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ScienceDirect

Catena 71 (2007) 76–83

CATENA

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Spatial and temporal patterns of vegetation recovery following sequences of forest fires in a Mediterranean landscape, Mt. Carmel Israel

Lea Wittenberg [a,*], Dan Malkinson [a,b], Ofer Beeri [c], Alon Halutzy [a], Naama Tesler [a]

[a] Department of Geography and Environmental Studies, University of Haifa, Haifa 31905, Israel
[b] Golan Research Institute, University of Haifa, Haifa 31905, Israel
[c] Earth Science Systems and Policy, University of North Dakota, Box 9011 Grand Forks, ND 58202 USA

Received 1 January 2006; accepted 1 June 2006

Abstract

The Mediterranean ecosystem of Mt. Carmel is subjected to increasing number of forest fires at various extents and severities due to increasing human activities. Accordingly, we tested whether in areas exposed to different fire histories vegetation regeneration is different in north versus south facing slopes, and the potential impact on erosion processes. Using remote sensing techniques we evaluated the Enhanced Vegetation Index (EVI) to monitor vegetation recovery following a single fire and three successive fires, using a series of Landsat images taken between 1985–2002. Following a single fire, vegetation cover reached pre-disturbance values within less than 5 years. Repeated fires caused further reduction of EVI values, especially at south facing slopes (SFS). The effects of three successive fires within 10 years, followed by a three year recovery period, however, are negligible when considering vegetation cover values. This was deduced as north facing slope EVI values returned to pre-disturbance conditions at the end of the 3 years and SFS EVI values to 80% of the pre-disturbance conditions. Our results indicate that Mediterranean eco-geomorphic systems are quite resilient, showing quick response, at least in terms of return to pre-disturbance states of vegetation cover, and hence of soil erosion rates. This is true not only in response to a disturbance caused by a single fire, but also for repetitive fire incidents.

Keywords: Mediterranean ecosystem; Forest fire; Remote sensing; Vegetation regeneration; Soil erosion

1. Introduction

Fires in Mediterranean ecosystems have a complex effect on geomorphological processes and vegetation regeneration due to the complexity of landscape structures as well as differential responses of such systems to various types of fire regimes. Specifically, different fire regimes are manifested by different fire intensities, seasonalities, recurrence probabilities and the extents of these events (Naveh, 1973). At the landscape level, post-fire regeneration would depend mainly on the initial vegetation and onsite environmental factors — climatic and terrain parameters (Pausas and Vallejo, 1999).

Vegetation cover plays one of the key factors affecting soil erosion and land degradation processes (Thornes, 1990; Shakesby et al., 1993). Assuming a rapid and considerable intensification of the erosive processes following fires (Inbar et al., 1997, 1998) vegetation recovery normally leads to a decline in post-fire runoff and soil erosion rates. Thornes (1990) suggested that a minimum value of 30% projective plant cover is sufficient for protecting the soil against water erosion. Risks of post-fire soil erosion are higher when the time required for the vegetation to reach this minimal vegetation threshold cover is longer. This has been widely demonstrated at various spatial scales and under different ecological conditions (Shakesby et al., 1993; Inbar et al., 1998; Cerda, 1998a,b). Apparently, much of the sediment loss occurs during the first year following the fire occurrence (DeBano et al., 1998; Inbar et al., 1998; Cerda and Doerr,

* Corresponding author.
E-mail address: leaw@geo.haifa.ac.il (L. Wittenberg).

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doi:10.1016/j.catena.2006.10.007

2005). Therefore, it is essential to evaluate vegetation recovery rates immediately after fires.

Most studies addressing post-fire geomorphological processes and vegetation dynamics, at various temporal and spatial scales, were conducted following a single fire event. At the landscape level, where burning occurs and regeneration takes place, both short and long-term effects of a single event are inevitably related to the long-term fire regime which creates a landscape mosaic consisting of patches with different burning history. The interrelations between these patch types largely determine the recovery patterns of frequently burnt areas, which are common in the Mediterranean landscape (Mouillot et al., 2003). In combination with ancillary spatial data such as soil properties and terrain characteristics, accurate estimates of vegetation cover and regeneration can be valuable for identifying areas of elevated erosion risks following fires.

