fire distribution (identification, classification and mapping) of the specific resource features, conditions and characteristics, but also the collection and comparison of post-fire subsequent data and information (burned areas, damages, vegetation recovery etc.) in order to detect and specify environmental changes and trends.

It is known that there is a direct connection between the availability of information necessary to sound decision making and the effectiveness of forest fire management of tactical and strategic options. However, as the complexity of such management decisions increase, more and more multitemporal information are required which in turn require more time and effort. Because of that the development of a comprehensive information system, which will include advanced monitoring and analysis methods, techniques and technology is a necessary requisite, which forms the cornerstone of the forest fire management process. Specifically the requirement is for a system which will enable to provide landscape characteristics structure, composition and distribution of forest communities, fire disturbances, post-fire vegetation trends and other conditions and effects at more regular intervals, collection of data of large areas at a comparable or even better degree of accuracy and maintenance of them on a computerised base which will ease, manipulation and provide them in computer compatible formats.

The development of remote sensing techniques and especially the satellite technology in combination with the geographic information systems, opened a new area in the forest fire research. The temporal, spectral, spatial and other characteristics of satellite data, combined with outputs from GIS management of other types of data, provide a wealth of information which may be used in all phases of a fire management program i.e. pre-fire planning procedures, fire detection and monitoring activities and post-fire operations.

This paper will attempt to analyse the contribution of remote sensing and geographic information systems technologies in post-fire management procedures.

Overview of Remote Sensing and Geographic Information Systems

Remote Sensing Systems

Aerial photographs are a pioneer remote sensing source of data used in post-fire management procedures. This inflexible media, requires subjective qualitative analysis and supplements the ground surveys and field observations, which it should be mentioned, are not free of errors. Since many years ago the remote sensing technology has advanced to a point, where it can provide various airborne and spaceborne passive and active data (images), which permit objective quantitative analysis.

Especially the satellite technology (LANDSAT, SPOT, ERS-1, MOS-1, NOAA etc.) has various characteristics which ensure an unbiased source of information for the operational support of fire management decision making. Due to these characteristics the satellite technology is probably the best monitoring system available today. More and more fire researchers and managers are turning to this technology to solve fire related operational problems on a cost/benefit basis. However airborne systems like Compact Airborne Spectrographic Imager (CASI), Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), Linear array images, Video camera systems, Airborne Data Acquisition and Registration (ADAR) System etc. are tested in order to assess their contribution to fire management related problems.

Geographic Information Systems

Since its introduction in 1970's geographic information systems technology has expanded and experienced rapid adoption by various private and public companies dealing with fire related problems. Many analytical functions which have been developed and incorporated into the geographic information systems, such as:

- handling of large, multi-layered and heterogeneous data sets
- query and display of spatial and attribute data
- calculation of various map features (length, area etc.)
- derivation, overlay and display of new data or information from the old ones, on the basis of complex statistical and topological criteria
- neighbourhood analysis and
- ability to predict through modelling the results of various fire management strategies and interventions and also to optimise certain approaches.

It is clear from the above that geographic information systems is an efficient forest fire management support tool. Given the size and diversity of resources, the complex ecological and silvicultural consequences of fire, the huge amount of related data and information etc., geographic information systems technology can provide a mechanism of solving fire management related problems by managing complexity.

An integrated fire monitoring and management system can become a routine process with geographic information systems, as the various professionals or scientists can collect their own specialised biotic or abiotic data and values, introduce them in the system, combine and analyse them and finally identify common fire related priorities limitations trends, changes, consequences etc. which will be managed in a way to provide the maximum benefits. However, such a fire system to be operational should have the following necessary requirement:

- systematic documentation and acquisition of data,
- fire monitoring network representative of the region,
- long term systematic fire monitoring process,
- comprehensive and transferable fire databases, which will provide the possibility of aggregating certain types of data.

