EVALUATION OF FOREST FIRE EFFECTS USING CASI (COMPACT AIRBORNE SPECTROGRAPHIC IMAGER) DATA

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ABSTRACT

In recent years, there has been a large number of forest fire studies to determine the affected areas by remotely sensed data (Arbiol et al., 1987, Chuvieco and Congalton, 1988). However in this paper we have introduced new ideas about data acquisition by means of a CASI sensor in order to obtain high spectral and spatial resolution of affected areas. The use of this sensor was efficient both in data acquisition and processing.

The CASI sensor characteristics were essential to fulfil the main objective of this study that was focused on the quick detection of burnt land cover of fires in Catalonia (Spain) in the summer of 1994. Particularly in this summer the number of forest fires increased spectacularly to lead to a catastrophic situation.

The process was developed in three parts. First, the acquisition images form CASI sensor, and LANDSAT-TM and/or SPOT-HRV always it was possible. Then, image classifications of burnt areas with different methods PCA, MLIS, NVDI and nPDF and combined with them. And the last step, the burnt areas were merged with land cover database of ICC to evaluated the damage situation.

Encouraging results have been obtained using CASI, not only due to the production of data achieved, but also to the radiometric quality of the information, that will allow the regeneration and restoration of burnt areas to be monitored.

INTRODUCTION

In the Mediterranean climate zones, the critically hot conditions and limited rains during the summer months combine with negligent human activities to cause many fires every year.

Both local and regional administrations need to know the exact impact of these fires for subsequent management. However, an accurate evaluation of damage based on traditional field work becomes very expensive and requires a long time.

In Catalonia (Mediterranean region in North-Eastern Spain), where these fires occur with varying degrees of frequency every year, the Government has been interested in receiving annual data about the surfaces of burnt areas by means of multispectral classification of Landsat and Spot images. Since 1984, the Government of Catalonia has signed an annual agreement with the Cartographic Institute of Catalonia (ICC) to undertake this study. By following this strategy based on remote satellite imagery, the final results have been obtained too late to immediately apply policies for subsidies of fire damages. The delay specially came from the selection and acquisition of remote images. Besides this, there were occasions when the limited impact of fires (less than 100 ha) or poor quality of Landsat and Spot images, particularly with forest regeneration, or when affected by cloud cover, meant that the final evaluations were not sufficiently satisfactory.

In the summer of 1994, forest fires increased spectacularly, totalling more than 50 and most of them occurred in a short period of time during July and August. This led to an extremely catastrophic situation in political, socio-economic and ecological terms. In such a situation the Environmental Department of Government signed a new agreement with the ICC, under the name FOCS'94, to study the fire effects using data produced in a short period of time. To achieve these objectives a new approach based on airborne multispectral imagery was considered.

The data acquisition process was carried out by using a CASI (Compact Airborne Spectrographic Imager) sensor in order to assure an overall coverage of burnt areas. The CASI was installed in an aircraft of the ICC which made a flight just after each fire. This sensor is an airborne pushbroom imaging spectrograph that collects high resolution data. It is programmable for selective acquisition of multispectral images in a digital format onto exabyte tapes.

Additional data has been acquired from TM Landsat and XS SPOT imagery. These satellite data will help to complete information about affected areas.

Four non-exclusive image classification methods were used to determine the boundaries and types of burnt areas. The results of classification data have been compared and merged to improve the area determinations.

Finally, the studied surfaces were introduced into a digital Inventory of Burnt Land Cover Database and combined with topographic information and affected land uses.

The last key contribution of this study lies in a rapid timing procedure. The CASI sensor plays an important role by reducing the process of data acquisition to a few hours.

OBJECTIVES

The main purpose of this study was to measure and classify the burnt areas reducing the total process time and the information quality. To be exact, these were the objectives:

1. Acquisition of high spectral and spatial resolution information from every fire by means of an aerial campaign carried out with a CASI sensor.

2. Fast mapping and accounting of burnt area from SPOT-XS, LANDSAT-TM or CASI imagery.

3. Damage evaluation by comparison of burnt areas with a 1992 land use database.

4. Determination of fire impact from CASI imagery, as a starting point for developing a rational policy in the restoration of natural landscapes.

