475

State and transition modelling as a contextual framework for indicators of restoration in the Western Australian Mulga rangelands.

Luxton, SJ[1]; O'Donnell[2], AJ; Richards[3], AE; Sudmeyer[4], R; Szetey[1], K; Waddell[4], PA; Watson[5], I; Williams[1], KJ; Prober[1], SM

[1]CSIRO, Environment, GPO Box 1700, Canberra ACT 2601; [2]CSIRO, Environment, PO Box 7229, Karawarra WA 6152; [3]CSIRO, Environment, PMB 44, Winnellie NT 0822;

[4]Department of Primary Industries and Regional Development, 1 Nash St, Perth WA 6000;

[5]CSIRO, Agriculture & Food, PMB Aitkenvale, Townsville QLD 4814

Key words: ecological condition, grazing, management interventions

Abstract

Opportunities for ecological restoration are rapidly increasing and require consistent tools to assess outcomes. In Australia, state and transition models have been used as a communication tool for land managers, to support ecosystem condition assessment on pastoral leases, and more recently, in the federal Nature Repair Market. A three-day expert elicitation workshop was conducted with government rangelands officers, pastoralists and restoration practitioners to develop a state and transition model for shrub-grass mulga in the WA rangelands. A reference and nine modified states were described, including four regenerating states. Modified states reflect key differences in ecosystem condition along gradients of degradation and regeneration. The key drivers of degradation are overgrazing and associated hydrological dysfunction as grazing impacts worsen, while restoration and regeneration are largely implemented through grazing management and (where soil surface condition has been degraded) hydrological interventions to increase water infiltration. Overall, the state and transition model provides a synthesised, coherent model of WA shrub-grass mulga ecology that is accessible to both experts and non-experts. The model is targeted at supporting the development of rangelands monitoring and condition standards, and the planning and implementation of appropriate management interventions for restoration, enabling land manager access to emerging nature markets.

Introduction

Rangelands represent 81% of the Australian continent (DCCEEW 2005). Their long-term use for livestock production, combined with feral herbivores and introduction of exotic species, have led to widespread decline in ecosystem condition (Landsberg *et al.* 2003). Despite this, the rangelands are often overlooked in ecological restoration initiatives in favour of more intensively used agricultural landscapes (WWF 2021). Opportunities for ecological restoration are rapidly increasing, driven by global and national drivers such as the Nature Positive Initiative, UN Decade on Restoration, Kunming Montreal Agreement, and Australia's Nature Repair Market. These initiatives require consistent tools for ecosystem assessment and projection of outcomes. One approach emerging

to facilitate this in Australia is the widespread application of state and transition models (STMs), for example, to underpin the Nature Repair Market, to support ecosystem condition assessment on pastoral leases (Richards *et al.* 2023), and more generally as a communication tool for land managers (Westoby *et al.* 1989).

State and transition models describe the integrity of different states in an ecosystem (including a historic and/or best-available reference state and current modified states) and the drivers of transitions between states (Westoby *et al.* 1989; Bestelmeyer *et al.* 2017; Richards *et al.* 2020). The application of STMs to ecological restoration requires ecosystem specific models that focus on restoration pathways. Although the concept was developed in Australian rangelands, STMs have only been patchily implemented in Australia (Bestelmeyer et al. 2017), and restoration pathways are often weakly developed. In this paper, we used an expert elicitation process to develop a STM for Australia's shrub-grass Mulga woodlands in the extensive production zones of Western Australia (WA), with a special emphasis on restoration pathways.

Methods

The WA mulga shrublands occur across the semi-arid zone of central WA, averaging 250-350 mm rainfall per annum (DCCEEW 2005). Mulga shrublands are areas where mulga (*Acacia aneura* species complex) are dominant in the tree or tall shrub stratum. This study focused on 'shrub-grass mulga' within the Murchison and Gascoyne IBRA regions, and the Hamersley (Pilbara) and Tallering (Yalgoo) IBRA subregions (Figure 1). Shrub-grass mulga include the range of *A. aneura* complexes found across the '*Acacia hardpan*' and '*Wanderrie grass'* pasture types (Waddell *et al.* 2023). Much of the area has been grazed by domestic livestock since the late 19th Century, first predominantly by sheep and more recently by cattle. Livestock numbers peaked in the 1930s before severe drought, while accumulated land degradation has prevented stock numbers from recovering and has a lasting and ongoing impact on ecosystem condition. During this period, total grazing pressure was also affected by feral goats, rabbits and changes in kangaroo numbers, potentially promoted by dingo culling and provision of water (Landsberg *et al.* 2003).