Two principal methods are commonly used to estimate post-fire vegetation dynamics — experimental vegetation/runoff plots and remote-sensed image analysis. The utilization of plots enables relatively accurate and detailed measurements of vegetation cover and plant community properties, as well as runoff and erosion rates, yet within restricted areas and limited time scales. Application of remote sensing indices is more appropriate at the landscape scale, yet endures many limitations. A number of vegetation indices have been developed and used for monitoring vegetation structure and function. Among these, is the Normalized Difference Vegetation Index (NDVI), which uses spectral information in red and near infrared bands, and is commonly used to estimate net primary production and fire effects on vegetation (Paltridge and Barber, 1988; Illera et al., 1996). Nevertheless, NDVI has several limitations, including sensitivity to atmospheric conditions (Holben, 1986) and sensitivity to soil background (Huete, 1987). To account for residual atmospheric contamination (e.g., aerosols) and variable soil background reflectance, the Enhanced Vegetation Index (EVI) was proposed, which directly adjusts the reflectance in the red spectral band as a function of the reflectance in the blue band (Liu and Huete, 1995; Huete et al., 1997). Many remote sensing fire recovery studies have been conducted in environments with Mediterranean climates (Jakubauskas et al., 1990; Marchetti et al., 1995; Viedma et al., 1997; Díaz-Delgado et al., 1998; Henry and Hope, 1998; Ricotta et al., 1998). Validation methods to correct for external factors affecting image quality include comparison with non-burnt sites characterized by similar environmental conditions located within the extent of the same image (Díaz-Delgado et al., 1998), validation with aerial photography and field studies (Kushla and Ripple, 1998). While using remote sensing techniques enables the investigation of such effects at large spatial scales, such studies are limited by the ability to accurately detect high resolution changes in the structure of vegetation communities.

Studies, based on both approaches have shown that post-fire recovery is quick for most species, due to their resprouting abilities, or the persistence of their seed bank. Rapid regeneration occurs within the first 2 years following fires (Trabaud, 1981; Kutiel, 1994; Inbar et al., 1998), with differential recovery rates at the north and the south facing slopes (Cerda and Doerr, 2005). Pausas and Vallejo (1999) noted that in the Iberian Peninsula, within a year after single fire event vegetation cover reached 52.4% on the north facing slope and 32% on the south facing slope. Similar trends were also found at the Mt. Carmel region, Israel, following the 1988 fire (Kutiel, 1994; Inbar et al., 1998). Notwithstanding, Díaz-Delgado et al. (2002) observed lower NDVI values after the second of two successive fires occurring within an 11 year interval, i.e. the green biomass diminishes significantly when disturbances occur within short time intervals. They concluded that increased fire frequency may reduce ecosystem resilience — the ability of the system to recover to a pre-disturbance state.

In spite of the considerable efforts invested in fire research, the ability to predict the impact of fires on the landscape is still limited (Moreno et al., 1998; De Luis et al., 2004). In light of the evident increase in the number of fires and burnt areas in the Mediterranean basin (Pausas and Vallejo, 1999) the need to evaluate fire effects on vegetation and geomorphological patterns and processes is essential. The objective of the study presented herein was to assess vegetation recovery rates under different fire occurrences and in different slope aspects. Specifically, we compared recovery rates in areas repeatedly burnt — three fires within a ten year period — to an area burnt only once during this period. Further, within those regions, we investigated whether differential vegetation recovery patterns are associated with slope aspects. The conceptual model of soil loss recovery (Inbar et al., 1998) was reexamined in light of the long-term vegetation cover monitoring, to examine the interrelations between vegetation and land degradation processes in a fire-prone environment.

2. Methods

2.1. Study site and data acquisition

The area studied is located at the north-western part of the Carmel Mountain ridge (35°W, 32°N). Mt. Carmel is an isolated mountain ridge, rising from the northern Mediterranean Sea shore of Israel to a height of 500 m above MSL (Fig. 1). The Mediterranean type climate at Mt. Carmel is characterized by dry and hot summers and rainy winters. In Northern Israel precipitation commonly commences during October and ends in May; where most rainstorms usually occur between November and March. Autumn precipitation is often convective in nature with relatively high rainfall intensities while winter rainfalls (December–February) are mainly a result of frontal activities related to wide synoptic systems. The average annual rainfall in Mt. Carmel ranges from 550 mm near the coastal plane to 750 mm at the highest elevations. Owing to long period of dry spells and the increased climatic uncertainty (Paz and Kutiel, 2003), Naveh (1973) characterized the region as a Mediterranean