It is a central hypothesis that the acquisition of images from CASI will guarantee quick results and improve the quality of information.

THE CASI SENSOR

CASI is an airborne bi-dimensional sensor that records, according to different user needs, spectral and spatial information. The sensor has a pushbroom imaging spectrograph based on a CCD array with an optical system which collects each line of information (*scanlines*).

Some fixed parameters determine the registered information. By this means, the CASI sensor of the ICC works within a spectral range between 403 nm in the blue region and 917 nm in the infrared region. This spectral area can be subdivided into 288 bands with an average width of 1.8 nm per band. The optical system has focal lens of 10 mm, a field of view of 42.05, and a f-stop aperture between 2.8 and 11 (with 5 positions).

Each scanline taken on the terrain has 512 pixels containing spectral information. The pixel width across the track depends on the flight height and focal width. The pixel length along the track depends on two variables, the speed of the plane and the integration time, defined as the minimum time the sensor needs to capture information for a maximum number of spectral bands maintaining the pixel size.

Due to these considerations the sensor works in two ways: spectral mode and spatial mode. In spectral mode, up to 39 columns (*look directions*) of the CCD can be selected to obtain information of the 288 bands (1.8 nm width). This operating mode is used to extract curves on spectral features of the land. In spatial mode, the user can select up to 19 bands without overlap and specify the limits of each one. This operating mode is the most commonly used and is the one employed in this particular study.

Radiometric CASI data is collected in electronic DNs with 12 bits (digital numbers between 0 and 4,096), and a subsequent calibration process transformed them in SRU (Spectral Radiance Units = $1{:}W{*}cm^{-2}{*}sr^{-1}{*}nm^{-1}$) mapped to 8 bits by using a *peak* SRU (=255) (Babey and Anger, 1989).

Other characteristics that could be taken into account is the low cost and rapid acquisition of multispectral imagery with this sensor. The minimum hardware system requires video display, instrument control unit, sensor head, vertical gyroscope and GPS receiver that can be put on board easily and quickly. If the studies need good geocorrected images to introduce them on a GIS (Geographic Information System), it is preferable to integrate an inertial navigation system (INS). However, that could increase the cost considerably (Cosandier et al., 1993).

THE STUDY AREA

The burnt areas of the study are located in Catalonia (32,000 Km2) in the North-East of the Spain. The majority of the region has a typical Mediterranean climate. This biogeographical area contains the natural conditions and human factors to be prone to cyclical fires.

In the summer of 1994, a great number of forestry

zones, -some of them, protected areas- were devastated. This study considered 54 fires with an impact of more than 50 ha, covering a total area of over 80,000 ha.

The dominant vegetation of burnt areas was coniferous forests of *Pinus halepensis* or *Pinus pinea* and sclerophyllous forests of *Quercus ilex* and *Quercus suber*. In some cases the fire occurred in previously

burnt areas that were only covered by scrub and grassland. Most of these areas are situated in mountains or hills with a moderate or steep relief. The remaining affected landscapes were agricultural land and under-populated areas.

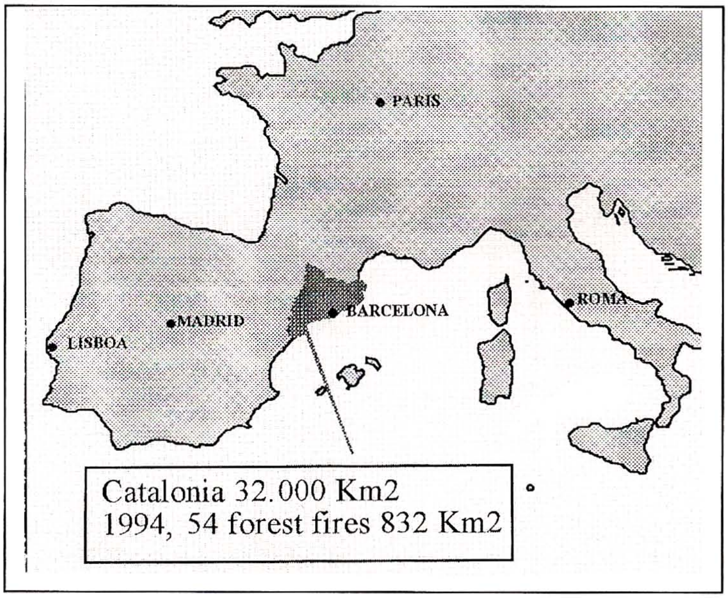

Figure 1 - « Location of Catalonia in the context of the western Mediterranean area ».

