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Multitemporal analysis of burned areas of the Selva El Ocote Biosphere Reserve, Mexico, using satellite data

Lilia Manzo-Delgado[a], Aide Franco-Martínez[b], Gloria León-Rojas[c]

[a, c] *Instituto de Geografía, Universidad Nacional Autónoma de México. Av. Universidad 3000, Ciudad Universitaria, 04510 Coyoacán, México, D.F. Apartado Postal 20-394, llmanzo@igg.unam.mx , glorisa.leon@gmail.com*
[b] *Facultad de Ciencias, Universidad Nacional Autónoma de México. Av. Universidad 3000, Ciudad Universitaria, 04510 Coyoacán, México, D.F., aideframa@ciencias.unam.mx*

Abstract
The aim of this study was to map the burned areas of the Selva El Ocote Biosphere Reserve for the period 1998–2012, using Landsat TM/ETM+ images. The method was based on a visual comparison of false color images and the pre/post-fire spectral indices Normalized Burn Ratio (NBR) and Normalized Difference Vegetation Index (NDVI); it used official records of wildfires from the National Commission for Natural Protected Areas and National Forestry Commission, and hotspots identified by the National Commission for Knowledge and Use of Biodiversity and the Fire Information for Resource Management System. Landsat images were downloaded during the fire season, January–June, for each year. According to the results, 54,756 ha were affected by 1095 fires during 1998–2012. We estimated that 352 of them involved tropical forest and 743 pasture, savannah and secondary tropical forest. The catastrophic years were associated with El Niño events 1998 (42,240 ha), 2003 (1,643 ha) and 2005 (1,248 ha), suggesting that the meteorological conditions contributed to the vulnerability of vegetation to fire. These results illustrate a method for analysing the pattern of spatial and temporal distribution of burned areas and for identifying zones that merit priority attention with regard to agricultural burning and wildfires.

***Keywords**: burned area, Landsat, NBR, NDVI*

1. Introduction

Each year, Natural Protected Areas in Mexico are affected by wildfires of varying frequency, intensity and extent (Ressl *et al*., 2009). The factors influencing the occurrence of forest fires are physical (topography and climate), biological (community structure and functioning) and anthropogenic (often caused by the cultural use of fire, tourism and transport). In recent decades, the combination of climatic anomalies such as hurricanes, followed by long dry periods associated with the El Niño Southern Oscillation (ENSO) phenomenon (particularly during 1998, 2003 and 2005) has produced much organic combustible material and large forest fires. In southeastern Mexico all these factors converge to favour extensive burned areas in tropical rainforest (Román-Cuesta *et al*., 2003). To counter this, a global integrated fire management programme was developed for protected areas. The Selva El Ocote Biosphere Reserve in Chiapas State was the first to adopt and adapt this programme, including prevention, suppression, fire use and registration of all annual records of wildfires (CONANP & TNC, 2009). However, this programme does not have maps of burned areas.

For more than two decades, remote sensing techniques and satellite imagery have been used in various regions of the word to identify burned areas, using principles based on the spectral response of the deposits of ash and charcoal left after combustion of plant material. The spectral behaviour of burned areas is characterised by an increase in the reflectance of wavelengths in the visible region (0.4–0.7 µm), a decrease in the near-infrared region (0.78–0.90 µm), and an increase again in the mid-infrared region (1.3–8.0 µm) and thermal region (8.0–14.0 µm). These changes are related to the interruption of photosynthetic activity, changes in the internal structure of leaves and loss of water (Pereira *et al*.,

1999). Although scars may persist, burned areas may be remove by wind and rain a few weeks or months after the fire. Burn scars are more evident when trees or shrubs have been eliminated: whereas the effect remains for two to three weeks in pasture it can persist for several years in temperate forest (Robinson, 1991; Pereira *et al.*, 1999).
The discrimination of burned areas is based on the use of vegetation indices such as NDVI (Normalized Difference Vegetation Index), false color images, supervised classification and principal components (Roy *et al.*, 2005a; Chuvieco *et al.*, 2005); however, Normalized Burn Ratio (NBR) and Burned Area Index (BAI) are a better alternative because they use near infrared and short-wave infrared bands, which are more sensitive to the presence of charcoal and ash on the soil (Pereira *et al.*, 1999; Cocke *et al.*, 2005). This process includes a visual analysis of multitemporal images or automated detection using algorithms; both need to consider the wide diversity caused by severity of the fire and the time elapsed since the fire was extinguished, and vegetation type (Bastarrika *et al.*, 2011).
Several products based primarily on data with coarse spatial resolution can be used to survey burned areas at the global level. For example, the project Global Burnt Area (GBA) 2000, with 1 km spatial resolution, was developed during 2000 with SPOT-VEGETATION data, later named L3JRC, and generated results until 2007 (Tansey *et al.*, 2007). Also, the official product for burned areas MCD45, from Moderate Resolution Imaging Spectroradiometer (MODIS) images, with 500 m spatial resolution, has provided monthly reports from 2000 to the present (Roy *et al.*, 2005b). Similarly, some regional studies have been developed, such as in Latin America (Chuvieco *et al.*, 2006). All information has been limited to large fires (> 250 ha). Nevertheless, local-level studies require high spatial resolution images such as Landsat Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+) or SPOT (Bastarrika *et al.*, 2011; Polychronaki & Gitas, 2012).
The Landsat near-infrared and middle-infrared bands provide stronger burned area discrimination than the visible bands and are less sensitive to smoke aerosol. The burned areas have low reflectance in all these bands, and so appear dark. The spatial and spectral appearances of the burned area vary within and between the two dates (Roy *et al.*, 2005a).
The aim of this study was to map burned areas in the Selva El Ocote Biosphere Reserve, Chiapas, for the period 1998–2012, using visual analysis of multitemporal Landsat TM/ETM+ images, in order to contribute to the spatial and temporal analyses of these events and identify priority areas regarding fire risk.

