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Assessing the geomorphic disturbance from fires on coastal dunes near Esperance, Western Australia: Implications for dune de-stabilisation

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ABSTRACT

Fire is commonly listed as a contributing disturbance to dune re-activation. This paper aims to characterise post-fire disturbance to vegetation and soil surface, and aeolian activity on coastal dunes. Field data were collected in February 2016 at two sites on coastal dunes near Esperance, Western Australia (WA) after recent wildfires in November 2015 and January 2016. We measured wind profiles at burnt and unburnt sites, and assessed recent sand movement, protective covering and burn severity. We also used remote sensing and on-site photos to monitor local patterns of short term biomass recovery. Results suggest that burnt vegetation enables near surface winds to flow with a similar profile shape to bare surfaces. Speed-up ratios (SR) were higher by 5–120% on burnt surfaces when compared with vegetated. However, burnt vegetation did not show the same topographic acceleration as bare dunes. This decelerating effect correlated with surface-level ground cover after removing topographically sheltered data points ($r^2 = 0.8$, $p < 0.001$). Burnt surfaces had up to 30% more ripples than vegetated sites, but had significantly fewer ripples than previously-bare surfaces (by 60–100%). This was likely due to ground cover ($r^2 = 0.95$, $p < 0.001$). Effective ground cover appears to be > 40%. At one burnt transect a high burn intensity may have inhibited short term germination and re-sprouting. Fire as the sole disturbance is not a major threat to the stability of these dunes, however, extreme burn intensities may leave dunes susceptible to further non-fire disturbance events.

1. Introduction

Coastal sand dune systems are dynamic environments, sometimes active with shifting sand, sometimes stabilised by plant growth, and often a mix of both (Hesp, 2013). Transitions from stable dunes to active dunes, termed 're-activation', has been observed but is not well understood (Barchyn and Hugenholtz, 2013). A hysteresis in dune behaviour occurs in response to environmental drivers, meaning significant environmental change is needed for re-activation (Tsoar, 2005). This may be gradual change (e.g. wind climate), or abrupt disturbance (e.g. storms) removing vegetation and leaving the surface susceptible to erosion by wind (Hesp and Martinez, 2007; Barchyn and Hugenholtz, 2013). Where this erosion forms a topographic depression known as a blowout, it may then develop into a substantial 'transgression' of sand moving parallel to the dominant wind direction (Barchyn and Hugenholtz, 2013; Hesp, 2013; Yizhaq et al., 2013). However, the nature and precise role of the disturbances necessary for destabilisation are poorly defined (Barchyn and Hugenholtz, 2013). Common suggestions include stock grazing, feral animal grazing (e.g. rabbits), drought, cyclones (or other storm-related foredune scarping), geomorphic changes (e.g. sand supply), anthropogenic disturbances, and fire (Conacher, 1971; Martini, 1981; Pye, 1982; Christensen and Johnsen, 2001; Hesp, 2002; Wiles et al., 2003; Lepczyk and Arbogast, 2005; Buynevich et al., 2007; Barchyn and Hugenholtz, 2013; Yizhaq et al., 2013; Ruz and Hesp, 2014). Barchyn and Hugenholtz (2013) propose that multiple disturbances are likely necessary. Fire is commonly listed as a significant contributing disturbance to deflation events, particularly when combined with periods of extreme climate (Filion, 1984; Filion, 1987; Filion et al., 1991; Seppälä, 1995; Käyhko et al., 1999; Mann et al., 2002; Carcaillet et al., 2006; Matthews and Seppälä, 2014). Indeed, the monitoring of post-fire soil erosion in grasslands and on dunes has shown increases in the saltation of sand

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grains (Zobeck et al., 1989; Whicker et al., 2002; Vermeire et al., 2005; Sankey et al., 2009 a; 2009 b; Ravi et al., 2012; Stout, 2012). However, contemporary observations often show that where dune vegetation is burnt, no significant landscape changes take place (Vermeire et al., 2005; Ward, 2006; Myerscough and Clarke, 2007; Levin et al., 2012).

With the broader goal of understanding the role that fires might play in destabilising dunes, the aim of this paper is to explore the nature of the disturbance to vegetated coastal dune surfaces after fires. Barchyn and Hugenholtz (2013) suggest that destruction of vegetation must be sufficient to break the protective skin of the dune and uncover bare and loose sediment. This includes aboveground biomass (covering the surface and reducing wind speed), and soil cohesion provided by roots, biogenic crusts, and soil properties (Wolfe and Nickling, 1993; Barchyn and Hugenholtz, 2013). Similarly, Arens et al. (2007) hold that dune activity is determined by the availability of loose sand, the capacity for vegetation to grow and offer protection, and the strength of sand-moving winds. Thus, post-fire wind erosion can be related to the degree of protection and wind-obstruction provided by remnant burnt vegetation and litter, and the post-fire soil cohesion (Wolfe and Nickling, 1993; van Dijk et al., 1999; Barchyn and Hugenholtz, 2013). These factors influence the availability of sediment, and the application of wind force to the surface. Additionally, the short-to-medium term state of the post-fire surface coverage is strongly influenced by ecological processes, particularly regeneration patterns and rates associated with dominant or significant species present (Díaz-Delgado et al., 2003; Myerscough and Clarke, 2007). These factors can be assessed with ground cover surveys and wind measurements on burnt sites and unburnt control sites, supplemented with measurements of post-fire aeolian activity. This combination has been used to effectively characterise post-fire disturbance in desert settings in the Kalahari (Wiggs et al., 1994) and Central and Western United States (Whicker et al., 2002; Miller et al., 2012). These studies reported decreased ground cover and drag effect on wind, and increased aeolian activity on burnt sites, but with no blowouts occurring during the study periods. However, the characteristics of fires differ greatly between climatic regions (Bowman et al., 2009), and no such study has been done on temperate or coastal dunes.