MULTISPECTRAL DATA ACQUISITION

Landsat TM data were acquired on 6 June and 25 August 1994 and Spot XS multispectral data on 10 July, and 8, 11 and 16 August 1994. These images were taken several days or weeks after the fires without cloud cover.

In order to capture CASI data, the ICC planned the same configuration bands and flight parameters for all fires. The spatial mode was selected with the «general» bandset configuration of 14 bands. This bandset had been tested during spring over vegetated areas with good results to distinguish classes or evolution stages of vegetation.

To obtain a spatial resolution of 10 x 10 m the ground speed of the aircraft was 242.72 Knt, the flight altitude was 27,301 feet and the integration time was 80 milliseconds.

The flight campaign was carried out with CASI installed on board the ICC aircraft simultaneously gathering image and GPS data. Data over 54 burnt areas were collected from 13 April to 15 November 1994.
In table 1 it is possible to confirm that the CASI sensor has improved the acquisition data operation in different ways; in radiometric and spatial resolution and acquisition availability.

METHODOLOGY

1. Geometric correction and radiometric analysis

Landsat TM and Spot XS images were geocoded with a second-degree polynomial function -derived from a collection of ground control points (GCPs of digital ICC orthophotomaps on a scale of 1:25,000) located in each image using a semiautomatic process- calculating the polynomial coefficients. The RMS was approximately less than one pixel (30 m for Landsat TM and 20 m for Spot XS). The images were rectified using the nearest-neighbour spatial method to retain radiometric integrity.

Table 1 - Comparative data collected by CASI, Landsat TM and Spot XS for this study.

	CASI	LANDSAT-TM	SPOT-XS
Spectral configuration (nm)	band 1 446.1- 453.2 band 2 477.8- 484.9 band 3 497.3- 504.4 band 4 527.5- 534.6 band 5 547.0- 554.2 band 6 564.8- 572.0 band 7 597.0- 604.2 band 8 622.1- 629.3 band 9 647.3- 654.4 band 10 674.2- 683.2 band 11 708.5- 715.7 band 12 746.4- 755.5 band 13 800.8- 808.0 band 1 4 844.3- 851.6	TM1 450 - 520 TM2 520 - 600 TM3 630 - 690 TM4 760 - 900 TM5 1550 - 1750 TM7 2080 - 2350	XS1 500 - 590 XS2 610 - 680 XS3 790 - 890
Pixel size	10 x 10 m	30 x 30 m	20 x 20 m
Image acquisition	54 images collected on the following dates: 13-04-94, 16-08-94, 17-08-94, 18-08-94, 19-08-94, 23-08-94, 31-08-94, 02-09-94, 26-09-94, 24-10-94, 08-11-94, 15-11-94.	2 scenes: 198031/6-6 198031/25-8	8 scenes: 042265/8-8, 042266/8-8, 043267/16-8, 044265/10-7, 044266/10-7, 044267/16-8, 045266/11-8, 045267/11-8.
Availability of image acquisition	Shortly after each fire or group of fires occurred.	Time frequency in good atmospheric conditions is 16-18 days after the last image.	Time frequency in good atmospheric conditions is 26 days after the last image.

The images captured by CASI sensor are affected by aircraft motion. Attitude data are needed in order to correct its effects. For this purpose, a vertical gyroscope is available. Pitch and roll are taken in each registered scanline. The yaw angle cannot be measured. Yaw angle estimation is calculated on the basis of GPS data. Sensor position data are needed too. The CASI system uses an onboard ASTECH GPS receiver. Since the precision of GPS data taken from the plane is low (50-100 m), a differential correction is needed to improve this precision (< 1m). This new accuracy is obtained by combining the position data of airborne and stationary GPS.

