Remote Sensing of Environment 126 (2012) 12–26

Contents lists available at SciVerse ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Mapping spatial and temporal patterns of Mediterranean wildfires from MODIS

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ARTICLE INFO

Article history:
Received 21 February 2012
Received in revised form 23 July 2012
Accepted 4 August 2012
Available online 31 August 2012

Keywords:
Remote sensing
MODIS
Landsat
Burnt areas
Israel
Spectral indices
Herbaceous vegetation
Military training zones

ABSTRACT

Wildfires are part of the Mediterranean ecosystem, however, in Israel all wildfires are human caused, either intentionally or un-intentionally. In this study we aimed to develop and test a new method for mapping fire scars from MODIS imagery, to examine the temporal and spatial patterns of wildfires in Israel in the 2000s and to examine the factors controlling Israel's wildfire regime. To map the fires we used two 'off-the-shelf' MODIS fire products as our basis—the 1 km MODIS Collection 5 fire hotspots, the 500 m MCD45A1 burnt areas—and we created a new set of fire scar maps from the 250 m MOD13Q1 product. We carried out a cross comparison of the three MODIS based wildfire scar maps and evaluated them independently against the wild fire scars mapped from 30 m Landsat TM imagery. To examine the factors controlling wildfires we used GIS layers of rainfall, land use, and a Landsat-based national vegetation map. Wildfires occurred in areas where annual rainfall was above 250 mm, mostly in areas with herbaceous vegetation. Wildfire frequency was especially high in the Golan Heights and in the foothills of the Judean mountains, and a high correspondence was found between military training zones and the spatial distribution of fire scars. The use of MODIS satellite images enabled us to map wildfires at a national scale due to the high temporal resolution of the sensor. Our MOD13Q1 based mapping of fire scars adequately mapped large (>1 km^2) fires with accuracies above 80%. Such large fires account for a large proportion of all fires, and pose the greatest threats. This database can aid managers in determining wildfire risks in space and in time.

1. Introduction

Wildfires are a natural part of the Mediterranean ecosystem, and are a major ecological factor affecting the evolutionary traits of plants, vegetation succession, soil erosion, as well as human perceptions of the landscape (Naveh, 1975). However, many centuries of human and livestock pressures, including burning, cutting and grazing, have modified Mediterranean landscapes (Naveh and Dan, 1973; Vannière et al., 2008). In recent decades fire frequency and the area burnt seem to be on the rise in European Mediterranean areas as well as in other areas around the globe, due to land use changes leading to fuel accumulation (e.g., abandonment of agricultural areas and the common past planting of pine trees) as well as climatic warming (Dimitrakopoulos et al., 2011; Keeley et al., 2012; Pausas & Vallejo, 1999; Westerling et al., 2006). The reconstruction of a 130-year fire history for the Valencia province (Spain) by Pausas and Fernandez-Muñoz (2012) identified a fire regime shift in the early 1970s, with fires being less fuel limited and more drought driven than before. At present, the wide majority of fires in the Mediterranean Basin are caused by human activities, either intentionally or through negligence (Chuvieco et al., 2010; Kutiel & Kutiel, 1991; Levin & Saaroni, 1999; Vilar et al., 2008). One of the major gaps in knowledge and research needs in Mediterranean areas relates to fire regime – quantifying its temporal and spatial patterns, so that better fire management can be applied in the face of land-use and global climate changes (Scarascia-Mugnozza et al., 2000; Stroppiana et al., 2012).

Remote sensing is now commonly used for monitoring wildfires (active fires, burnt areas and fire severity) using various space-borne sensors, such as Landsat (Boschetti et al., 2006; Levin et al., 2012; Miller & Thode, 2007; Russell-Smith et al., 1997; Wittenberg et al., 2007), MODIS (Chuvieco et al., 2005; Davies et al., 2009; Giglio et al., 2003; Justice et al., 2002; Levin et al., 2012, in press; Roy et al., 2005, 2008; van Leeuwen et al., 2010) and BIRD (Wooster et al., 2003), to name just a few. Despite the effort invested in mapping fires in Mediterranean areas from satellite imagery (e.g., Chuvieco et al., 2002; Stroppiana et al., 2012), some MODIS burnt area products have been found to contain relatively common errors of omission in Mediterranean areas so areas that have been burnt are not being correctly identified (e.g., de Klerk et al., 2012).