Post-Fire Analysis

Post-fire monitoring and analysis using remote sensing and geographic information systems technology includes identification, classification, mapping and qualitative and quantitative assessments of fire disturbances on forest and other natural ecosystems. Such procedures can be divided into two main categories: direct consequences and indirect consequences.

Direct or short term consequences

This category of post-fire disturbances is closely related to the recording and mapping of burned areas on remote sensing data and also to the assessment of forest damages.

The first case, which affects the fire management strategy, have been examined in several remote sensing studies (Anonymous 1975, Boissonneau 1975, Laachowski & Anderson 1979, Minich & Shain 1981, Mychasiw 1983, Tanaka et al. 1983, Lee & Liu 1984, Milne 1986, Chuvieco & Congalton 1988, Jakubruskas et al. 1990, Olmedo 1994, Martin et al. 1994, etc.). These studies have been conducted using either high resolution earth resources satellite (LANDSAT, SPOT etc.) data or low resolution meteorological satellite (mainly NOAA) data. The researchers reported various difficulties in locating, identifying, separating and mapping burned areas from their surroundings. Such difficulties have been related to the confusion between burned areas and shadows, slightly burned and healthy vegetation etc. However, in certain cases the reported mapping accuracy reaches 95% of the ground truth data (Hitchcock & Hoffer 1974, Benson & Briggs 1978).

Generally, satellite data can be considered the management quick and reliable source to general appropriate statistics on burned areas. However, which satellite data are the most appropriate to be used, depends on the required frequency or time interval of collection data and the scale of the monitoring level.

NOAA AVHRR data provide adequate temporal (daily) information on a regional or global scale. However, the coarse resolution gives a certain degree of generalisation which limits their usefulness especially in the case of small fires and if high mapping accuracy is required. On the other hand if the purpose of monitoring is the detection and detailed evaluation and mapping of burned areas on a monthly basis or at the end of the fire danger season or to produce statistical data of burned areas within a certain period, then the available earth resources satellites provide enough time coverage and spatial resolution. Combination of earth resources and meteorological satellite data can be complimentary and may improve the overall contribution of remote sensing technology in fire management. The role of this technology may be further improved by using SAR data of ERS-1 satellite. However, such research efforts are at the early stages and they should be seriously considered and enhanced in future projects.

Burned area estimation from satellite data can be significantly improved by incorporating, through geographic information systems, ancillary data. Actually integration of topographic data and creation of a 3-D model of the burned area landscape results in the calculation of the actual (sloped) area, instead of the projected one (Kritikos et al. 1994). Such approach has certain practical implications and benefits like more accurate statistics of burned areas, better plans for salvage logging operations, better economic calculations and treatments for artificial regeneration, preventive measures etc.

Based on the frequency and distribution of burned areas, over the years, fire sensitive terrain zone categories may be identified and mapped. These are essential information in developing a forecast of probable fire incidences and in planning various management measures aimed to better protect the forest ecosystems in the different zones. Such zonation should be established on a national and regional basis. Remote sensing and geographic information systems play a significant role in carrying out such a work.

There is no standard classification techniques and procedures applied during the analysis of remotely sensed data for identification and mapping of burned areas. They vary according to the general scope and specific objectives of the research study and the budget available (Thomson & Dixon 1975, Caetano et al. 1994, Martin et al. 1994). In recent years several investigations (Sader et al. 1989, Burgan & Hartford 1993, Ardo 1993, Martin et al. 1994) have focused their analysis utilising various vegetation indices, which seem to give acceptable results as these indices are quite sensitive to vegetation changes related to forest decline due to fire or other destructive factors.

However, the key element in the whole procedure is the spectral signatures themselves of the burned areas. Certain research results (Tanaka et al. 1983, Chuvieco & Congalton 1988, Garcia & Caselles 1991, Karteris & Kritikos 1992) indicated that there is a particular spectral behaviour of burned areas only in the non visible satellite bands, especially in band 4 and 5. However, more work is required in order to better clarify the effect of vegetation structure composition and stress, the landscape and climatic conditions and other factors on the spectral variability and trend of burned areas.