2. **Methods**

2.1. **Study area**

The study area is in southeastern Mexico, in western Chiapas State, south of the Nezahualcoyotl dam (16° 45’42” to 17° 09’00” N, and 93° 54’19” to 93° 21’20” W). At the end of 2000, the Selva El Ocote Biosphere Reserve, was established; it consists of 101,288 ha divided into two core zones with a total area of 40,432 ha and a buffer zone of 60,856 ha (Diario Oficial de la Federación, 2000) and its elevation ranges from 180 to 1500 m asl. It is a mountainous karstic region, with shafts, sinkholes and caverns. Warm and humid climates dominate, favouring the development of tropical rainforest, dry tropical forest and savannah, as well as pasture and agriculture lands.

2.2. **Fire data and satellite images**

The official fire records were provided by the National Commission for Natural Protected Areas (CONANP) and the National Forestry Commission in Chiapas State (CONAFOR). Also, hotspots (active fire) identified by the National Commission for Knowledge and Use of Biodiversity **(**CONABIO) and the Fire Information for Resource Management System (FIRMS) were downloaded (https://conabio.gob.mx; https://earthdata.nasa.gov/data/near-real-time-data/firms). The different data were visualised in layers and organised monthly with ArcMap software.

Fifty-nine Landsat TM/ETM+ images (Path/Row 22/48) for the period January – June from 1998 to 2012 were downloaded from the USGS Global Visualization Viewer (http://glovis.usgs.gov), Geotiff format, Level-1G, <43% cloud cover and georeferenced (Universal Transverse Mercator projection), with a ground spatial resolution of 30 m. Eight images were acquired out of the fire season to ensure cloud-free data for multitemporal comparisons.

The Land Cover maps produced by the National Institute of Statistics, Geography and Information Technology (INEGI) at scale 1:250000 were also available for the study area. This information was used to identify land cover classes affected by fire.

2.3. Discrimination of burned areas

Discrimination was based on a visual analysis of consecutive false color images Landsat images: bands 5(15.5–17.5 µm), 4(7.50–9.00 µm), 3(6.30–6.90 µm) and 7(20.90–23.50µm), 4(7.50–9.00 µm) 3(6.30–6.90 µm) displayed as red (R), green (G), and blue (B) respectively (Roy *et al.*, 2005a). Dark-red or purple areas (Figure 1) were considered to be potential burned areas that could be associated with charcoal and ash deposited after the combustion of plants (Pereira *et al.*, 1999). At the same time, the official fire records and hotspots were overlayed.