As Israel is a small country (~22,000 km^2), forest fires in Israel are generally small in their area (compared to other countries). The total forest and other wooded land burnt in Israel between 1990–1997 ranged between 35–83 km^2/year, whereas in other Mediterranean countries it was one-two orders magnitude higher (e.g., between 598–4376 km^2/year in Spain, 500–1696 km^2/year in Portugal), and in Australia it has been estimated that between 310,000–710,000 km^2/year were burnt in 1998–2000 (Forest Resources Assessment Programme, 2001). However, due to the cultural significance of planted forests in Israel (Perevolotsky & Sheffer, 2009), when large forest fires take place, they are of national significance.

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0034-4257/$ – see front matter
http://dx.doi.org/10.1016/j.rse.2012.08.003

The largest forest fires in Israel's history were those of the Carmel Park (4 km^2, September 1989; Kutiel & Kutiel, 1991; Safriel, 1997) Sha'ar Haguy (13 km^2, July 2005; Levin & Saaroni, 1999) and again the Carmel Park (22 km^2, December 2010; Paz et al., 2011).

In spite of their national importance and despite Israel's small area, wild fires are not mapped nationally, and there is no national database that enables examination of the spatial and temporal factors influencing fire occurrence and spread (as in many other Mediterranean countries; Stroppiana et al., 2012). A partial database of forest fires is managed by the Jewish National Fund (JNF; Israel's forestry agency), and there have been some studies that examined recent forest fire history in Israel (Levin & Saaroni, 1999; Tessler et al., 2007, 2010; Wittenberg & Malkinson, 2009) but to date no study has examined the spatial and temporal patterns of all wildland fires in Israel. Fire hazard can be estimated using remote sensing and GIS, based on variables such as vegetation type, fuel moisture content, slope, aspect and proximity to roads (Chuvieco & Congalton, 1989; Chuvieco et al., 2010; Yebra et al., 2008). Recently it has been suggested that fire risk can be evaluated using Monte-Carlo simulations of fire spread that are based on vegetation maps and the susceptibility of vegetation types to burn (as in Carmel et al., 2009). In the face of global climate change, rising temperatures and a probable drying trend in the eastern Mediterranean (Shohami et al., 2011), it is highly important to understand the spatial and temporal distribution of wildfires in the Mediterranean Basin.

Our major aim in this study was, therefore, to develop an algorithm, suited to Mediterranean conditions, to identify burnt areas from MODIS imagery. While Landsat imagery provides better spatial resolution and better coverage of small fires (Stroppiana et al., 2012), Landsat does not offer the temporal resolution and spatial coverage needed to monitor fires regularly and consistently. In addition, we aimed to quantify the spatial and temporal patterns of wildland fires in Israel since 2000, and to study the physical and human factors explaining fire frequency. By mapping Israel's wildland fire hotspots, we aim to map when and where fire risk is higher, and to examine to what extent land-cover and land-use patterns can explain fire risk.

2. Methods

2.1. Study area

The study area covered the land area of Israel. In 2009, Israel's average population density is 329 people/km^2 (http://www1.cbs.gov.il/reader/) with 92% of the population living in urban areas. As the southern part of Israel is desert, most of the population resides in the Mediterranean climate region, where population density is much higher, at 827 people/km^2 (Levin & Duke, 2012). About 8.9% of Israel's area is covered by maquis and forest areas (19.4% in the Mediterranean region of Israel), and about 30.3% of Israel's area is protected within nature reserves, national parks, and JNF forests (18.6% in the Mediterranean region of Israel; Achiron-Frumkin, 2011). While Israel is small, it is a biodiversity hotspot (Medail & Quezel, 1999), covering a wide range of climatic conditions representing the habitats found around the Mediterranean Basin, from extreme desert in the south of Israel (25 mm/year in Eilat) to moist Mediterranean areas in the north (>1200 mm/year). All agricultural and built-up areas were excluded from the analysis using a GIS layer provided by the Survey of Israel (Fig. 1). We classified Israel into 11 natural ecoregions based on Israel's Ministry for Environmental Protection layer of landscape units (Kaplan & Slotsky, 2002; Fig. 1).

