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Fire behaviour on engineered landforms stabilised with high biomass buffel grass

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ABSTRACT

Rehabilitated lands created by open-cut coal mines are generally protected by land managers from fire and grazing disturbances. This practice is employed to reduce negative impacts, such as erosion, on the developing ecosystems. However, fire exclusion over long periods inadvertently contributes to increased fire risk on rehabilitated landforms, particularly when high biomass, mono-dominant grasses form a major component of these new ecosystems. In May 2015, an experimental fire burnt 117 ha of rehabilitation at a coal mine site in the Bowen Basin, Australia. Standing grass fuel loads, dominated by buffel grass (*Cenchrus ciliaris* L.), were up to 9.3 t/ha in grassland areas and 5.3 t/ha in areas of open woodland. Average litter fuel loads were 2.4 and 3.6 t/ha for grassland and open woodland, respectively. Calculated fire intensity was higher in grassland (4612 ± 502 kW m^{-1}) than open woodland areas (1977 ± 804 kW m^{-1}) indicating that rehabilitated landforms dominated by buffel grass may represent a higher fire risk to mine sites and regional areas in the Bowen Basin when compared to the original vegetation. Fire behaviour reflected the varying underlying terrain, fuel loads and surface soil or overburden conditions. Further research is recommended to investigate fire behaviour in buffel grasslands across a range of fuel load and curing conditions, with the aim to develop an invasive grass fire spread model that can be used inform both landscape reconstruction prescriptions for ecological engineers and more broadly in managing the fire risk across landscapes dominated by these vegetation types.

1. Introduction

For more than four decades, rehabilitated mined lands in the Bowen Basin of Central Queensland, Australia, have been planted with buffel grass (*Cenchrus ciliaris*), to provide rapid, stabilising and erosion reducing cover to reshaped landforms (Erskine and Fletcher, 2013; Grigg et al., 2000; Harwood et al., 1999; Naidu et al., 1997). Historically introduced and encouraged by pastoralists in the early 1900s (Humphreys, 1967), buffel grass has been extensively used by mine managers in seeding mixes due to the increased establishment success, drought tolerance and high pasture yields compared with other native and introduced species (Coaldrake and Russell, 1970; Edye, 1975).

With over 40 open cut coal mines in Central Queensland (DNRM, 2016), a considerable amount of land is either disturbed mine footprint (156,200 ha), or rehabilitated landforms (29,200 ha) (Dale, 2015). The bulk of rehabilitation consists of relatively young (<30 year old) developing ecosystems, with demonstrated buffel grass biomass fuel loads of up to 20 t/ha (Grigg et al., 2000).

Rehabilitation managers are tasked with creating landforms that are safe, stable, sustainable and non-polluting (DEHP, 2014); and many mine sites across Queensland aim for an end use of native bushland, using local reference communities as targets (Erskine et al., 2007). However, due to the invasive nature of buffel grass, many areas in Central Queensland are now dominated by, and resemble, buffel grassland communities rather than native pastures or local remnant native ecosystems (Erskine and Fletcher, 2013).

The invasive nature of buffel grass and the resulting ecological impacts are well documented in Australia (Butler and Fairfax, 2003; Eyre et al., 2009; Fairfax and Fensham, 2000; Fensham et al., 2015; Franks, 2002; Miller et al., 2010; Wang et al., 2008) and in North and South America (Marshall et al., 2012). Buffel grass is a high biomass C4 grass and has been shown to outcompete native semi-arid grasses because its root systems are larger in diameter and can grow to greater depths (Christie, 1975). As a result, buffel grass can achieve higher growth rates in a variety of nutritional

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conditions (Christie and Moorby, 1975). Buffel grass has negative impacts on biodiversity (Fairfax and Fensham, 2000; Jackson, 2005; Smyth et al., 2009) and demonstrates a fire positive feedback loop. High fuel load conditions lead to intense fires that become more frequent; which in turn favour conditions for buffel grass dominated communities (Butler and Fairfax, 2003; McDonald and McPherson, 2011) in what is termed the 'grass-fire cycle theory' (D'Antonio and Vitousek, 1992). Current research suggests that the most important vector for buffel grass invasion and migration is linked to seed dispersal through adjoining invaded lands, rather than through impacts such as fire and grazing (Fensham et al., 2013).

Other invasive grasses create high fuel loads that far exceed the biomass of native grasses, resulting in altered fire regimes (Brooks et al., 2004). In northern Australia's monsoonal savannah, grasslands dominated by gamba grass (*Andropogon gayanus*) have recorded fuel loads up to 30 t/ha (Setterfield et al., 2014) or seven times that of native sites (Rossiter et al., 2003). Similarly, mission grass (*Pennisetum polystachion*) can produce fuel loads almost five times that of native grasslands (Douglas et al., 2004). In southern Australia, the pasture species phalaris (*Phalaris aquatica*), when left unmanaged, can produce fuel loads three times greater than grasslands dominated by the native kangaroo grass (*Themeda triandra*) (Stoner et al., 2004).