The geocoding CASI software uses both position and attitude data to rectify each scanline. Reference map co-ordinates (UTM projection) are required in this process. In this way geometrical distortions are removed and the image pixels are relocated in a geographical co-ordinate system. Remaining distortions and errors were detected comparing the images with orthophotomaps, and some problems appeared while mosaicking them.

To improve results, the ICC has developed a geometrical model to simultaneously take into account ground control points, attitude and position data. This model was solved by a least squares adjustment. Then the rectification is made by nearest-neighbour and DTM (Digital Terrain Model). At the end the geocoding RMS was in the range of 1.5 to 2.5 pixels depending on the flight altitude. This error is mainly produced by the low precision of the attitude data measured by the current gyroscope. In the near future, the ICC expects to improve the geocoding process by using an Inertial Navigation System (INS).

When a fire is recorded with more than one path, it is necessary to mosaic different images. In many cases, path to path co-registration based on common points was applied to reduce the remaining geocoding distortions. As an example, figure 2 shows a mosaic of CASI images in a mountainous landscape with satisfactory results.

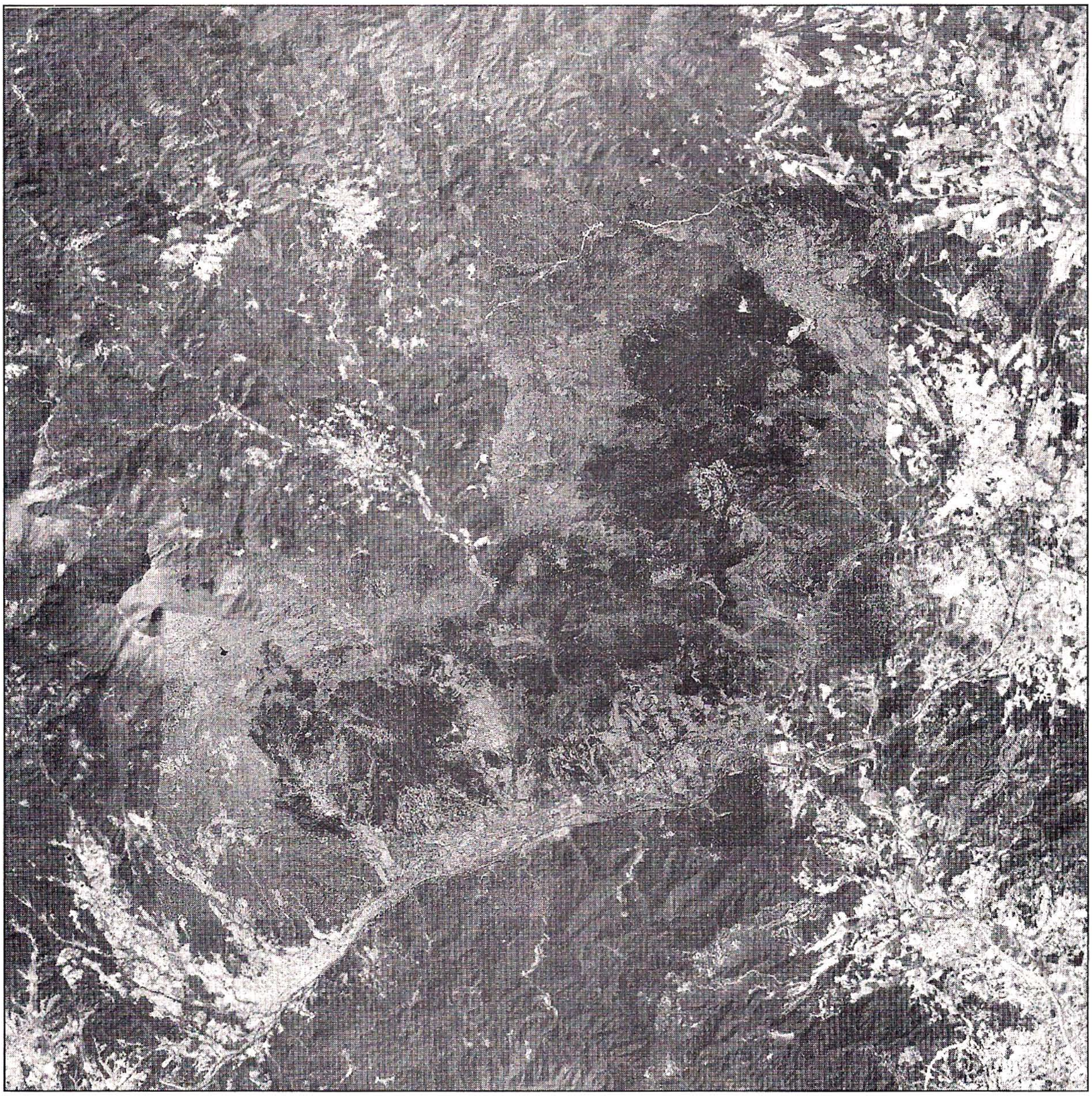

Figure 2 - An example of a forest fire in the Montseny area that occurred on 10 August 1994. False colour multispectral image obtained from CASI (channels 12,11,10 and spatial resolution of 10 m) after applying ICC geometric correction and mosaicking of 7 flight paths. The mosaic is framed on a black and white TM image (spatial resolution 30 m). Scale: 1/150000.

See Plate XI at end of volume

No atmospheric corrections were performed in the radiometric calibration of data.

CASI original data (electronic DN, 12 bit) is calibrated and remapped to 8 bit using a single *peak* SRU for all bands ranging between 11 and 13 SRU according to the flight path.

This peak SRU is calculated in band 12, situated in the infrared spectral region to optimise all vegetation information. The radiance range is between 0 and the peak SRU value. Although this range is unsuitable for studying reflective areas, because they would be saturated, it obtains more detail in the dynamic range of the vegetation response (Baulies and Pons, 1994). On the other hand, with Landsat TM or SPOT the peak of radiance is high in order to avoid the saturation level and, therefore, the spectral information of vegetation is poorer.

