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Should we burn or bust the biocrusts: an overview of biocrust management in the Australian rangelands.

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Key words: Biocrusts; Savanna; Fire; Grazing; Rangelands

Abstract

The biocrust microbiome that occupies the surfaces of rangeland soils globally are key contributors to carbon sequestration, nutrient cycling and sustain vegetation cover. Previously, research in northern Australia has demonstrated N inputs from biocrusts of 5 kg/ha seasonally that accounts for approximately one sixth to half of the annual pasture N demand. Biocrusts are important indicators of rangeland health, and we address how management actions can facilitate their survival under climatic extremes.

We explored the resilience of biocrusts to fire and grazing at two long-term research sites at Kidman Springs (NT) and Wambiana (QLD), respectively. At Kidman Springs in our first DNA analysis (metabarcoding) we examined the recovery of biocrusts after one year of burning, on plots 2 and 4 year prescribed burning regimes, carried out late dry season. Biocrusts were resilient to fire and recovered in the first wet season with no grazing pressure, as there were no differences in composition between the control and late 2- and 4-year burns. However, DNA analysis from nearby grazing exclosures showed that after 60 years of no cattle grazing, biocrust composition had significantly diverged from grazed areas. Furthermore, in our second DNA analysis (metagenomics) we included samples from 2, 4 and 6 years prescribed fires, burnt early and late in the dry season, and we collected samples at the dry and wet season, demonstrating that there was significant variation in biocrust bacterial composition between all fire treatments and soil types. Bacterial genes responsible for nitrogen fixation were sensitive indicators, that responded to seasonal conditions. Biocrusts also had significantly more nitrogen and carbon than bare degraded soil.

At Wambiana, moderate stocking rates maintained good land condition and strengthened nitrogen fixation potential of biocrusts. Key indices of landscape function including biocrust cover were informed by land condition and climatic conditions. Moderate stocking rates combined with wet season rotational spelling on average every

three years also facilitated nutrient cycling. Recently, we have shown that discrimination of biocrusts using satellite imagery is a feasible monitoring tool on a landscape scale. We can track changes in ground cover including biocrusts both spatially and temporally. Bare ground covered with biocrusts are sensitive indicators of landscape function.

Introduction

Tropical and dry savannas in Northern Australia are one of the largest intact mixed grass-woodland ecosystems globally. They cover >17% of Australia (tropical savanna, 1.9 million km^2, subtropical savanna, 272,000 km^2), where 99% remains as native vegetation of which >65% is grazed native vegetation, and ~35% are conservation zones or natural vegetation (DCCEEW, 2024.). They contribute to 12% of the existing tropical savannas in good environmental condition, and its conservation value is of global significance (Woinarski et al., 2007). The vegetation is diverse, from the eucalypt-dominated woodland to open woodland, shrubland and tussock grassland. The savanna structure is shaped by anthropogenic activity, herbivores, and fire (Cowley et al., 2014). Beef production in Northern Australia contributes $17.6 billion to the economy, carrying over 60% of the total herd of the Australian cattle industry. While most grazing lands are in good condition, a combination of drought, overstocking and intense selection for preferred land types has led to significant degradation in many areas. Fires are also common in these savanna landscapes and can cause changes in ecosystem characteristics such as physiological function, species composition and structure at multiple scales from leaf to landscape (Barger et al., 2016; Cowley et al., 2014).

Recent studies have highlighted the importance of biocrusts across these landscapes (Chilton et al., 2022; Williams et al., 2014) where cyanobacteria dominated biocrusts are estimated to cover 617,000 km^2 (~28%) of the soil surfaces (Fig. 1a), (Williams and Driscoll 2012, unpublished data). Biocrusts form an expansive protective cover on the soil surface (Fig. 1c-d), and serve important ecological functions including soil stabilization, nitrogen fixation and carbon cycling (Williams et al., 2018, Williams et al., 2014, Elbert et al., 2012). These microbial communities are dominated by a diverse suite of cyanobacteria and liverworts, together with micro-lichens, mosses, bacteria, algae, and fungi (Williams et al., 2014). Nitrogen fixation by cyanobacteria and other diazotrophic bacteria provides a direct source of bioavailable N for plants that fluctuates seasonally (Williams et al., 2018, Barger et al., 2016). Loss of biocrust cover (Fig, 1d) results in erosion and degradation of critical soil resources (Eldridge and Delgado-Baquerizo, 2017).