2.2. Satellite imagery used

Burnt areas were mapped using Landsat and MODIS satellite images:

- Landsat images (tiles 174/37 and 174/38) were used to map vegetation cover (as of 2002, see details below) and to validate the MODIS fire mapping (for the years 2006 and 2010). Landsat images were downloaded from the USGS website (http://edcsns17.cr.usgs.gov/EarthExplorer/).
- We used the MODIS Collection 5 fire hotspots which provide point locations of active fires, corresponding to a spatial resolution of ~1 km (Davies et al., 2009). Data for the years 2000–2011 were downloaded from The Fire Information for Resource Management System (FIRMS) (http://maps.geog.umd.edu/firms/).
- We used the 500 m MCD45A1 fire scar product of MODIS (Roy et al., 2002, 2008) for an inter-comparison with our own MODIS fire mapping (details below). This MCD45A1 is available on a monthly basis, and its time series was comprised of 135 months, between April 2000 and July 2011.
- Images of the MOD13Q1 product of MODIS Terra (morning overpass) were downloaded from the NASA website (https://wist.echo.nasa.gov/api/) for the time period between 18 February 2000–04 March 2000 until 13 August 2011–28 August 2011. This time series was comprised of 265 16-days composites. We used the MOD13Q1 product (tiles 20/5, 21/5, 20/6 and 21/6) which offers 16-days surface reflectance for bands 1–3 and 7 (red, NIR, blue, and MIR (2105–2155 nm)) at a coarse spatial resolution of 250 m. MODIS bands 3 and 7 are originally acquired at a 500 m spatial resolution, but are resampled to a 250 m resolution for this product. The four tiles were mosaicked and reprojected into Israel Transverse Mercator (ITM, also known as Israel New Grid) coordinate system at a spatial resolution of 250 m.

2.3. Fire mapping

In general, satellite images can be used for mapping fires using two approaches: a change detection approach, where fire scars are identified based on changes in their spectra (e.g., Miller & Thode, 2007); or a hotspot approach, where active fires are identified using thermal bands (e.g., Roberts & Wooster, 2008). Both approaches were used here.

The multispectral TM images were used to validate burnt areas mapped from MODIS. Following the protocol described by Roy and Boschetti (2009), burnt areas were identified based upon multitemporal visual comparison of the ETM+ near- and middle-infrared bands (where in a false color composite of bands 7, 5 and 4 fire scars appear as brown areas; Fig. 2). Using pairs of Landsat images it was possible for us to identify in which season a specific wildfire took place. Fire scars were digitized manually within ArcGIS 10 (ESRI, 2010) for two years, 2006 (north of Israel) and 2010 (all Israel). To this end we used the following multitemporal images: Landsat P174R37 (30/5/2006, 17/7/2006, 2/8/2006, 3/9/2006, 19/9/2006, 5/10/2006, 26/6/2007, 14/5/2009, 1/5/2010, 6/9/2010, 3/12/2010, 12/1/2011), Landsat P174R38 (30/1/2009, 15/4/2010, 1/5/2010, 6/9/2010, 3/12/2010), ALI (21/12/2010 covering the Carmel fire), UK-DMC (9/12/2010 covering the Carmel fire). Where possible we validated our visual interpretations with external sources (e.g., Paz et al., 2011 for the Carmel fire, Achiron-Frumkin & Frumkin, 2006 for the wildfires resulting from the second Lebanon War). However, a complete spatial database of wildfires in Israel is lacking.

The MODIS Collection 5 fire hotspots contains point locations of active fires. The average detection confidence of the active fires in our study area was 68%. We used all active fires whose detection confidence was above 70%, and rasterized them to monthly maps of burnt areas at a spatial resolution of 1 km.

The MCD45A1 product of MODIS contains a layer which expresses a quality assessment (QA) of the burnt area pixel ('ba_qa'), with the value '0' indicating non-burnt pixels, the value '1' indicating the "most confidently detected pixels regardless of temporal direction", the value '2' indicating "pixels where backward and forward temporal direction predict the same change", the value '3' indicating "pixels selected in the first stage of the contextual analysis" and the value '4'