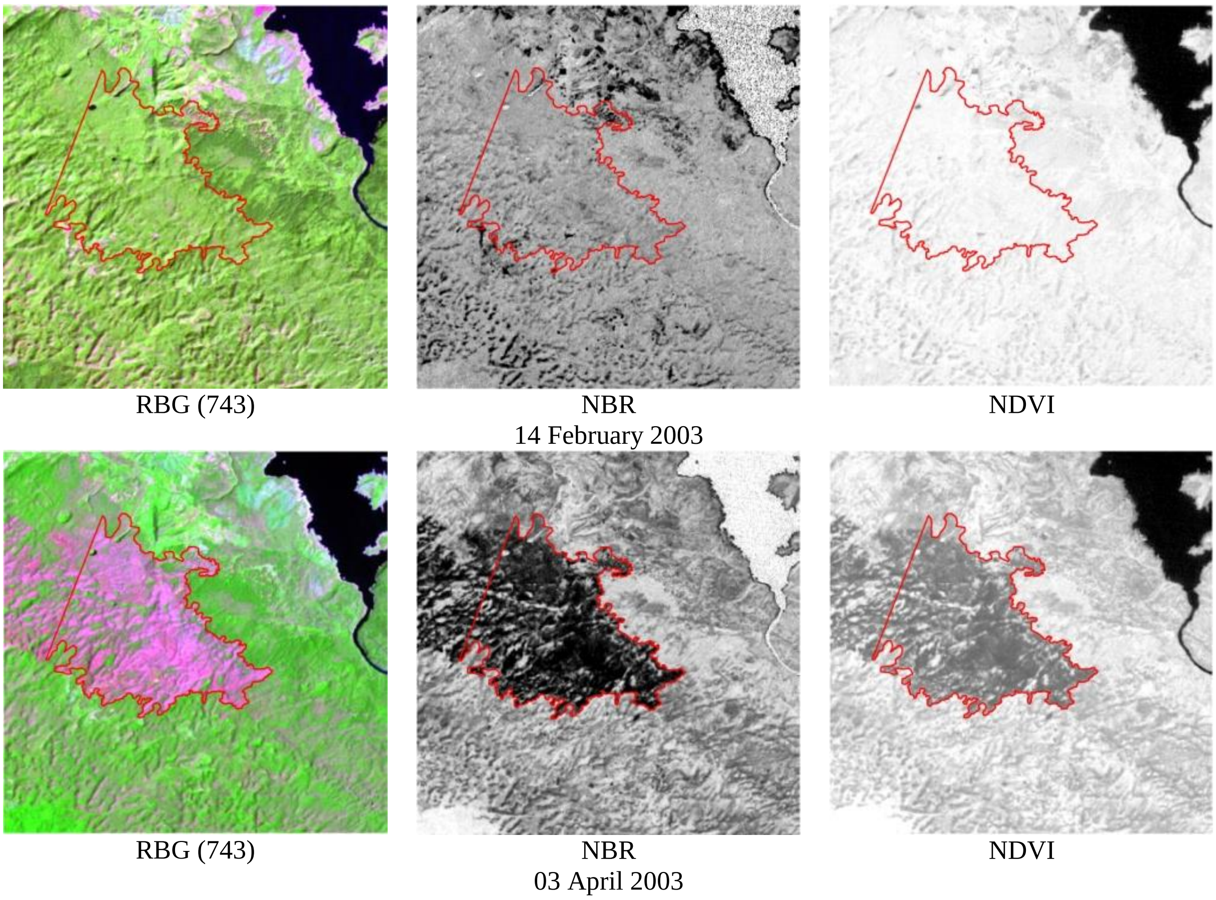

Figure 1. Visual comparison between pre/post-fire (top/bottom) Landsat ETM+ images. The fire perimeter in the Reserve is the red outline. At the top is part of the Nezahualcoyotl Dam.

To confirm the areas thus identified, a visual comparison between pre/post-fire spectral indices NBR (Normalized Burn Ratio: B4 - B7/B4 +B7) was used. A diminished NBR confirms the presence of a burned area (Cocke *et al.*, 2005). During this phase, the vegetation index NDVI (B4 - B3/B4 +B3) was also used to identify significant changes in the areas affected by fire (Figure 1). Fire perimeters were digitised and labelled with the dates of images, the official record and the hotspot, as well as vegetation type. The different processes were supported by ArcMap and ENVI.

3. Results

According to the visual comparison in 1998, 229 fire perimeters were delimited, with surface variation from 0.3 to 2600 ha, and 42,240 ha affected; this was less than half of the total area. During 1999–2012, 866 fire perimeters were delimited, with surface variation from 0.3 to 600 ha, and 12,517 ha affected. We estimated that 352 involved tropical forest (wildfires) and 743 pasture, savannah and secondary tropical forest (agricultural burning). With the exception of 1998, burned areas smaller than 20 ha were more frequent (90%) at the buffer zone and near to villages and roads, confirming the relation with traditional fire use. Nowadays, in the core zone, many areas affected during 1998 have recovered their forest density; however, the portion west of the core zone sometimes experiences severe fires (Figure 2).