The second important case, which falls within the direct post forest fire consequences, is related to the assessment of vegetation damages. Actually, questions like what forest stands or parts of them were not burned? Which were burned? What is the fire severity? What are the total wood volume losses? etc. require well documented answers in order first to analyse the fire short or long impacts on the structure composition and extent of the forests and estimate the ecological and silvicultural disturbances and second give the appropriate information to the forest manager who is responsible for introducing certain post-fire management measures. Remote sensing data in combination with geographic information systems provides such information timely and quite accurately.

Acquisition of satellite data, especially of high resolution, shortly after the fire, permits the location of unburned vegetation within the burned area. Such information are not usually collected (depending of course on the size and pattern of the unburned areas) or well documented (e.g. maps) by the field survey mainly because of the way these surveys are conducted. So, the satellite data provide a wealth of such information, which are hot, usually available on the classical fire maps. The analysis of the satellite data and the subsequent results are restricted only by the minimum mapping unit. This is a critical point which influence not only the under discussion item, but all the post-fire information e.g. number of fires, total acreage of burned areas etc. This is why it should discussed, decided and established on a national and regional basis.

The multitemporal characteristic of satellite data permits fire managers to extent their knowledge about the vegetation damages, immediately after the fire. Classification analysis of pre-fire satellite data merging with the fire perimeter provides spatial and quantitative information about the burned forest area, categorised by forest types and certain forest species affected (Karteris & Kritikos 1992, Olmedo 1994). In addition to that, information on the levels of fire severity reveals better the degree of forest disturbances. However, such research results vary in terms of classification accuracy especially those cases related to moderate or slight level of severity. Also, the classification systems used in the analyses are not standard, as various authors propose a different number of damage categories with different or unknown qualitative and/or quantitative criteria (usually is used the percentage of tree crown damage (Jakubauskas et al. 1990, Furyayev 1991). It should be mentioned that the fewer the classification fire severity categories are, the better the accuracy of the analysis will be. Such a classification system requires thorough discussion which will improve the exchange of data and of course the communication.

Such estimations combined with digital forest management maps of the burned areas, permit the fast extraction of additional data related to the age classes, the forest compartments affected, the wood volume available, the existing road network etc. Based on the above, the forest manager can react rapidly and develop a time and spatial schedule of salvage timber logging operations, which will reduce the possible degradation of burned timber by insects, diseases etc. (Smith & Woodgate 1985). At the same time the manager can apply forest valuation approaches, calculate the total economic losses and establish timely planning of actions to correct the adverse disturbances of fires.

Indirect or long term consequences

Although the post-fire direct consequences discussed before may be considered somehow static and related to short term evaluation of the forest conditions, the indirect consequences seem to be more interesting, with a dynamic profile and long term or periodic evaluation procedures. Such consequences can be the evaluation of vegetation recovery, the forest natural regrowth, the artificial reforestation, the land degradation, the hydrological response, the atmospheric pollution, the ecological impacts in terms of modifying or affecting animal or plan species etc.

Various studies (Hall et al. 1980, Milne 1986, Lopez-Garcia & Caselles 1991, Furyayev 1991) discuss the use of satellite data and geographic information systems to monitor the sequence of post-fire effects. The multitemporal characteristic of these data enable the researchers to give acceptable answers to the above problems. Various analytical techniques have been applied in these cases. Multitemporal satellite data can be combined with physiographic, vegetative and other types of data to estimate the state and trend of vegetation recovery. It should be noticed that the controlling factors in such cases appear to be the physiographic and climatic data. After a few years of recovery the distinction of the burned area is quite difficult, except the case where the new vegetation is quite different from the surrounding, as a result of different spectral reflectance values.

