Modern Environmental Science and Engineering (ISSN 2333-2581)
November 2020, Volume 6, No. 11, pp. 1147-1156
Doi: 10.15341/mese(2333-2581)/11.06.2020/001
Academic Star Publishing Company, 2020
www.academicstar.us

An Analysis of Burned Areas in the Region of Cantabria, Northern Spain: 2016-2017

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Abstract: Mapping the burned areas in Cantabria (Spain) is an arduous task, mainly due to its complex orography, with hard-to-reach areas, and the existence of a large number of fires occurring in a short period of time. These amount to an average of 650 fires and 8,500 hectares burned annually for the reference period 2006-2015. The use of sensors on board satellites provides important advantages for the detection of burned areas. The incorporation of new earth observation satellites within the framework of the European Space Agency's Copernicus program makes it possible to implement an operating system for determining burned areas from earth observation data. The Directorate General for the Natural Environment of the Government of Cantabria in collaboration with the company ITD Medioambiente, with its "Project for the Analysis and Quantification of the Condition of Forest Fires Through Sensors Aboard Satellites", has developed a methodology for mapping of the surfaces burned in the region during the period 2016-2017. An evaluation has been made of the reliability obtained through statistical on-site sampling. The results have been compared with those obtained using traditional methods. In addition, the link between the mapping obtained and the number of forest fires has been analyzed.

Key words: remote sensing, burned areas, sentinel, Copernicus, processing level, L1C, Cantabria, image processing, parallel programming, C/C++

1. Introduction

The Autonomous Community of Cantabria is a region in the northern of Spain, in Cantabrian Mountains (from 0 to 2600 m); with 120 km of coastline, with an average of 1200 mm of rainfall and 14°C temperature. These conditions are favorable for forests (67% of land are forests, shrubland and grasslands). Cantabria has an area of 5,321 km^2 of which forest fires burn more than 6,000 ha every year. This poses a serious threat to the conservation of natural ecosystems. By leaving the soil devoid of vegetation or causing its serious decline, in most cases repeated fires induce and accelerate soil degradation (loss of fertility, acidification, etc.) phenomena that seriously deteriorate the health of the ecosystem and compromise its persistence.

Most of the territory of Cantabria is susceptible to the passage of forest fires. A large portion of the area burned each year requires restoration and/or reforestation measures in order to prevent incipient erosion phenomena and avoid the deterioration of the affected ecosystems. In order to identify where to focus actions and carry out an adequate distribution of resources, preference should be given to areas where this restoration work should be carried out as a priority. Some of the fires affect ecosystems that require urgent environmental restoration measures to prevent deterioration after the passage of fire. In some of these cases rapid intervention is decisive to avoid the loss of soil fertility and habitat impoverishment that may be irreversible.

Due to the seasonal characteristics of forest fires in Cantabria, most of them, linked to southern wind

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phenomena and particular climatic conditions, occur in large numbers and are concentrated in short periods of time. Thus, in the winter months and early spring a large number of forest fires are spread throughout the territory.

Within the framework of the project *Analysis and quantification of the condition of forest fires by satellite sensors* conducted by the Directorate General of the Natural Environment of the Government of Cantabria (DGMN), all fires that occurred during 2016-2017 were monitored during the period 01/06/2016–31/05/2017, with resulting reports drawn up for the most relevant fires.

Mapping the burned areas in Cantabria is an arduous task, mainly due to its complex orography, with surface areas difficult to access and the existence of a large number of fires occurring in a short period of time.

The use of sensors on board satellites provides important advantages for the detection of burned areas. These include the ability of these sensors to capture energy from regions of the electromagnetic spectrum not "visible" to our eyes, but sensitive to burned areas; the capacity to periodically revisit any given point of the territory and the possibility of harmonizing an objective methodology for the whole territory of Cantabria.

On the other hand, as contemplated in the Strategic Plan for the Prevention and Fight against Forest Fires in Cantabria (PEPLIF), forest fires are a major environmental problem in the region, and reversing the current situation is a priority for the Government of Cantabria and a responsibility for society as a whole.

