THE EFFECT OF WILDFIRES ON VEGETATION COVER AND DUNE ACTIVITY IN AUSTRALIA'S DESERT DUNES: A MULTI-SENSOR ANALYSIS

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ABSTRACT:

Desert dunes shift between states of activity and stability as a function of fluctuations in climate and changes in human land use. Most of Australia's desert dune fields are stable, with only small patches of mobile sand on dune crests. However, wildfires may reduce vegetation cover so that sand movement may take place until vegetation recovers. In this study we aimed to study the recovery rate of vegetation cover on desert dunes following wildfires using satellite image derived spectral indices to: (1) determine for how long after fire these dunes may be active until critical levels of vegetation cover are attained; (2) which vegetation index is the most suited for monitoring vegetation in this area. Our study area was located in the Great Victorian Desert of Western Australia. We have used a combination of MODIS, Landsat and Aster images to analyze vegetation cover following fire at various spatial and temporal scales. The following spectral indices were compared: NDVI, SAVI, EVI, CI, BI and BSCI. Wildfire scars were identified from time series of Landsat and MODIS images, as bright areas. The CI and BI were found to outperform NDVI, SAVI and EVI in monitoring vegetation cover in this area, probably due to the relatively large cover of biological crust and the large proportion of non-photosynthetic vegetation of perennial and annual plants. Whereas full recovery of vegetation following wildfires is attained only after 25-30 years, critical thresholds of vegetation cover limiting sand movement are attained after just 1-5 years.

1. INTRODUCTION

Desert dunes shift between states of activity and stability as a function of fluctuations in climate and changes in human land use. The larger part of the Australian desert dune fields is comparatively stable, usually with only small patches of mobile sand on dune crests (Hesse and Simpson, 2006). Yet, dunes may become locally active over their entire surfaces, most obviously in areas of present or past vegetation disturbance. Indices of dune mobility are traditionally based on climatic variables such as rainfall, temperature, evapotranspiration and wind energy (Tsoar, 2005). However, dunes may also become reactivated due to extreme events that reduce vegetation cover dramatically. In many areas in Australia spontaneous wildfires may reduce vegetation cover so that sand movement may take place until vegetation recovers.

In this study we aimed to study the recovery rate of vegetation cover on desert dunes in Australia following wildfires using satellite image derived spectral indices to:

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(1) determine for how long after fire these dunes may be active until critical levels of vegetation cover are attained;
(2) which spectral index is the most suited for monitoring vegetation in this area.

2. METHODS

2.1 Study area

The climate of the Great Victoria Desert is arid, with summer and winter rain averaging 200 mm per annum. Landforms consists of red sand plains with patches of aeolian dunefields, salt lakes and major valley floors with lake derived dunes. Dune vegetation is comprised of three components in the study area: Compact low perennial shrubs and clump-forming grasses, low (<50 cm) forbs and cyanobacterial crust. In the Great Victoria Desert, plant cover has been estimated to range from 25–40%, and is mostly comprised of a monospecific carpet of spinifex grass *Triodia basedowi* (Haydon et al., 2000). Although they occur primarily in the semi-arid zones of Australia, spinifex species are well adapted to fire, and may regenerate either as seedlings or as resprouts. At present most wildfires are started by lightning strikes.

2.2 Satellite imagery

We have used a combination of MODIS, Landsat and Aster satellite images to analyze vegetation cover following fire at various spatial and temporal scales, as detailed in Table 1.

Satellite	Sensor	Image ID	Date
Landsat	MSS	Path 113 row 79	01/10/1972
Landsat	MSS	Path 113 row 80	04/02/1973
Landsat	TM	Path 106 row 79	06/07/1989
Landsat	TM	Path 106 row 80	12/07/1991
Landsat	ETM+	Path 106 row 79	27/08/1999
Landsat	ETM+	Path 106 row 80	27/08/1999
Terra	Aster	AST_07_00301212007014448_20080724103922_10010	21/01/2007
Terra	Aster	AST_07_00301212007014457_20080724103922_10012	21/01/2007
Terra	Aster	AST_07_00310292007013809_20080724103852_9853	29/10/2007

Table 1: Landsat and Aster satellite images that were used in this study to calculate spectral indices.

Landsat images were radiometrically and atmospherically corrected following Chavez (1996), as implemented in IDRISI GIS. The Aster images were downloaded from the USGS Internet website in reflectance values following the automatic correction described in Thome et al. (1999). MODIS Images covering the time period between 18/02/2000-04/03/2000 until 27/07/2008-11/08/2008, were based on the MOD13Q1 product which offers surface reflectance bands 1-3 and 7
(red, NIR, blue, and MIR (2105-2155nm)) at a spatial resolution of 250m.