2. Classification of burnt areas

Most fire classifications could be made with different images. The selection of one particular image depended on the dimensions of the fire and the quality of the images.

The fires over a relatively small area covered by one or two CASI flight paths, were studied with CASI images, whereas the biggest fires were studied using SPOT or TM images. Spatial and radiometric resolution of CASI data improved results in the case of small fires. On the other hand, remote images are appropriate for large fires to avoid making mosaics with CASI images. For instance, the Berga-Manresa (38,978.55 ha) fire was recorded with ten flight paths of CASI but the information from these flights was not used because mosaic process was time-consuming. For this reason the study was carried out using two SPOT images. In this case CASI data was only used to make a visual check of doubtful areas.

Sometimes this selection of images could not be made following this strategy. This was the case of the large fire that occurred in the Montseny (9,048.87 ha) area in July. The remote sensing images could not be used because the first available one had abundant cloud cover; furthermore, the following week it rained, and grass cover invaded the entire burnt area, thus rendering the subsequent images of little use. This study was made with seven paths of CASI images obtained the day after the fire. The work was more labourious due to the radiometric and mosaic processes, but the results were more precise in terms of burnt area identification.

The fires occurred in different circumstances, that is to say, different kinds of vegetated surfaces, atmospheric conditions, topographic effects, surface impacts, annual seasons, etc. The classification of burnt areas was approached using the following four different non-exclusive methods depending on the above-mentioned circumstances:

1.- Principal Components Analysis (PCA) was used to reduce spectral redundancy and discriminate the different spectral information. Normally the first and second components are the best ones to distinguish the fire effects.

2.- Maximum Likelihood Image Segmentation (MLIS) unsupervised provided classes defined by spectral centres, grouping pixels with similar values. After a visual interpretation between the image and classification some classes were selected to indicate the burnt area. Usually this method was used after PCA when the different intensities of the fires, or to the later acquisition of images, the burnt terrain showed initial herbaceous recuperation and the classification is more difficult (Siljestr_rm and Moreno, 1995).