The document provides for specific action to improve the mapping of burned areas: "ACTION_3.1.3: Incorporate remote sensing techniques to support the annual mapping of burned surfaces and the controlled burns carried out".

Therefore, the main objective of this project is to evaluate the potential of data from certain earth observation satellites to determine the areas burned across the territory of Cantabria from an operational perspective.

For this purpose, all the areas burned throughout Cantabria were identified for the period 01/06/2016-31/05/2017. Once the mapping of the burnt areas was obtained, a reliability analysis of the spatial results obtained through field sampling was carried out.

The spectral data used comes from ESA's (*European Space* Agency) Sentinel-2 Earth Observation Mission. Data from NASA's (*National Aeronautics and Space Administration)* Landsat 7 and 8 space missions were also used to identify burned areas and assign dates to the fires.

2. Material and Methods

Data from three sensors installed on three satellites, namely the Operational Land Imager (OLI) and Enhanced Thematic Mapper Plus (ETM+) sensors, installed on Landsat 8 and Landsat 7 (managed by the National Aeronautics and Space Administration-NASA and the United States Geological Survey-USGS) and the Multispectral Instrument (MSI) sensor aboard the Sentinel-2A satellite included in ESA's (*European Space Agency*) Copernicus program were used to determine the burned areas. The identification of burned surfaces was carried out through the data captured by the MSI sensor, while those from the OLI and ETM+ sensor were used as auxiliary information for certain processes within the technical procedure used.

The availability of data captured by OLI sensor, ETM+ (Tables 1 & 2) and MSI (Tables 2 & 3) is variable per month in the territory of Cantabria for the duration of the project from 2016 to 2017.

The data for the two Landsat 7 and 8 platforms (Tables 1 & 2) have a 16-day revisit period. This obtains data corresponding to the entire territory of Cantabria for grid 202-30 of the WRS-2 (*Worldwide Reference System 2*) every 16 days and from the eastern half for the 201-30 grid with an 8-day offset with respect to the previous one. Thus, 90 images corresponding to these sensors have been processed during the study, of which 60 have been shown useful for the purpose of the project. The Sentinel-2 platform data (Tables 2 & 3) with a 10-day revisit period (for the last quarter of 2017 this period will be halved due to the incorporation of a new satellite). This obtains data corresponding to the entire territory of Cantabria that come from the UN, VN, UP and VP grids. Thus, 26 images corresponding to this sensor have been processed during the study period, of which 19 have been shown useful for the object of the project.

Sentinel L2A data is inaccurate in situations of high slopes and mountainous terrain. This situation most probably derives from the use of a digital terrain model with a resolution much higher than the size of Sentinel 2 pixel used in the L2A product available for download [7]. For this reason, L1C level data have been used and are subsequently processed. The Landsat data used are L1GT level and are also processed.

These data have been processed to obtain the corrected surface reflectance of the ground lighting effects. A C/C++ language processing chain has been implemented to that effect using multi-node technology. This allows corrections to be accurately carried out on a large volume of information during the course of the project.

In general terms, the starting point was a level of data processing corresponding to the Top of Atmosphere (TOA) spectral radiances. Obtaining Bottom of Atmosphere (BOA) reflectances from TOA radiances has been carried out using the DOS3 model [9], applying the following equations for the calculation of atmospheric transmittance T_z.

$$T_z = s \exp(-tau_r/\cos\text{-}z_z)$$

where,

z_z is the solar overhead angle and tau_r is the optical thickness of Rayleigh scattering [11]

$$tau_r = 0.008569\lambda^{-4} (1 + 0.0113\lambda^{-2} + 0.00013\lambda^{-4})$$

where,

λ is the center wavelength of each band.

$$\rho = \{(L_{sat} - L_{haze})\pi d^2\}/\{E_0 \cos\theta_z T_z\}$$

where,

ρ is the BOA reflectance; L_{haze} is the radiant path (calima), d is the earth-sun distance in AU and E_0 is the exoathmospheric solar radiance.