Biocrusts, are important post-fire to boost plant-available nutrient pools in savannas globally, although are less well understood in the context of fire in Australian savannas (Weber et al., 2016; Williams et al., 2018). Recovery of biocrusts post-fire varies with fire regime, locality, time since fire, biocrust community type, and broader geographic range (Palmer et al., 2020, Weber et al., 2016). The impact of fire on biocrusts depends on fire intensity, frequency, and patchiness (Johansen, 2001). In the Great Basin (USA) interactive effects of fire and cattle grazing on biocrust communities, can mediate the effects of invasive grass species and regulate site resistance to invasive species and future fires (Condon and Pyke, 2018). In the northern Australian savanna, we quantified how biocrusts responded to fire and grazing.

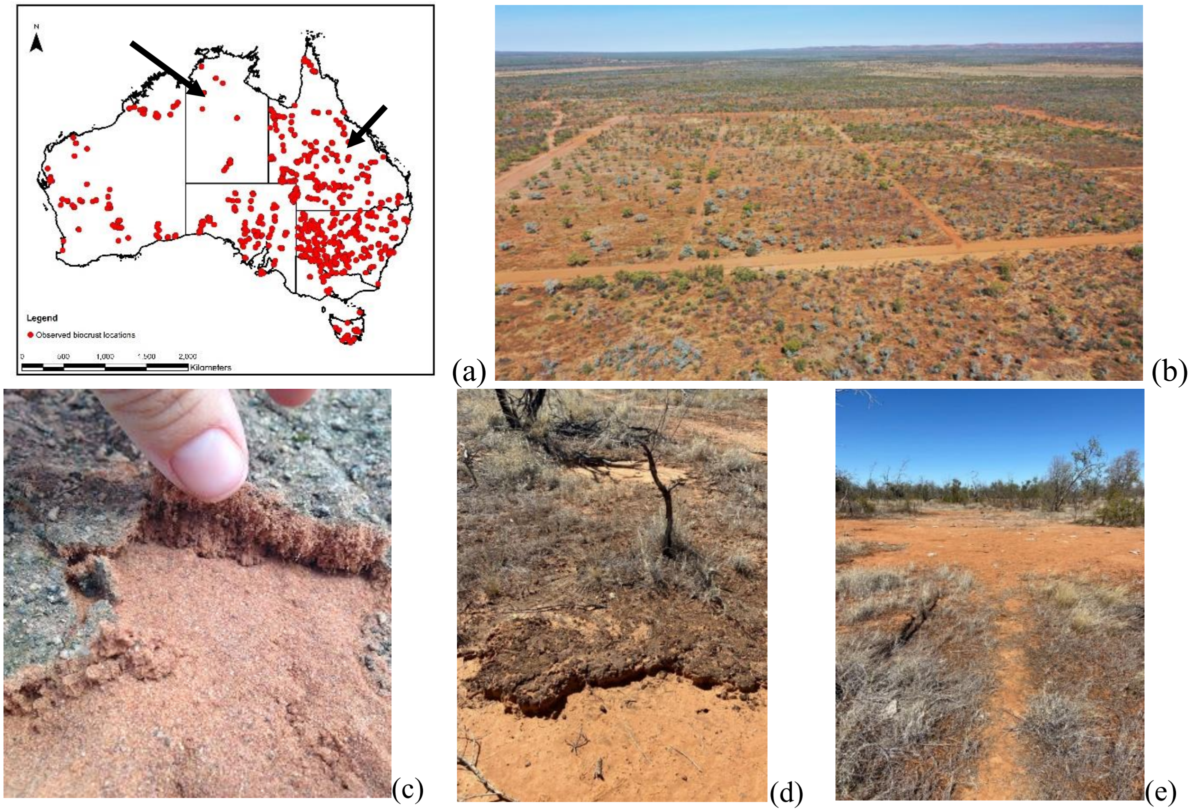

Figure 1 (a) Current survey points recording the presence of biocrusts across Australia compiled from published works and authors' unpublished data (arrow indicates Kidman Springs (left) and Wambiana (right), (b) Kidman Springs fire plots on calcarosols, (c,d) examples of biocrust (state 1) securing the ground cover with erosion caused by cattle 'camps' and water washing the degraded areas away, (e) results of erosion and compaction with no biocrust and ongoing trampling (state 2).

Background

At Victoria River Research Station (VRRS) in the Northern Territory, a cattle station at Kidman Springs, biocrusts have been subject to long-term fire trials for 30 years (1994–2024), with fire intervals of no fire (controls), 2, 4 or 6-yearly burning and season, early (June) or late (October) dry season (Cowley et al., 2014). Since 2013, wet season resting from grazing followed the two-yearly burns but were applied to all treatments. The fire plots (Fig. 1b) are set across two soil types (calcarosol and vertosol) and divided into 16 x 160 m x 160 m square plots, separated by fire breaks. On each soil type there are two replicated plots for each treatment and four unburnt control plots. At VRRS there were two 50-year cattle exclosures approximately 20 ha in size (Bastin et al., 2003) where we compared grazed and ungrazed biocrust diversity for sites that had no regular fire regimes (Vega-Cofre et al., 2023). Separately, in October 2022, a late burn was carried out across a heterogenous 2.6 km^2 Conkerberry paddock containing patches of grass, sparse cover and degraded areas (Fig. 1c-e.). Planet Scope imagery (3 m resolution, 8 MS bands) was used to determine the effect of fire and grazing on biocrust cover pre- and post-fire events (Myint Swe et al., these proceedings). Biocrust cover was substantiated by ground-truthing. Cattle were fitted with tracking collars and left to graze over the course of the following wet season.