Wildfire scars were identified from time series of Landsat and MODIS images as high albedo areas. With time the scars tend to fade away, and we calculated several spectral indices to analyze seasonal, annual and decadal trends in vegetation cover.

The following vegetation and soil spectral indices were compared: the Normalized Difference Vegetation Index (NDVI; Tucker, 1979), the Soil Adjusted Vegetation Index (SAVI; Huete, 1988), the Crust Index (CI; Karnieli, 1997), the Brightness Index (BI; Mathieu et al., 1998), the Enhanced Vegetation Index (EVI; Huete et al., 2002), and the Biological Soil Crust Index (BSCI; Chen et al., 2005). As the Aster sensor does not have a blue band, only NDVI, SAVI, BI and BSCI were calculated for it.

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

$$SAVI = \left(\frac{NIR - R}{NIR + R + 0.5}\right) * (1 + 0.5) \quad (2)$$

$$CI = 1 - \frac{R - B}{R + B} \quad (3)$$

$$BI = \sqrt{\frac{B^2 + G^2 + R^2}{3}} \quad (4)$$

$$EVI = 2.5 * \frac{NIR - R}{((NIR + 6) * (R - 7.5) * (B + 1))} \quad (5)$$

$$BSCI = \frac{1 - L \times |R - G|}{(R + G + NIR)/3} \quad (6)$$

$$Pv = \frac{VI - VI_{baresoil}}{VI_{100\%} - VI_{baresoil}} \quad (7)$$

where NIR, R, G and B stand for spectral reflectance values in the Near Infrared, Red, Green and Blue spectral bands, respectively. Vegetation cover *Pv* was calculated based on vegetation indices (NDVI, SAVI, EVI) as shown in equation 7, where *VI* stands for the value of a Vegetation Index in a certain pixel, VI_{baresoil} stands for the vegetation index value in an area with no (or almost no) vegetation (i.e. immediately after fire), whereas $VI_{100\%}$ stands for the vegetation index value in area with maximum vegetation cover (i.e. an area that did not experience wildfire for at least 30 years). Equation 7 was slightly modified for soil spectral indices such as BI where high values represent low values of vegetation cover.

2.3 Statistical analyses

Soil and vegetation indices are known to be affected by seasonal patterns of rainfall in desert areas, exhibiting a lag of several weeks-months (Richard and Poccard, 1998; Schmidt and Karnieli, 2002). To examine the effect of rainfall on seasonal changes in soil and vegetation indices valyes, monthly rainfall values were downloaded from the website of the Australian Bureau of Meteorology (http://www.bom.gov.au/; these are based on 0.025×0.025 degree gridded data). A regression analysis was performed between the rainfall data (interpolated into bi-weekly values) and MODIS based spectral indices (using an average from the entire MODIS tile) to determine the optimal lag time for highest correlations between summed rainfall values and the spectral indices. Using the optimal lag time that was found, we then calculated the correlation values between summed rainfall in the previous weeks and spectral indices of NDVI and EVI on a pixel by pixel basis, using CORRELATE function available in IDRISI GIS. Based on the correlations obtained we created a layer of non-burnt areas, as those areas where correlation between summed rainfall and NDVI or EVI was below 0.63 and 0.53, respectively. We were then able to select 61 regions of interest

(ROIs) within the MODIS image where wildfires occurred after September 2000. For each of these ROIs we examined temporal trends in spectral indices values as a function of the time since the fire.

To examine the recovery of vegetation over time periods longer than eight years, we used Landsat and Aster satellite images. Due to the lower temporal resolution it was not possible to examine seasonal trends in these images, only annual and decadal trends, as a function of the time since the last fire. To this end 63 ROIs were identified on Landsat images, and 84 ROIs within the Aster images (147 ROIs altogether).

3. RESULTS

Highest correlations between summed rainfall and bi-weekly MODIS spectral indices were found for a lag time of 2.5 months, with NDVI values being the most affected by rainfall fluctuations (Table 2).

		MODIS bands				MODIS spectral indices				
		Blue	Red	NIR	MIR	BI	CI	NDVI	EVI	SAVI
Correlation with rainfall previous 2.5 months	Full scene	-0.49	-0.72	-0.46	-0.67	-0.69	0.41	0.75	0.70	0.65
	Non-burnt areas	-0.60	-0.76	-0.40	-0.77	-0.77	0.47	0.89	0.83	0.78
Correlation between mean value of spectral indices within ROIs and	time since fire	-0.65	-0.89	-0.80	-0.91	-0.86	0.74	0.62	0.45	0.37
Correlation between mean vegetation cover within ROIs and	time since fire	0.73	0.90	0.83	0.92	0.88	0.67	0.70	0.49	0.44

Table 2: Seasonal trends in MODIS spectral indices values as a function of summed rainfall, and the annual changes in MODIS spectral indices values as a function of time since fire.