3.- Normalised Different Vegetation Index (NDVI=(IR-R)/(IR+R)), concept of Kriegler et al, 1969) has a range of between -1 and 1, and a critical threshold of 0.2 for vegetation cover (Chuvieco, 1990). This approach was used to identify the different degrees of intensity of the fires. NVDI is also introduced in multitemporal analysis to distinguish the fire area according to the index differences (Marcheti et al., 1995).

4.- The n-Dimensional Probability Function (nPDF) procedure transforms the original spectral data into new hyper-spectral distance bands. In nPDF data transformation, output bands are calculated by determining the hyper-spectral distance from each pixel to selected corners in the data space using the equation: (Cetin & Levandowski, 1993)

$$nPDF_i = S * D_i / (2^{BIT} * NB^{1/2})$$

where

$nPDF_i$ = component i of nPDF,
i = corner number,
S = desired scale for the nPDF axes,
D_i = calculated distance for component i,
BIT = number of bits of input data, and
NB = number of bands used

The nPDF classifier was quicker than other classifiers when processing a large volume of information, as was the case with CASI images of 14 bands. Furthermore, the detection of burnt cover was excellent in several calculated bands.

Finally, in the majority of cases the results of two or more methods were merged in order to optimise the study area. It was also possible to gain greater precision by combining the graphics of affected areas and removing the remaining pixels.

3.Inventory of Burnt Land Cover Database

Since 1992, the ICC has taken advantage of a digital database of land use and land cover (Land Cover Data Base of Catalonia) with 20 categories and a spatial resolution of 30 m. This information has served as a basis to create a Inventory of Burnt Land Cover Database which includes 12 categories grouped into three kinds of thematic areas:

Forests and semi-natural areas: Bare rocks, deciduous forest, sclerophyllous forest, coniferous forest, scrub, grassland and burnt areas (1991 and 1992).

Agricultural areas: Non-irrigated arable land, irrigated herbaceous crops, vineyards, non-irrigated fruit trees and irrigated fruit trees.

Artificial areas: Residential or scattered urban areas (located in forest areas mainly).
Finally, the burnt surfaces were introduced into a GIS and compared with data from a Topographic Data Base (1:50,000). In this way, the burnt areas were integrated with the transport networks (roads, railway, etc.), urban systems, relief effects, and a diversity of topographic variables.

This mixed topographic information will help to provide an understanding of the possible reasons for the beginning of the fire. Moreover, it serves as a valuable instrument in planning the next actions to be taken in these areas.