$$L_{haze} = Rad_{min} - (0.01E_0 \cos\theta_z T_z)/\pi d^2$$

where,

Rad_{min} is the minimum radiance detected over selected deep land-based areas of water within the geographical environment of the study area. BOA reflectance has been normalized to mitigate the effects due to the gradient of ground lighting [6].

$$\rho_{h,i} = \rho_T (\cos\theta_i + C_k)/(IL + C_k)$$

where,

$$IL = \cos\theta_i \cos\theta_p + \text{sen}\theta_i\, \text{sen}\theta_p \cos(\Phi_a - \Phi_o)$$

$$C_k = (b_k/m_k)$$

$$\rho_T = b_k + m_k IL$$

$$m_k = \{n\Sigma IL\, \rho_T - (\Sigma IL)(\Sigma\rho_T)\}/\{\Sigma IL^2 - (\Sigma IL)^2\}$$

$$b_k = \{\Sigma\rho_T - m_k(\Sigma IL)\}/n$$

where,

$\rho_{h,i}$ is the corrected BOA reflectance; ρ_T is the uncorrected BOA reflectance; θ_i is the solar overhead angle; θ_p is the angle of slope; Φ_a is the solar azimuth angle and Φ_o is the orientation angle of the slope.

MSI data were used to map the burned areas. For this purpose, the NBR (*Normalized Burn Ratio*) index was calculated using the spectral bands for NIR B8 (842 nm) and SWIR B12 (2190 nm).

$$NBR = (B8 - B12)/(B8 + B12)$$

Burned areas were detected using a multi-temporal analysis of MSI data. The NBR index was applied to differentiate between consecutive images. In a first phase, on surfaces where a significant drop in the index (with surfaces greater than 1 ha) was determined, a frequency histogram analysis was performed to establish the cut-off threshold for the determination of the burned area. Where cloud cover did not allow the use of consecutive images, the one with the closest data in time was chosen.

The areas determined in this first phase have been filtered by using the information of the visible bands to detect those areas that correspond to vegetation clearings (with a spectral signal that differs from the burned areas).

In a third phase, a geographical quality control was applied over each of the areas permitting the detection of inaccuracies in the georeferencing of MSI images (usually 1-pixel offset). This quality control process has used the most up-to-date aerial orthophotography provided by the PNOA (*National Air Orthophotograph Plan*) that has been used as the basis for the correction of displacements.

In some cases, fire detection data was used to locate some of the burned areas. The data was provided by the DGMN. For the most part, burned areas were identified through the recording of multi-temporal changes in the NBR index. However, in some particular cases (surface fires under forest cover, shaded areas, etc.) the detections provided by the DGMN made it possible to locate burned areas not detected through MSI data.

In a final phase, each of the mapped burned areas was assigned a fire code, associated with the database used by the DGMN for administrative control. This was made possible through the estimated location provided by the DGMN for some of the fires. It also made it possible to detect those burned areas resulting from a prescribed burn.

The dates of the fire were assigned using the MSI data described and the false color compound 753 (OLI) and 742 (ETM+). This information has made it possible to establish a period determined by two dates between which the fire has occurred. This period is defined by the last available image in which the burned area was not detected and the first image in which it was detected.

In order to ascertain the reliability of the method used for identifying burned areas, field sampling was designed to ascertain the ground truth so as to establish a relationship with the results obtained.

The purpose of this test is to check at certain randomly chosen points on the ground whether or not the area has been burned and moreover, through a confusion matrix, to determine possible conflicts and the reliability of the classification process.

To this end, for the purposes of selecting the areas of the territory in which to carry out the sampling, the variables related to the nature of the territory that have the greatest impact on the reliability of the method used have been identified “a priori”. It is estimated that these are, essentially, the radiance emitted by the soil and the time of greatest frequency of fire.

Based on these two variables, two municipalities were selected. On the one hand, the municipality of San Roque de Riomiera, an extreme case in terms of its orographic conditions and the time of maximum influx of fires in the winter, which results in general conditions of extreme irregularity in terms of lighting, and therefore radiant energy, reflected by the ground. On the other hand, the municipality of Cabuérniga has its peak fire season in early spring, which, together with the less abrupt orographic conditions, makes for more favorable “a priori” conditions.