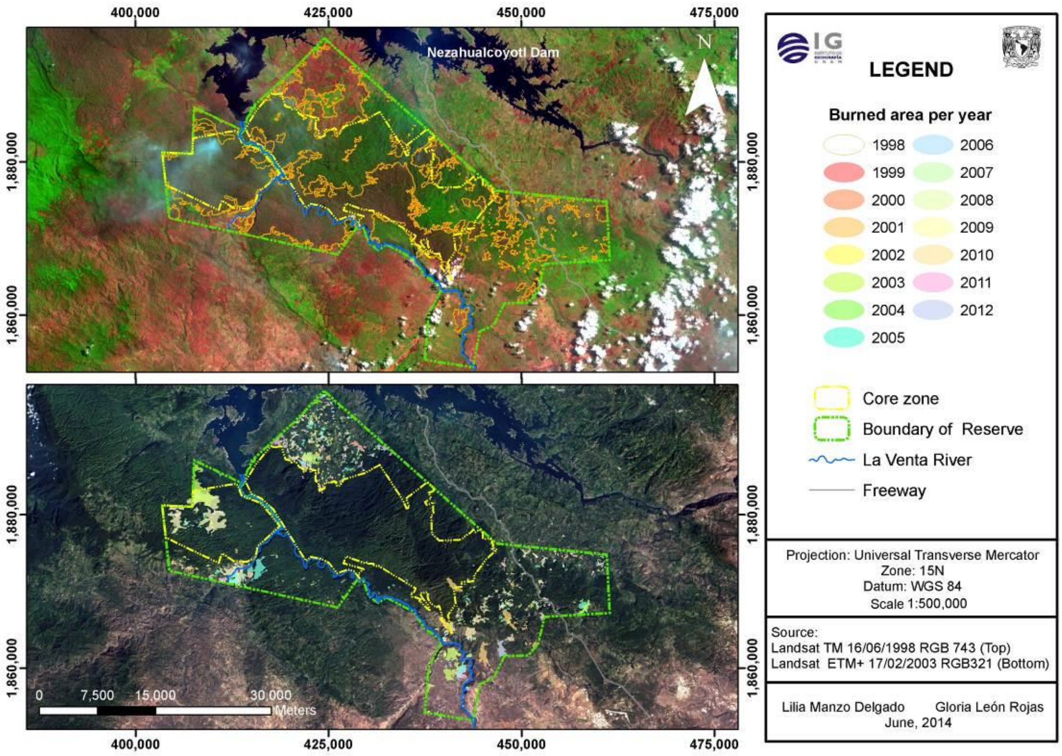

Figure 2. Burned areas of the Selva El Ocote Biosphere Reserve, Mexico, 1998 (top), 1999-2012 (bottom), from Landsat TM/ETM+

The catastrophic years were associated with El Niño events 1998 (42,240 ha), 2003 (1,643 ha) and 2005 (1,248 ha), suggesting that the meteorological conditions contributed to increased vulnerability of vegetation to fire. Comparative analysis between total fires and affected areas from Landsat images and official records of fires within the Reserve showed important differences each year (Table 1).

Table 1. Annual burned area derived from Landsat TM/ETM+ and official records of wildfires

	Landsat TM/ETM+				Official records	
Year	Agricultural burning (Number)	Surface (ha)	Wildfires (Number)	Surface (ha)	Wildfires (Number)	Surface (ha)
1998	111	10243	118	31997	7	22000
1999	3	13	2	12	2	1
2000	21	116	21	66	0	0
2001	9	195	31	893	6	211
2002	34	155	29	123	1	8
2003	12	342	17	1301	28	9275
2004	20	179	10	186	1	4
2005	35	571	29	677	10	553
2006	13	85	7	115	1	20
2007	13	130	13	76	8	82
2008	169	1063	14	78	3	5
2009	67	809	6	1537	6	2743
2010	57	732	25	547	3	24
2011	124	1676	29	104	0	0
2012	55	729	1	8	4	8

The month of May saw more agricultural burnings because it is a better time to prepare cropland, just before the start of the rainy season. At the same time, fires are common in the buffer zone; sometimes a few grow out of control and become forest fires in the core zone. The fire team of the Reserve are always alert; they have a range of measures for monitoring fire, such as CONABIO hotspots and fire reports, fire brigades and involvement of inhabitants of the communities in fire fighting. However, agricultural fires are a threat to the conservation of the Reserve.

High clouds from May to October are very common in the study area. This hindered identification of burnt areas for some years, particularly for 2003 during which there were many forest fires.

Hotspots were important for the discrimination of burned areas. A hotspot represented small agricultural burning (<1 ha) into contiguous land; multiple hotspots in the same area were associated with large wildfires (> 10 ha) that remained active for more than two days.

Official fire reports for the Reserve include underground fires; however, neither hotspot nor Landsat images could confirm these events. This issue is very important and it will be convenient necessary to use other methods to study these fires.

4. **Conclusions**

Visual analysis of multitemporal Landsat TM/ETM+ images was a good method for obtaining the first local burned areas map of the Selva El Ocote Biosphere Reserve, Chiapas, for 1998 and the period 1999–2012. These results illustrate an alternative means for analysing the pattern of spatial and temporal distribution of burned areas and for identifying zones that merit priority attention with regard to wildfires.

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