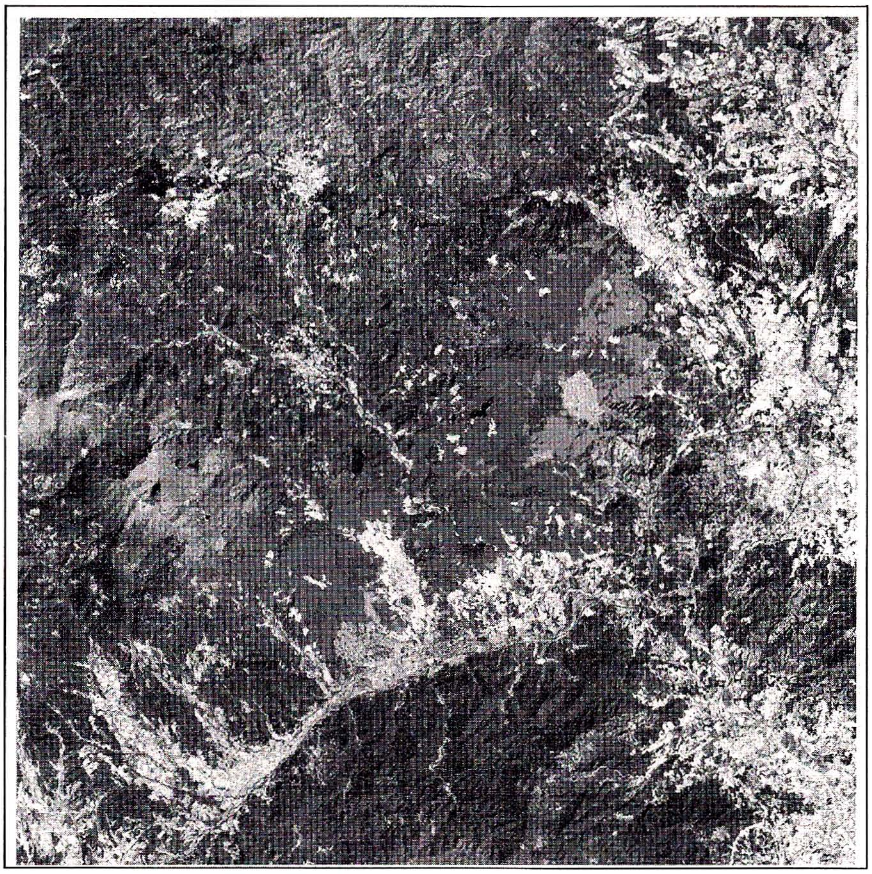

Figure 3a - The burnt area of the Monseny merged with affected land use and land cover information.

See plate XII at end of volume

RESULTS AND DISCUSSION

Table 2 contains the time scheme of three sensors used to acquire multispectral data. The CASI ,TM and SPOT times of data acquisition were remarkably different.

All flights of CASI started and finished in Prat Airport (near Barcelona), and the longest return journey time made by the Cessna Citation plane into Catalonia was no longer than 50 minutes, plus approximately 10 minutes for each flight path. 70 % of recorded fires needed one single path which never exceeded 60 minutes. However, in most cases groups of fires were recorded by the same flight in order to save time and money.

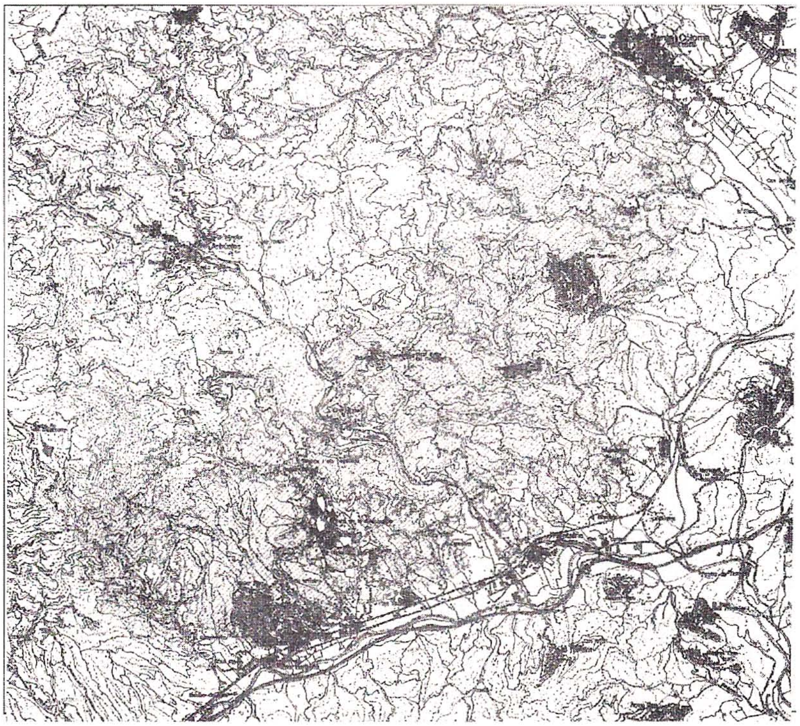

Figure 3b - The burnt area of the Montseny merged with topographic information

See plate XII at end of volume

Acquisition of the remote images of the same areas was more difficult with Landsat or Spot sensors, because the cycle of these satellites was very long, and good weather conditions were not always available. Then, after the image was selected, it was necessary to wait 15-20 days before receiving the digital tape.

With respect to the fire classification time, it is evident that the image acquisition time was fundamental factor in achieving a fast mapping process. All other stages - geometric correction, classification and damage evaluation- required similar times.