In this way a random non-aligned sampling is designed as follows through a GIS (*Geographic Information System*): a mesh with a random start of 1 km on each side is generated over the whole territory; a randomly distributed point is generated within this mesh, generating 1 point per square defined by the mesh; and a mask of the area defined as forest land according to the Spanish Forestry Map is superimposed, in such a way that all points that are not within forest land are discarded.

Thus, by using a systematic non-aligned sampling a certain degree of randomness is introduced in the choice of the sample, while reducing bias due to periodicity. Moreover, a complete review of the territory remains guaranteed. Non-aligned systematic sampling has been extensively employed in classification verification tasks [2, 3, 10]. A total of 93 field sampling points were obtained. 20 points in the municipality of San Roque de Riomiera and 73 points in the municipality of Cabuérniga.

Table 1 Data from the OLI and ETM+ sensor for the study area during the second half of 2016. The data utility according to cloud coverage is shown in different colors: in red are those passes without data; in yellow those that have some area with data; in green those in which most of the study area has data.

Month/Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
June						L7	L8							L8	L7							L7	L8							L8	
July	L7							L7	L8							L8	L7							L7	L8						
August	L8	L7								L8							L8	L7							L7	L8					
September		L8	L7							L7	L8								L7							L7	L8				
October				L8	L7							L8	L8							L8	L7										
November					L8	L7							L7	L8							L8	L7							L7	L8	
December							L8	L7							L7	L8							L8	L7							L7

Table 2 Data from the OLI and ETM+ sensor for the study area during the second half of 2016. The data utility according to cloud coverage is shown in different colors: in red are those passes without data; in yellow those who have some area with data; in green those in which most of the study area has data.

Month/Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
January	L8							L8	L7							L7	L8							L8	L7						
February	L7	L8							L8	L7							L7	L8							L8	L7					
March					L7	L8							L8	L7							L7	L8							L8	L7	
April						L7	L8							L8	L7							L7	L8							L8	
MAY	L7							L7	L8							L8	L7							L7	L8						
June	L8	L7																													

Table 3 Data from the MSI sensor for the study area during the second half of 2016. The data utility according to cloud coverage is shown in different colors: in red are those passes without data and in green those in which most of the study area has data.

Month/Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
June																															
July																S2										S2					
August																									S2						
September				S2																				S2							
October			S2																												
November			S2										S2										S2								
December			S2										S2										S2								

Table 4 Data from the MSI sensor for the study area during the first half of 2017. The data utility according to cloud coverage is shown in different colors: in red are those passes without data and in green those in which most of the study area has data.

Month/Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
January		S2										S2																			
February	S2										S2										S2										
March			S2										S2										S2								
April												S2										S2									
MAY		S2										S2										S2									
June	S2																														

3. Results and Discussion

The burned area detected within the scope of the project (01/06/2016-31/05/2017) amounts to 17,076.78 ha distributed in 2,216 polygons. These areas have been differentiated for prescribed burns and wildfires (Table 5).

Some of the mapped fires had not been recorded by the procedures commonly used (Table 5). This is mainly due to the difficulty of the method used previously to determine burned areas based solely on field observations. The conditions of the fires, mostly happening in winter, before the onset of spring, means that the regeneration of herbaceous vegetation and scrub regrowth is extremely rapid, making field detection difficult just a few months after the fire.

The distribution of fires shows a dependence on seasonal conditions linked to the winter and spring months (Fig. 3). The concentration of the high number of fires in a short period of time and the rapid recovery of the plant cover means that the visual method is not sufficiently effective.

Table 5 Total number of fires and burned surface throughout the project period.

Nº fires	Fire surface (ha)	Nº prescribed burns	Prescribed burns surface (ha)
2,089	15,964.88	127	1,111.90

Table 6 Number of registered and unregistered fires and affected area.

	Nº fires	Fire surface (ha)
Registered fires	568	9,538,18
Unregistered fires	1,521	6,426.70
Total	2,089	15,964.88

Through the confusion matrix we can verify the adequacy of the classification made; in this case, the determination of the burned areas through the data obtained by the sensors. In the previous tables we have the verification points for which we have both their real coverage, that is, whether the area has been affected by the fire or not, and the one determined through the mapping method employed.

