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Impact of wildfire on interdune ecology and sediments: an example from the Simpson Desert, Australia

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<http://dx.doi.org/doi:10.1016/j.jaridenv.2010.05.032>

PUBLISHER

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Strong, Craig L., Joanna E. Bullard, Chloe Dubois, Grant H. McTainsh, and Matthew C. Baddock. 2019.
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1 **SHORT COMMUNICATION**

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3 **Impact of wildfire on interdune ecology and sediments: an example from**
4 **the Simpson Desert, Australia.**

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SHORT COMMUNICATION

Impact of wildfire on interdune ecology and sedimentology: an example from the Simpson Desert, Australia.

ABSTRACT

The stability of many sand dunes and their interdunes is dependent on vegetation and surface crust cover. When this cover is removed, the sand can be activated and fine sediments deflated making the dunefields into sources of dust. This paper reports the impact of devegetation by wildfire on an interdune in the Simpson Desert, Australia. The fire occurred in 2001 and six years after the event pronounced differences between a pair of burnt and unburnt sites was clearly discernible. The variables examined included vegetation assemblage, cyanobacteria abundance and sediment aggregation, particle-size distribution and colour; but whether they apply to all such situations is uncertain. Rate of recovery has been slow and the differences are likely to have been sustained by a combination of negative feedback processes and climate.

Keywords

Fire, Wind erosion, Cyanobacteria, Dust, Biogeomorphology, Vegetation

58

59 Until recently, global dunefields have not been recognized as
60 significant dust sources because they have a low fines (<100 μm) content,
61 and often have a vegetation cover which stabilises the surface and reduces
62 aeolian activity by increasing surface roughness; reducing near surface wind
63 velocities and promoting sediment deposition (Wiggs et al., 1994; Hesse and
64 Simpson, 2006). In addition, biological soil crusts can play an important role
65 in dune stabilization (Belnap, 2001) through physical binding of sediment with
66 their filaments or via the excretion of polysaccharides which act as a glue
67 (McKenna Neuman et al., 1996). Such crusts are often capable of surviving
68 drought conditions, continuing to stabilize dune surfaces (Eldridge, 2001)
69 even when vascular plant cover declines.

70

71 Dust emissions from semi-stabilized dune areas can however be
72 significant if they are reactivated by climate change or vegetation removal due
73 to fire or grazing pressure – for example, Bullard et al. (2008), and McGowan
74 and Clark (2008) have documented dust storms in Australia where the
75 sediment source can clearly be traced to firescars in dunefields. The
76 associated decrease in surface roughness and threshold wind velocity
77 increases potential wind erosion (Wiggs et al., 1994) and saltating grains
78 promote the entrainment of any fines in the dune sediment (resident fines).
79 Saltation activity can also generate new dust-sized particles by abrasion
80 and/or the removal of clay coatings on the grain surfaces (Bullard and White,
81 2005; Crouvi et al., 2008) but these will rapidly be removed. Dune
82 geomorphology can also be modified following devegetation, for example the
83 dune may become taller and steeper, be reworked into smaller dunes, or
84 become reoriented to reflect a wider range of wind speeds (Tsoar and Møller,
85 1986; Hesse and Simpson, 2006).

86

87 This paper focuses on the impact of fire on interdune ecology and
88 sedimentology. It is unclear how rapidly vegetation and crust cover can re-
89 establish in a dunefield once devegetated by fire, but the effects are known to
90 last from one or two years to over ten years (Eldridge, 2001; Wiggs, 2006).
91 Rate of recovery is likely to be determined by a combination of burn severity,

soil type and climate, as it is in most environments, but in dunefields aeolian activity and position on the dune (erosional, depositional or stable locations) are also important (Lesica and Cooper, 1999). Once a sand surface has been reactivated, it becomes hostile to vegetation and crust redevelopment because many species have a low tolerance for mobile surfaces (Kadmon and Leschner, 1995) and deflation of the fine fraction will significantly reduce the moisture-holding capacity of the soil. In addition, the impact of dune topography on airflow and sediment transport means that dune crests are usually less stable than interdunes, so the latter will support more rapid ecological recovery. This idea is supported by Wiggs (2006) who found that vegetation renewal in interdunes was twice as rapid as those in crestral regions.