Indeed, the success of invasive, high biomass grasses has led to calls for a review of operationalised fire behaviour models to account for such high fuel loads (Simmons et al., 2006), and for improved planning to manage regional fire threats (Setterfield et al., 2013). Compounding the problem, future climate conditions are likely to favour buffel grass migration into southern Australian states (Martin et al., 2015b) leading to further dominance of the species in more fire prone environments.

The risks that mine managers face from uncontrolled fire are required to be managed to within acceptable limits and by reasonably practicable means under the Workplace Health and Safety Act (2011). However, a limited understanding of fuel loads increases the risk that uncontrolled fire poses to rehabilitated landforms that are commonly located in close proximity to mining infrastructure, neighbouring communities, open coal pits with exposed flammable coal seams and flammable stockpiled coal resource. Mine lease holders in Queensland have the added responsibility of managing and protecting any endangered regional ecosystem communities, flora and fauna listed federally under the Environment Protection Biodiversity and Conservation Act (1999) or the state Vegetation Management Act (1999), and culturally significant sites such as Aboriginal scar trees or middens under the Aboriginal Cultural Heritage Act (1994). Additionally, uncontrolled fire in rehabilitated landscapes within Central Queensland poses an unspecified risk to mine site closure goals, with the potential to create altered states and stalled ecological trajectories (Grant, 2006).

To date, the bulk of fire research conducted on mine site rehabilitation in Australia has been on developing forest ecosystems in Northern and Western Australia (Chaffey and Grant, 2000; Cook, 2012; Grant, 2003; Grigg and Grant, 2009; Herath and Lamont, 2009). As a result, fire behaviour in buffel grasslands created through mine rehabilitation in semi-arid Australia is largely unknown.

In this study, we aim to examine the grass fuel component and resulting fire behaviour on 21-year-old mine site rehabilitation dominated by buffel grass. We discuss the implications that site preparation techniques can have for fire management at both the mine-site scale and the broader regional scales as well as wider implications for the mining industry. Our findings also provide insights for fire management on disturbed landscapes where buffel grass is dominant.

2. Methods

2.1. Site description

The fire experiment took place at the Wesfarmers Curragh open-cut coal mine, located approximately 200 km west of Rockhampton and 15 km north of the township of Blackwater in Queensland, Australia (Fig. 1). GIS analysis indicates that 1427 ha of the lease area has been rehabilitated.

2.2. Rehabilitation techniques

The experimental block was stratified based on manual aerial photography interpretation (API) using a historical image taken in 1996 and an orthophoto taken in 2013. The historical image was used to determine topsoil coverage, while the 2013 image was used to confirm the delineation of vegetation boundaries. The site was rehabilitated in early 1994, using two rehabilitation techniques:

(i) Topsoil applied with 100% coverage of the reshaped landform. Understorey species (grasses and legumes) were seeded in 10 m wide swathes alternating with 10 m swathes of native trees and shrubs along the contour.
(ii) Topsoil applied in 10 m wide swathes along the contour; alternating with 10 m wide swathes of bare spoil (see Supplementary Fig. 5). Topsoiled swathes were seeded with grass and legume species; while spoil swathes were seeded with native trees and shrubs.

Deep ripping and seeding occurred simultaneously, and no fertiliser was applied to the site. The two site preparation techniques produced different vegetation types, with technique (i) resulting in a grassland community dominated by buffel grass, while technique (ii) resulting in open woodland, with a sparse canopy dominated by *Acacia stenophylla*, *Acacia salicina*, *Corymbia citriodora*, *Eucalyptus populnea* and *Eucalyptus coolabah*. Buffel grass was seeded at the site and is the predominant ground cover, but is generally restricted to the topsoiled swathes (note that the mine ceased the application of buffel grass seeds to rehabilitated areas in 2003).

For the purposes of this study, vegetation resulting from rehabilitation technique (i) is termed 'grassland' and technique (ii) is termed 'open woodland'.

The landform is 'box-cut' (i.e. first entry to the coal seam) and therefore the rehabilitated landform intergrades into remnant Brigalow regrowth on the western boundary and unmined paddocks on the northern boundary. Slopes are generally less than 10% across the block, with some relief along the western boundary, where ridgelines can produce slopes to 20% for short distances (<30 m).

2.3. Field transects

In the week prior to the experimental fire, five 8 m × 50 m transects were randomly located in the grassland community and five in the open woodland community. Along each transect, ten 1 × 1 m quadrats were sampled on the right hand side of the measuring tape every 5 m (Supplementary Fig. 6). Per cent cover scores were given for bare, rock (>2 cm diameter), litter and standing vegetation in each quadrat, and were averaged for each vegetation community. Proportions of species contributing to the standing vegetation were also scored. Soil media conditions were noted (topsoil or spoil) at each quadrat sampling point. To enable comparisons with a published fuel estimate methodology (CFA, 2014a), a matrix of per cent cover of grass and average height of grass was scored.

An assessment of fuel layers before the burn indicated that the key fuel loads included the near-surface fuel (grass) and surface