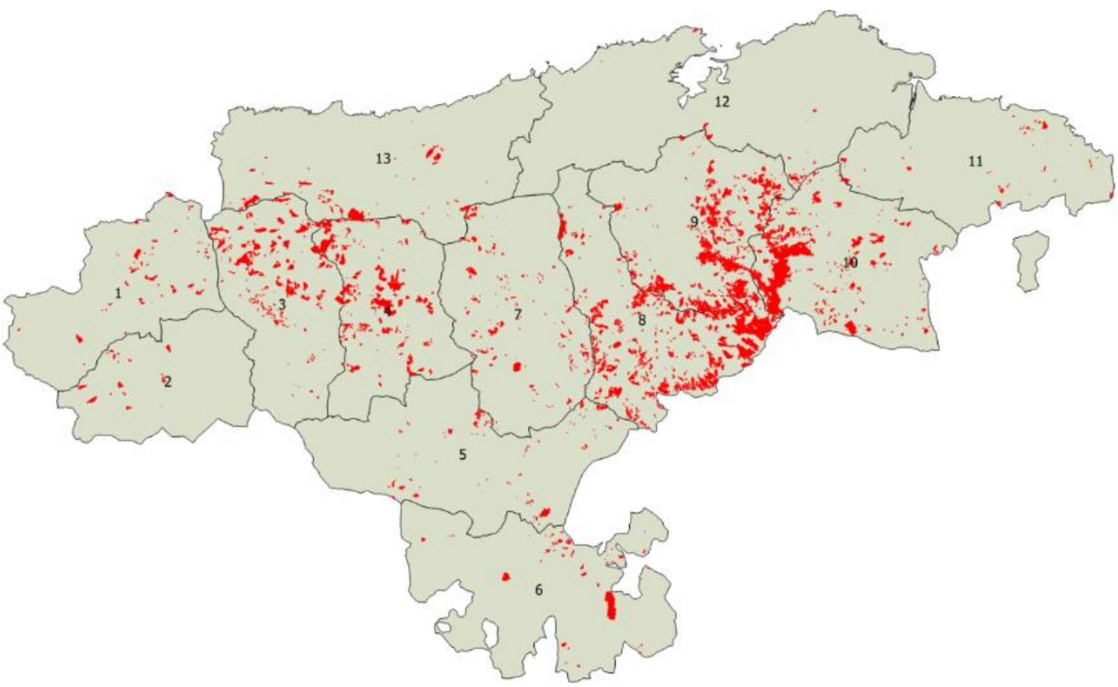

Fig. 1 Burned areas throughout the project period by forest region.

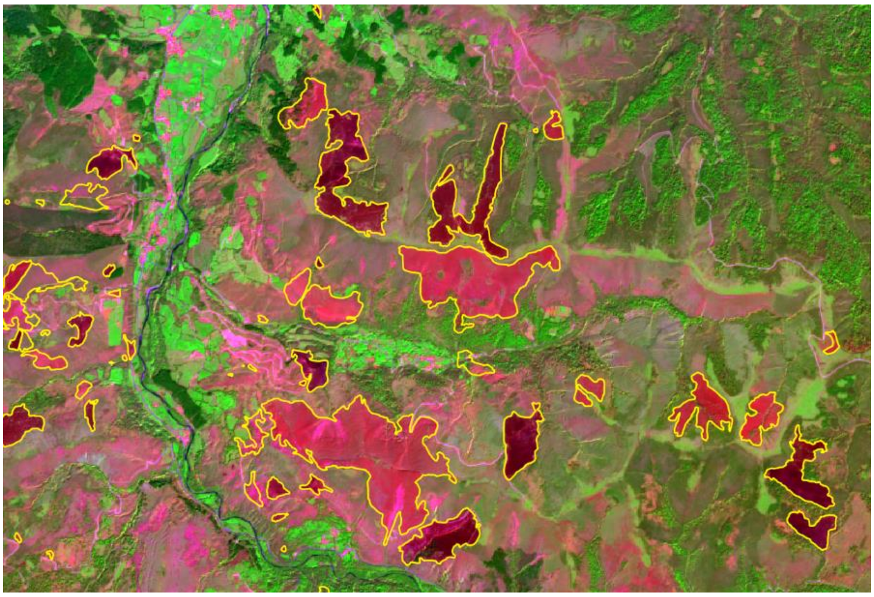

Fig. 2 Mapping of fires in the Cabuérniga Valley (yellow line) on an MSI image from 22/04/2017.