Table 2 - Timing scheme of fire classification process.

Sensors Stages	CASI (One path)	CASI (seven paths)	LANDSAT TM	SPOT XS
Image acquisition	1.00 hour	3.30 hours	15-20 days	15-20 days
Geometric correction	0.30 hour	1.30 hour	0.45 hour	1.00 hour
Classification	0.15 hour	0.30 hour	0.25 hour	0.25 hour
Evaluation of burnt land cover	0.20 hour	0.40 hour	0.30 hour	0.30 hour

On the other hand, considering that ICC owns both hardware and software components of the CASI system, it would be more expensive to buy remote sensing images. For example, one hour using the Cessna Citation plane with the CASI sensor cost about \$2,000, while a SPOT programmed image costs between \$2,500 to \$8,000, and a TM full scene costs approximately \$5,000. During the ICC aerial campaign 12 flight were made covering 54 fires, which cost about \$45,000, a smaller sum than the total cost of remote sensing images acquired for only a few fires.

Even though the remote sensing images would be used for other purposes, it is not the object of this study.

With relation to the spectral data quality, the reflectance values were not used. If the atmospheric and radiometric corrections were made in the three types of images, the whole process would be delayed. In addition, in the majority of cases it would not be possible to find all the physical information to guarantee correct reflectance, because the images corresponded to different days and areas. In this particular summer, the atmospheric conditions could change completely in a short period of time. These atmospheric variations were due to the fires themselves with the smoke, ashes and air currents they produced. For all these reasons it was not possible to consider undertaking field work to collect physical data. Despite this, it was possible to discriminate without any problems between burnt areas and vegetated areas using radiance values for CASI images and original DNs for TM and SPOT images.

Table 3 shows a comparison between burnt surfaces estimated by the fire brigade, based on a quick visual identification drawn on a topographic map, and the same surfaces calculated with multispectral data by the ICC. There are some important differences between these two methods that can exceed 50 %.

Table 3 - Some examples of fire surfaces estimated by the fire brigade and then calculated with multispectral data by the ICC.

FIRE LOCATIONS	Burnt surfaces estimated by the fire brigade (ha)	Burnt surfaces calculated by the ICC		
		ha	Place according to size of fires	Sensor model
GARRAF	4000	4593	4	CASI
MONTSENY	9100	9048	2	CASI
MARGALEF	1255	1770	9	SPOT
PRATS de LLUÇANES	480	231	25	SPOT
LA BISBAL de FALSET	100	83	48	CASI
MANRESA-BERGA	23000	38978	1	SPOT
Serrelada de St. MATEU	460	898	13	LANDSAT
OLESA de MONTSERRAT	60	41	54	LANDSAT

Pixel resolutions of 30 m or 20 m of remote images gave less powerful discrimination results than CASI images. The advantages of the high spatial resolution of CASI were detected in two ways. Firstly, the burnt area perimeter was more accurate, and the number of homogeneous pixels was higher.

CONCLUSIONS

Studies of environmental impacts of the nature of FOCS'94 that map the impact areas of fires rapidly and accurately represent the first step towards developing restoration management.

There are great advantages in using an airborne multispectral sensor such as CASI to develop this kind of study. Firstly, with respect to the period of data acquisition, since it is possible to fly over the affected area the day immediately after the fire, if the atmospheric conditions so allow. It is especially important to detect the affected vegetation before this vegetation begins to regenerate. Secondly, the high spatial and spectral resolution in comparison with remote sensing sensors enables both the geographic and thematic quality to be improved and permits subsequent merging with GIS databases.

The use of a multiple approach based on four classification methods - PCA, MLIS, NVDI and nPDF facilitates the detection of the burnt areas in any situation. That means, the best study has been to combine the four classifiers and, after interpretation with the original image, remove the uncorrected burnt areas.

As a final conclusion, this experience shows the potential of a calculated strategy in order to obtain sensitive data in a short period of time. This becomes an essential component of a rational approach to fire mapping in Catalonia, and it may be applied on a regional scale in other countries of the Mediterranean area.

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