The natural regrowth of the old forest stands are identified and monitored on satellite data after several years, when the new forest generation become big enough to spectrally characterise the properties of a certain number of pixels. Prior knowledge of the vegetation types improves to a certain degree the floristic enumeration. Also, the nature and the conditional the vegetation changes much easier depicted if there are available pre fire vegetation or forest management maps of the damaged area. In any case, it seems that more research attempts are needed in order to better formulate the assess of the long term post-fire vegetation recovery. Also the characterisation of the effects should be determined by developing of certain indices e.g. the relation between pre and post-fire vegetation, the frequency of the fires on the same area etc.

Destruction of vegetation cover has considerable impact on land degradation, as the unprotected soil can be eroded by heavy rains and winds. By combining multitemporal satellite data with physiographic and soil data, and conjunction with the various stages of growth as well as the distribution of patterns of the post-fire vegetation, it is possible to identify, evaluate and map areas susceptible to erosion (Pinto et al. 1993). The long term benefit of having such a database is the potential of using it at a later time and extract information regarding erosion which are not identifiable earlier (Monday & Benkelman 1993). In addition it may be used to detect changes in the vegetation appearance, due to land degradation conditions the trend of erosional status, the location of new sites which are major sources of erosion (mainly in areas where the vegetation recovery was poor) and to monitor rehabilitation measures to reduce erosion hazard.

National or even regional assessments of land degradation or desertification processes are possible only with the contribution of satellite data (Asare 1993, Zhihua 1993). However, for better study of such phenomena, the development of easily identified on the remote sensing data landscape indicators is required (Alekseyeva et al. 1991).

Hydrological responses, nutrient losses, runoff, soil moisture content etc. as post-fire consequences can be estimated through modelling, where satellite data consists a significant independent variable providing mainly spatial information.

Air pollution, in the form of smoke from fires, has an adverse effect on photosynthesis. However, as far as know, there are no reported results on using remote sensing data to estimate such post-fire effects. This case requires attention from the scientific society, because of the continuous environmental degradation of living conditions.

Contribution of geographic information systems to post-fire operations

The potential contribution of a geographic information system is to evaluate the role fire plays in forest ecosystems. As it was mentioned before, within the framework of a Fire Monitoring and Management System geographic information systems facilities the analysis of fire impacts. It is considered as a very promising tool for inventorying, monitoring and analysing post-fire vegetation recovery, other short or long term effects and management alternatives.

Detection of various severity spatial patterns and consideration of them with other data layers stored in the geographic information systems database, such as wood volume classes, slope and aspect distribution, road and logging train network, administration and forest compartment boundaries, location of reserve areas etc., allows the forest managers to have a quick valuation of the fire ecological and economical losses and in turn to plan the liquidation measures of the damaged timber.

By simulating post-fire conditions, forest managers can examine and evaluate certain preventive options and judge various assumptions. Reallocation of forest emergency services, in order to establish a spatially optimum network, which minimise the initial attack time requires quite a large number of data, which can be handled only within a geographic information system. With this tool managers can depict various management zones, where different rehabilitation measures and other post-fire strategies can be employed.

The perspective that geographic information systems opens, permits the managers to create additional sets of data related to social and economical implications fires have raised. Also geographic information systems fire models give better insights by linking such decisions with the best available knowledge of fire effects on the ecosystems. Geographic information systems functionality allows operations of complex sets of post-fire data and interactions on micro and macro scale (local, regional or global). Also, it allows integration of fire related diverse data from various organisations over long distances. As the pertinent post-fire related data are voluminous and heterogeneous, only proper development of a geographic information system database, with temporal and spatial completeness and easy and unconditional access by the decision makers, will assist the formulation of post-fire or generally the forest fire policy on national and international level.

CONCLUSIONS

Remote sensing and especially satellite data properly combined, through geographic information systems, with other ancillary (terrain, climatic etc.) data, can provide rapid and economic means of inventorying, evaluating and mapping forest fire damages, vegetation succession, rehabilitation activities etc.

The successful results of such approach suitably justified, will allow the adoption of this technology on an operational basis in all Mediterranean countries.

Remote sensing and geographic information systems technology provides better information on the problems generated by forest fires. But better information means better future. So, let's use this technology.

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