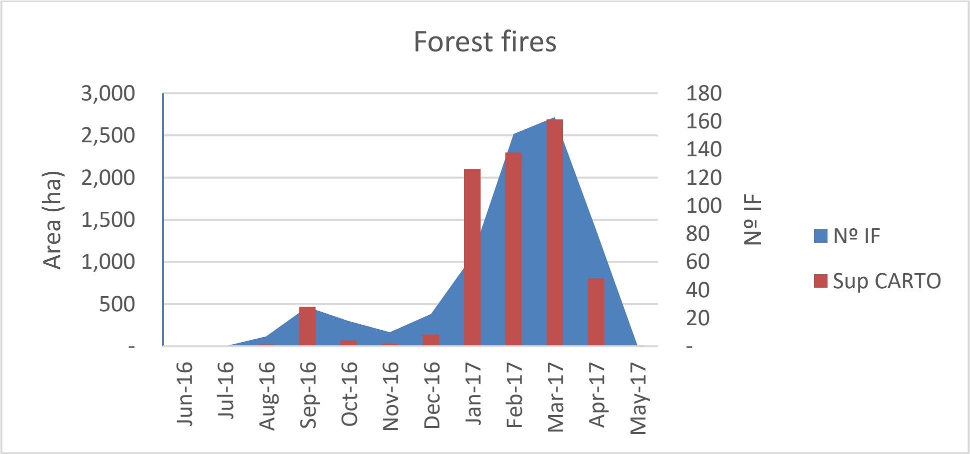

Fig. 3 Monthly distribution of the number of fires and the affected area.

Residuals in columns indicate types of actual cover that were not included in the map, while residuals in rows imply coverage of the map that does not conform to reality. In short, they represent errors of omission and commission, respectively [5, 8].

This list can be used to generate a table called the confusion matrix that lists conflicts between categories. In this matrix the columns indicate the reference classes, and the rows the categories obtained through the method employed. The diagonal shows the number of checkpoints where agreement occurs between the two sources (map and reality), while the marginal ones imply assignment errors. The relationship between the number of correctly assigned points and the total indicates the overall reliability of the map. Residuals in columns indicate types of actual coverage not included in the map, while residuals in rows imply coverage on the map that do not match reality. In short, they represent errors of omission and commission, respectively [5, 8].

The interest of these confusion tables stems from their ability to translate conflicts into categories. In this way, we know not only the overall reliability of the classification, but also the accuracy achieved for each of the classes, as well as the main conflicts between them [1].

In this case, since this constitutes a validation for binary classes, the result will have two categories, so the analysis can be solved with a simple confusion table with four possible crosses. In addition to the mismatches between the results obtained from the application of the method and the ground truth, this confusion matrix (Table 7) can also encounter problems arising from the different spatial resolution used for both classifications [1]. This circumstance must be taken into account especially in those sampling points located at the edges of the burned areas established by means of the classification.

Table 7 Resulting confusion matrix for global data.