Soil spectral indices proved superior to vegetation spectral indices in monitoring the recovery of dune vegetation and crust cover following wildfires. This was evident from the higher correlation values found between spectral indices with burnt ROIs and time since fire (Table 2), as well as from observing the trend of recovery. As an example, the brightness index showed a gradual increase in its values following fire (reaching pre-fire values after approximately 20 years; Figure 1a) whereas the EVI returned to pre-fire values after three years.

Landat and Aster based trends of post-fire recovery that were based on longer time series than those of MODIS images found higher correlations between time since fire and vegetation cover based on soil spectral indices, than when vegetation cover was calculated based on vegetation spectral indices (Table 3). The spectral index that offered the highest correlation with time since fire was the BSCI (Table 3, Figure 2).

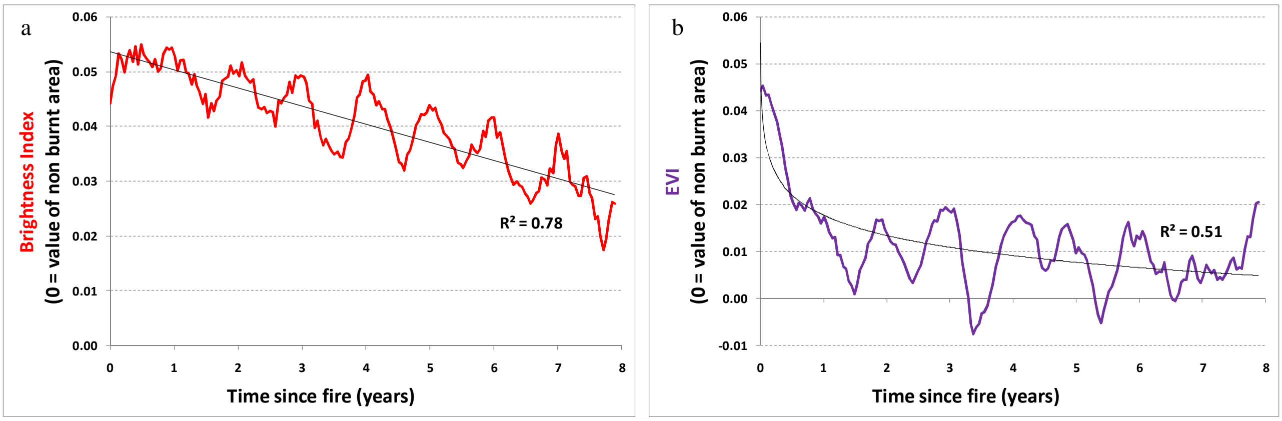

Figure 1: Changes in spectral indices with time since fire, based on 61 ROIs from MODIS images. (a) Brightness index (BI); (b) Enhanced vegetation index (EVI).

vegetation indices			soil indices		
NDVI	SAVI	EVI	BSCI	BI	CI
0.69	0.28	0.16	0.91	0.85	0.58

Table 3: Correlation between vegetation cover and time since fire within 147 ROIs from Landsat and Aster images.

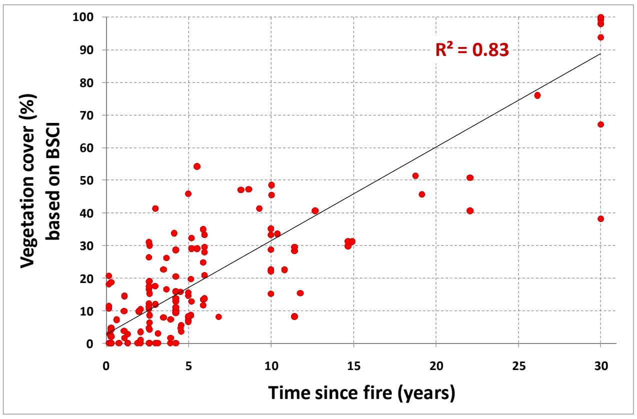

Figure 2: Vegetation cover recovery after fire.

4. CONCLUSIONS AND DISCUSSION

Traditional vegetation indices were not sensitive enough for monitoring the recovery of desert dune vegetation following wildfires. This may be explained by the large proportion of non-photosynthetic vegetation and biological soil crust in desert areas, which can only be mapped using hyper-spectral sensors (Asner and Lobell, 2000).

Soil spectral indices such as the brightness index or the BSCI were more effective in monitoring vegetation recovery after wildfires. Changes in the values of this index represent overall changes in surface albedo, governed by biological crust, annual and perennial plants.

Following wildfire vegetation recovers very quick, reaching 15% in about 5 years or even earlier.

Assuming that above a vegetation cover threshold of 15%, aeolian activity of sand movement becomes negligible (Wiggs et al., 1995; Lancaster and Baas, 1998), means that sand movement on these desert dunes is mainly restricted to less than five years after wildfire.

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