This difference in aeolian activity with position means that dune crests typically contain less fine material, whilst interdunes contain more, and hence interdunes may be more important dust sources immediately post-fire. For example, in the southwest Kalahari dunefield, the proportion of dust-sized particles in interdunes can be up to 7 % whilst dune crests only contain 1-3 % fines (Livingstone et al., 1999). Dust production by abrasion and coating removal will continue while the surface is active, and long-term retention of dust particles in the dune surface layers is only likely to take place once vegetation cover has re-stabilised the surface. In comparison to an unburnt dune, therefore, a dune recently devegetated by fire would be expected to have less vegetation and biological crust cover, potentially a different vegetation structure given that annuals and perennials recolonise at different rates, and to contain less fine sediment having lost dust-sized material through deflation. These feedback processes are summarized in Figure 1 and mean that although dune activation occurs rapidly post-fire, re-stabilization through recovery of both ecology and sedimentology may be a much longer processes. Fire can also have an impact on sediment colour, causing particles to redden by dehydrating the hydrated iron oxides in dune sand grain coatings (Jacobberger-Jellison, 1994).

Despite these expected physical changes there is a notable paucity of literature exploring the effects that fire has on interactions among dune ecology, sedimentology and geomorphology. Dunefield responses to vegetation change stimulated by climate change have been studied and modeled (Hugenholtz and Wolfe, 2005; Bullard et al., 1997), but responses to the impacts of fire are typically limited to the post fire response of vegetation (Winkworth, 1967; Letnic, 2003) or sediment mass collected downwind of burnt areas (Whicker et al., 2002; Sankey et al., 2009) and most field studies take place within two years of the event.

This short communication reports the results of a field study to quantify the ecological and sediment characteristics of an unburnt and burnt site in the Simpson Desert, Australia, six years post-fire, to explore whether any of the expected differences persist. The dunefield is dominated by partially-vegetated linear dunes and natural fires typically occur following dry electrical storms in the austral summer (Griffin et al., 1983). Wildfires are common throughout central Australia wherever the spinifex grass community exists, with Winkworth (1967) suggesting that at any one time 80% of the dune field vegetation communities within the Northern Territory are rejuvenating following fires or in a degenerative state due to lack of moisture. Fire return interval varies, but can be as short as 3-10 years (Kimber, 1983). Fires in the arid zone are more common and more widespread in years following above-average rainfall which increases vegetation fuel loadings; conversely, drought periods tend to be associated with less frequency and smaller fires (Turner et al., 2008).

Fires leave clear 'scar' marks that are visible on satellite imagery and aerial photographs (Figure 2). The site chosen (25°18'23" S, 137°56'2" E) covers an area of 2807 km² and is known to have burnt prior to 1984 with the most recent fire affecting the area in 2001. Fieldwork was conducted in May 2007 – six years after the last burn. Given the importance of interdunes as relatively stable environments and stores of dust-sized material, sampling focused on two randomly assigned 40 m long west-east oriented transects across the same south-north oriented interdune (Figure 2). The northern-

most was located entirely within the area burnt in 2001; the transect 1.3 km to the south was located within an area that satellite imagery indicates has not burnt since at least 1984. Due to the proximity of the transects, it was assumed that the two locations had common vegetation and sediment characteristics before the fire and experience the same climate conditions. Soils comprise deep and infertile red siliceous sands.

In the field, vascular plants and cyanobacteria percent cover were calculated using a 1 m² quadrat placed at 5 metre intervals (n=9 at each site). Any vascular plants present were identified and recorded as either annual or perennial. Surface soil samples (0-20 mm depth) were taken at the same intervals and indicators of aeolian activity were noted (aeolian sand ripples, slipfaces). In the laboratory, cyanobacteria abundance was estimated through in-vitro incubation and light microscopy. For this, the soil samples were kept in an incubation chamber, hydrated with deionised water for 3 days, exposed to 12 hour light and kept at 20 °C. Searching for cyanobacteria filaments occurred across seven fields of view (@ 100x magnification) for 3 minutes each, and presence/absence of filaments was recorded. Soil organic carbon content was determined using loss-on-ignition. Polysaccharide content was extracted from the soil according to Chaplin and Kennedy (1986) and measured as per Lowe and Carter (1993). Sediments were sieved at 0.85 mm to determine percent dry aggregation (Leys et al., 1998). High resolution particle-size analysis was conducted and deconstructed to individual sediment populations following the methods of Leys et al. (2005). Sediment colour can be indicative of grain history and processes operating on the particles, however it can also be affected by fire as thermally-induced reddening takes place at temperatures from 250°C to 400°C (Jacobberger-Jellison, 1994). Sediment redness was quantified using a GER 3700 Spectrometer to ascertain any differences between the sites.

After 6 years there are still differences between the unburnt and burnt sites, with respect to vascular plants and cyanobacterial crust cover (Table 1). Vascular plants at the burnt site comprised mostly annual species such as *Sclerolaena* sp. (copperburrs) and *Ptilotus* sp. (longtails), with *Triodia*

193 *basedowii* (spinifex) the only observed perennial. At the unburnt site annuals
194 included *Sclerolaena* sp, *Eragrostis basedowii* (neat lovegrass) and *Portulaca*
195 *oleracea* (pigface) and perennials comprised *Triodia basedowii*, *Artistida*
196 *cortorta* (tall kerosene grass), *Eragrostis eriopoda* (woolybutt) and *Abutilon*
197 *otocarpum* (desert chinese lantern). No cyanobacterial crust was visible at the
198 burnt site, however laboratory study revealed that some cyanobacterial cells
199 were present.