Classification	Reference				
	Burn areas	Non burn areas	Total	Accuracy User	Error Commission
Burn areas	23	1	24	0.96	0.04
Non burn areas	1	65	66	0.98	0.02
Total	24	66	90		
Producer accuracy	0.96	0.98			
Error omission	0.04	0.02			

From the confusion matrix an overall map reliability (*F*) of 0.98 is obtained.

$$F = (\sum_{i=1,n} x_{ii})/(\sum_{i=1,n}\sum_{j=1,n} x_{ij})$$

If we consider the calculated value as an estimator of the probability that each sample has been correctly classified, and we further assume that the event "number of errors and hits" follows a binomial distribution, and that its distribution function can be calculated through an approximation of the Normal distribution, then we can make some inferences about this estimator [1]. In this case the confidence interval of (*1- α*) for *p* is given by:

$$IC_p = p \pm z_{1-\alpha/2} * [(p*(1-p))/(n-1)]^{0.5} + 1/2n$$

where,

α is the supported error; *n* is the sample size; *p* is the proportion of the population having certain characteristics; and *z* is the value of the cumulative normal function for an area equal to *1-α/2*.

Therefore, there is 95% confidence that the interval [0.94; 1] crosses the true value of the overall accuracy of the area studied.

For the purpose of evaluating mapping accuracy in the assessment of burned surfaces, 17 burned areas were measured with GPS. Measurement with GPS has been compared with that of the method (Table 8). In the total areas analyzed, the surface mapped with GPS differs from the one obtained by the above method by 2.6 ha, which is 0.7% over the measured surface. However, the spatially coincident area is somewhat lower, accounting for 95%.

Some incidents of fires not detected by the proposed method were found. Fifty-four percent of these cases corresponded to surface fires under tree cover that had not been significantly affected. 4% of the cases correspond to the existence of shade due to the relief. In the rest of the cases the areas are smaller than 1 ha.

4. Conclusion

From the results obtained we can draw some general conclusions on the method used and other more specific conclusions regarding the scope of the project. The main general conclusions obtained from the study are as follows:

Table 8 GPS-measured fires.

	Nº	Surface. (ha)	Coincidence surface (ha)
Remote sensing	17	343.67	329.11
GPS sketching		346.27	
Difference		-2.6	

The high frequency in data collection (this response will be increased in the fall to 5 days after Sentinel 2B's entry into operational mode) and the high spatial resolution of the sensors carried on the satellites used provide unprecedented rapid response capabilities compared to other methods used to date.

This method makes it possible to ascertain the extent of the most relevant fires by generating reports almost immediately upon data availability. The interface with other auxiliary mapping information is direct since the resulting format of the cartography is compatible with GIS, the surface data to be obtained by type of vegetation affected, land ownership, etc.

Based on the analysis of the reliability of the method, highly accurate data are obtained, resulting in a 98% reliability of the mapping of burned areas with a 95% confidence interval of [0.94; 1].

The conditions under which there is a loss of reliability in the method are small and limited. This is because it is directly related to variables such as lighting, which is a recognized and measurable variable. Well organized field work adequately complements mapping under these conditions.

The method used is based on the measurement and analysis of changes of certain physical parameters captured by the sensors. It is therefore a methodology with an objective technical basis, and which is applied uniformly throughout the territory.

The FEGA (Spanish Agricultural Guarantee Fund) in a circular “Control of CAP in burnt areas” dated May 23, 2017, states that in order to carry out an admissibility control of burned areas, it must be determined which SIGPAC (Geographic Information System for the Identification of Agricultural Plots) areas are affected by forest fires. As stated in this document, the Autonomous Communities are in charge of creating the coverage of burnt areas that must be loaded into the system in order to obtain the areas affected by fire and establish the conditions of eligibility. This document determines the use of data from the Sentinel 2A earth observation satellite included in the ESA Copernicus program, as an appropriate source for the mapping and monitoring of burned areas.

The main specific conclusions drawn from the study are as follows:

A total of 1,521 fires have been mapped, burning 6,426.70 hectares that have not been recorded. It is therefore not known to what extent fires have been mapped that might otherwise have gone unrecorded.

Most of the fires recorded by the authorities have been mapped. However, difficulties have been detected in the case of fires smaller than 0.5 ha and for fires that have occurred under trees with a high proportion of coverage and where the fire has not significantly affected the tree canopy or under shaded conditions. Therefore, the number of fires in this case accounts for 8% of the total number of fires and 0.42% in terms of surface area.

The cartography carried out conforms to a relatively high degree to that obtained through GPS, with a 0.7% difference in surface area in the fires tested.

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