The overall aims of these research projects were to provide in-depth studies of the effects of fire and grazing management at a local and commercial scale. This was intended to demonstrate the benefits of burning at the right time, and to contrast the effect of carrying stock post-fire with wet season resting. Additional research took place at the long term Wambiana grazing trial, Charters Towers, Qld, (1997–2023) where the impacts of heavy stocking, moderate stocking and moderate stocking with rotational wet season spelling (resting) on biocrusts were assessed.

Our central aims in the above studies were to determine pasture and biocrust recovery post-disturbance that would result in healthy soils and sustainable levels of ground cover. In doing so we can provide an accurate and rapid assessment of degradation events and post-disturbance monitoring of ground cover recovery at several levels. In turn we can provide support for land managers to sustainably manage Australia's extensive northern savanna. We discuss recent international research together with preliminary findings to understand the importance of biocrusts in the Australian rangelands.

Biocrusts, indicators of soil health

Where biocrusts exist in the rangelands they are both a protection against erosion as well as a useful indicator of soil health, cover and therefore stability and soil function or its potential (Aye et al., 2024). Moreover, biocrusts remain a relatively intact form that can be measured during both periods of stability and climate extremes such as drought. Based on a global drylands' dataset, Chen et al. (2020) found biocrusts formed alternative stable states:

1. Biocrust cover, ~80%; vascular cover, ≤10%, balance bare unprotected soil
2. Biocrust and vascular cover, ≤10%, balance bare unprotected soil
3. Vascular plants (vascular cover, >50%; biocrust cover, ~50%

At Kidman Springs evidence of these states were found across much of the 2.6 km^2 burnt Conkerberry paddock (e.g. Fig. 1c-d). Game camera records from the following wet season (W. Williams, unpublished data) showed the gradual degradation of new grass plants, biocrusts, and ongoing erosion of the soil surface with a further estimated 20% loss in functional integrity (Than Myint Swe et al., this publication), likely caused by ongoing cattle trampling, exacerbated by a significant loss of carbon and nitrogen in degraded areas (W. Williams unpublished data). Our results reflect many other studies that demonstrate the loss of resources that occurs with the loss of biocrusts (Zhang, 2024).

The effects of fire and grazing on biocrust communities and the subsequent influence these factors have on nutrient cycling and pasture quality is highly relevant for land management on grazing properties in northern Australia (Vega-Cofre et al., 2023). In this 2017 study, Vega-Cofre and coworkers found there were significant effects of grazing on bacterial community composition in the vertosol soils that were generally associated with increased cyanobacterial taxa in the 0–1 cm. Our findings demonstrated that the presence of livestock in rangelands increased the proportional representation of cyanobacteria whereas they were not strongly impacted by fire management (Vega-Cofre et al., 2023). Further analyses showed many cyanobacteria and bacteria were associated with nitrogen fixation and cycling. In the more frequently burned sites (early and late season 2-years, both soil types), there were significant impacts of fire management on the overall composition of bacterial communities (unpublished results).

At the Wambiana trial, biocrust cover was highest in the moderate stocking with rotational wet season spelling treatment. Here biocrust cover was dominated by cyanobacteria that bound soil particles, reduced erosion, sequestered carbon, fixed nitrogen, and improved soil fertility (Büdel et al., 2018; Williams et al., 2018). The results emphasised the advantages of wet season spelling combined with moderate stocking rates adjusted seasonally, as effective management strategies in these landscapes (Williams et al., 2021).

Challenges include extreme rainfall variability, intensified drought, and inherently nutrient-poor soils. In drought-prone environments, monitoring the presence and integrity of biocrusts connects landscape function and soil health. Biocrusts that protect and enrich the soil will support long-term ecosystem integrity and economic profitability of cattle production in rangelands (Williams et al., 2021).

Acknowledgements

We acknowledge the traditional owners of Kidman Springs. Many thanks to students, volunteers, researchers and landowners alike, these projects were a team effort. This project was also funded and supported by Meat and

Livestock Australia, Department of Agriculture and Fisheries Northern Territory, Department of Primary Industries Queensland, and the University of Queensland.

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