200
201 The sites also had different sediment properties. The unburnt site
202 contained a high proportion of aggregated sediment (21 %). Aggregates are
203 a product of soil formation processes and are easily broken down during
204 saltation, which is probably why there are fewer at the burnt site. Analysis of
205 the soil particle-size distributions highlights common populations (modes at 62
206 μm and 100 μm) at both sites, but the presence of a third finer population (16
207 μm) in the unburnt site likely reflects the importance of vegetation in trapping
208 fine particles (Danin and Ganor, 1997). Any such fine sediments will have
209 been deflated from the burnt site. The sediments at the burnt site were found
210 to be redder than those at the unburnt site. Under conditions of enhanced
211 aeolian activity, the clay coatings present on grains in this part of the Simpson
212 dunefield would be expected to be removed by aeolian abrasion, reducing the
213 sediment redness (Bullard and White, 2005), however the fire would be
214 expected to enhance the sediment redness. At this interdune site, it must be
215 assumed the fire-induced reddening exceeded any reduction in red colour
216 caused by aeolian abrasion.

217
218 Fire has had a marked effect on the dune ecology and sedimentology
219 and all the expected differences between the burnt and unburnt sites at this
220 one location and one sampling time are clearly discernible six years after the
221 event. Much vegetation in the desert dunefields of Australia is adapted to fire
222 and has developed survival strategies such as fire ephemerals, post-fire
223 resprouting or obligate seeding (Winkworth, 1967; Wright and Clarke, 2007).
224 These plants include the *Triodia* species (spinifex) which is common in much
225 of arid Australia, including the north Simpson dunefield. Spinifex grassland
226 fuels large-scale fires but quickly regenerates post-fire (Letnic, 2003; Griffin et

al., 1983) and was the only perennial observed at the burnt site. Just as fire frequency is dependent on rainfall, so too is post-fire recovery of both vegetation and cyanobacterial crusts. Although the timescale for vascular plants recovery varies depending on the overall assemblage and degree of adaptation to fire, many studies have highlighted that climate also plays an important role (Whicker et al., 2006).

For the burnt site examined here, it is likely that ecological recovery rate has been slow due to a series of low rainfall years. Total rainfall at the Birdsville meteorological station, southeast of the study site, was below the long term average (164.9 mm yr^{-1}) for 5 out of the 6 years between the fire and these field observations (BoM, 2009). Although episodic rainfall facilitates short-lived annual plant growth it also creates moisture competition between annual and perennial seed germination, restricting regrowth to rapid germinating species. Following a major fire in central Australia, it has been proposed 630 mm of cumulative rainfall is required for sufficient fuel to develop and reburn (Griffin et al., 1983). Biocrusts can respond rapidly to relatively low rainfall events but they too require follow-up rain for strong growth (Belnap, 2001).

As suggested in Figure 1, however, it is not just the biological characteristics of dunes that change post-fire, and rainfall is not the only variable controlling recovery. Enhanced aeolian activity will also slow the rate of recolonisation by cyanobacteria and vegetation (Hesse and Simpson, 2006), but even if crusts can start to develop, their resistance to wind erosion is strongly dependent on a lack of surface disturbance (Belnap and Gillette, 1997). Total annual dust concentration observed at Birdsville suggests higher than average aeolian activity over this time period. Sedimentological evidence, such as lower fines content and lack of particle aggregation, support the idea of sustained aeolian activity at the burnt site. As an active surface prevents the retention or storage of fine material, this may explain why Bullard et al. (2008) found that most dust source locations within the Simpson dunefield were unique; i.e. once an area within a firescar had been a

dust source, within the three years of their study, it was not recorded as a dust source again.

Existing research points in different directions with regard to the impact of fire on ecological patchiness in arid areas. For example, Ravi et al. (2007) suggest that fire can promote vegetation homogeneity by the evening out of resources, whereas Lesica and Cooper (1999) suggest that surface instabilities will lead to a heterogeneous distribution of flora and fauna. Where the landscape is dominated by sand dunes, the dune geomorphology and sedimentology can also clearly be affected both directly and indirectly by fire. These affects will be at a smaller spatial scale than the area affected by climate change; most fires in the Australian deserts affect an area of < 100 km² (Turner et al., 2008), most in southern Africa affect < 10 km² (Korontzi et al., 2003), but in both regions, very extensive fires can occasionally occur. Models of landscape-scale biogeomorphic response to climate change demonstrate that dune activation occurs rapidly whereas stabilization is a much longer process (Hugenholtz and Wolfe, 2005). This pattern will also be observed following fire where the initial perturbation to the biogeomorphic system will be rapid, and, due to negative feedback between aeolian activity and ecological recovery, the return to a semi-stable or stabilized state will take significantly longer. Such feedback may lead to patchy variation in dunefield morphology, dunefield ecology and also the presence of vegetated and unvegetated dunefields under the same climatic conditions.