To test the hypothesis that fire plays a role in dune de-stabilisation, this paper reports on field data collected at two sites on coastal dunes near Esperance, Western Australia (WA) after recent wildfires. We assessed whether and how the remnant burnt vegetation and litter is acting to protect the surface by measuring wind profiles at selected burnt and unburnt sites, as well as recording evidence of recent sand movement. Burnt and unburnt surfaces were assessed in terms of protective covering by vegetation, litter and crust. We also made visual estimations of local burn severity. Furthermore, we used remote sensing and on-site photos to monitor short term biomass recovery. The two sites surveyed in February 2016 had been burnt in November 2015 and January 2016 respectively with different intensities. This allowed comparison of disturbance from fires with higher and lower burn severities.

2. Materials and methods

2.1. Study area

Coastal dunes to the east and west of Esperance, WA exist on a coastal terrain of Cainozoic and Quaternary sediments amidst gneissic and granitic bedrock hills (Fig. 1) (Semeniuk and Semeniuk, 2011). The reworking of shore-sediments has formed large calcareous dunefields with complex parabolic, star and barchan forms (Fig. 1) (Semeniuk and Semeniuk, 2011). Dunes east of Esperance overlie a Holocene higher sea-level deposit forming a cemented calcrete sheet at the level of the once higher water table (~2 m above present sea level). These sheets are occasionally exposed in active dune areas (Semeniuk and Semeniuk, 2011). Blowouts and active dunes persist despite disconnection from the beach and associated sediment delivery (Overheu et al., 1993). Road cuttings expose buried soil profiles indicative of multiple phases of recent dune activity (Overheu et al., 1993). Stabilised dunes are typically complex long-walled parabolic forms (Overheu et al., 1993). Older, less well-defined, Pleistocene dunes are oriented east-west, and have lithified calcrete cores (Overheu et al., 1993). Some areas of dune swales were cleared for grazing after European settlement but have since been abandoned to hobby farms and residential areas (Overheu et al., 1993). Several existing blowouts are presently accessible for recreational 4WD and All-Terrain Vehicle (ATV) use (Fig. 2b). The Holocene parabolic dune vegetation has been characterised as tall closed shrubland dominated by *Leucopogon parviflorus* and *Acacia* sp., while the dune swales exhibit low closed shrubland dominated by *Acacia* sp. (Overheu et al., 1993).

During the Western Australian summer of 2015/16, two fires burned extensive areas of coastline near Esperance. On 17 November 2015, a lightning strike sparked a fire 13 km east of Esperance, near Mullet Lakes (Fig. 1; 2). Driven initially by winds from the north-west, approximately 14240 ha of land burned with moderate intensity through reserve areas and some rural properties toward Wylie beach between Esperance and Cape le Grande (Fig. 1). On 4 January 2016, driven by winds blowing predominantly from east-north-east, a second lightning fire burned 13500 ha from 10 km west of Esperance (near Pink Lake) through unmanaged reserve and National Park land across 35 km of coastline toward Quallilup Beach. This fire had a comparatively high intensity. Aside from some cleared land, both fires were confined to uninhabited areas of coastal dune heath vegetation. The fires burnt extensive areas of dune and moved toward the coastline up to the lee slope of the foredunes, leaving most incipient foredunes and some foredune crests unburnt (Figs. 1a; b and 2).

From 10-15 February 2016, data were collected along four separate transects shown in Fig. 1a; b. At Quallilup Beach one transect named 'Quallilup 1' (Q1) ran across an area of previously vegetated dune, burnt with a high intensity, and another transect, 'Quallilup 2' (Q2), ran across a currently active dune (Q2) (Fig. 1a; 2 b). At Wylie Beach we ran one transect named 'Wylie 1' (W1) across an area burnt with moderate intensity, and another, 'Wylie 2' (W2), along a remnant patch of unburnt dune with heath vegetation (W2) (Figs. 1b and 2a). Wind profile and vegetation measurement locations along each transect were chosen to represent key dune features (e.g. foredune crest, interdunes, windward slopes, and inland dune crests) (Table 1). The enumeration of the survey locations [e.g. 'Q1_2(1)'] is structured as follows: The first letter and associated number (e.g. 'Q1') indicates the transect; the second number (following an underscore or dash) indicates the anemometer staff used at the location (1 refers to the beach reference staff and 2 refers to the roving staff – further details for anemometer use are outlined in Section 2.2); and the final number (within the parentheses) indicates the point along the transect, beginning at '0' for the beach reference location.

The Esperance region experiences an average annual rainfall of 617 mm (1969–2016), peaking in July, with the lowest rainfall occurring from December to January (Australian Bureau of Meteorology, www.bom.gov.au/climate/data/). The annual mean maximum temperature is 21.9 °C, peaking at 26.2 °C through January and February. Regional winds are typically strongest in December through to February (mean 3 pm speed = 29.2 km/h). Esperance experiences generally