Acknowledgements

The field observations reported were partly funded by The Leverhulme Trust, (JEB, MCB) and the laboratory analyses by the Australian Research Council (CS, GMcT). The authors would like to thank Dr. Kevin White, Reading University, for the spectrometer analyses.

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Table 1 Ecological and sedimentological characteristics of an unburnt and burnt interdune. The *t* values of significant results are highlighted in bold *, *t*<0.01; **, *t*<0.001; ***, *t*<0.0001.

	Variable	Unburnt site n=9		Burnt site n=9		<i>T</i> values
		Mean	Standard error	Mean	Standard error	
Ecological indicators	Loss on ignition %	1.057	0.083	0.432	0.015	-7.43***
	Vegetation cover %	37	5.8	5	1.2	-5.28***
	No. annual species	4	—	5	—	—
	No. perennial species	5	—	1	—	—
	Cyanobacterial crust cover %	53	6.3	0.7	—	-8.55***
	Polysaccharide concentration (ppm)	11.05	2.60	1.24	1.05	-3.50**
	Total filament (cell) counts	401.1	98.3	70.2	10.6	-3.55**
	Aggregates > 850 µm %	21	1.58	0.1	0.06	-12.9***
Sediment indicators	Disaggregated sediment mode 100 µm % vol.	83	—	88	—	—
	Disaggregated sediment mode 62 µm % vol.	13	—	12	—	—
	Disaggregated sediment mode 16 µm % vol.	4	—	0	—	—

Figure 1 Feedback model to illustrate processes leading to post-fire increased dune activity and destabilization.

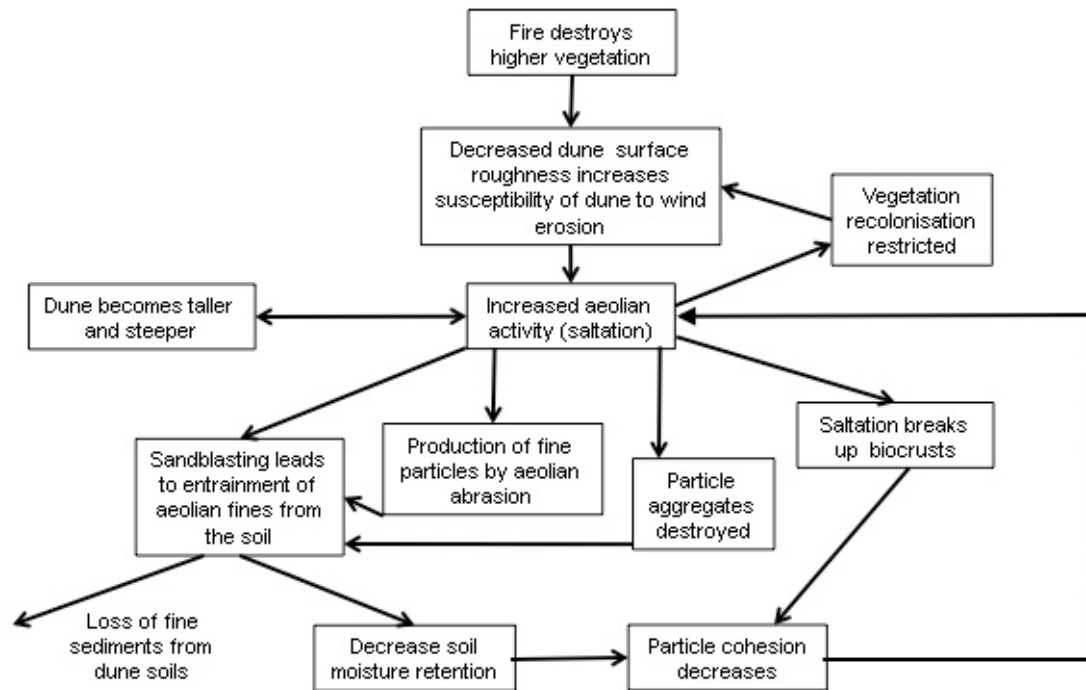


Figure 2 True colour Landsat 7 ETM images from a) prior to the burn; b) the first image available after the burn and c) the same month that the fieldwork was undertaken. Inset map shows the area of the image, and the white cross marks the site of the fieldsite. Photographs of the fieldsite showing d) aeolian sand ripples between sparse vegetation in the burnt interdune; e) well-vegetated unburnt interdune.