The model-building process took place through a series of meetings and a three-day in-person workshop held in Perth (13-14 August, 2024) with 30 experts in rangelands ecology participating, supported by an extensive literature of peer-reviewed science publications and rangeland management reports (e.g. Waddell *et al.* 2023). Experts included government rangelands officers, ecologists, pastoralists and restoration practitioners. The purpose of the workshop was to develop a STM for shrub-grass mulga (including identifying restoration-specific dynamics and interventions), following the methodology of Richards *et al.* (2023). At the workshop, experts were provided with an overview of the Australian Ecosystem Models Framework (Richards *et al.* 2020), state and transition modelling and key ecological information about shrub-grass mulga, including pasture types and maps. Starting from a preliminary model developed by the core project team, experts were asked to describe the key states for a 'reference' model (highest ecological integrity). This process was then repeated for the modified states. Finally, experts were asked to describe plausible transitions (including drivers, timeframes and conditions for transitions to occur) including both degradation and restoration drivers and to identify potential indicators for monitoring ecological recovery. Following the workshop, the models underwent further development by the authors.

Results

A reference and nine modified states were described for the shrub-grass mulga STM, including four regenerating states (Figure 2).

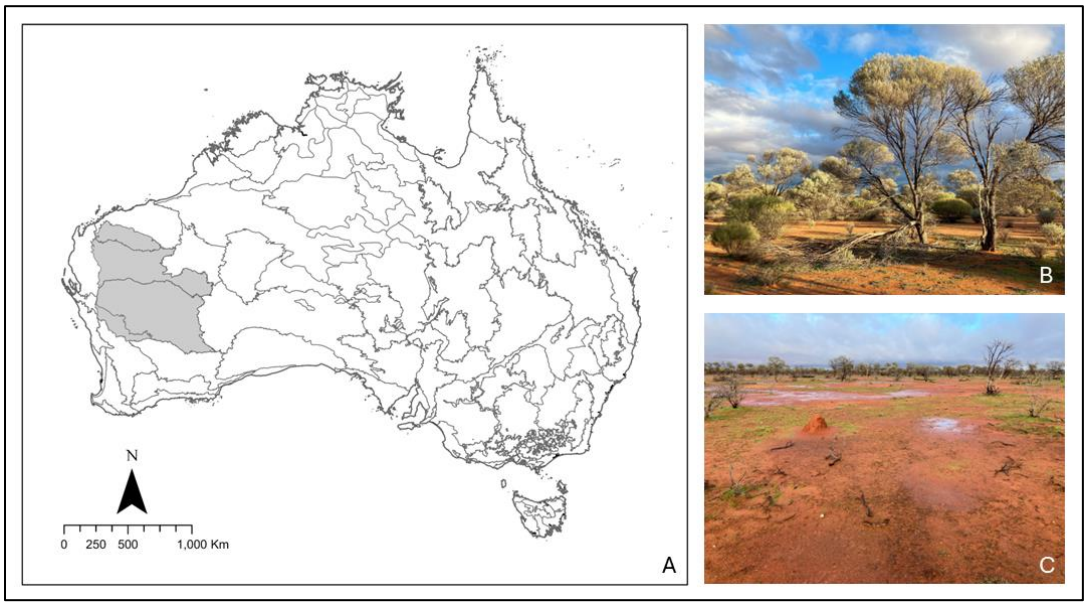

Figure 1. A) IBRA bioregion boundaries of Australia, showing the study region (grey shading): Murchison, Gascoyne, Hamersley and Tallering. Examples of mulga shrubland in B) fair, and C) collapsed condition. Source of IBRA data: DCCEEW (2023). Photo credits: S. Luxton.

Reference state: consists of a mosaic of mulga-dominated vegetation with grassy to shrubby understorey, with high grass richness and cover in more fertile parts of the landscape (including under trees). Uniform tree distribution may occur in the more productive environments, while banded or clustered groves become more pronounced in less productive areas. Reference fire regimes in shrub-grass mulga are inferred to be patchy and infrequent (>100 years based on mulga fire sensitivity, as it takes at least 50 years for mulga woodland to regain structure). Mulga is usually killed by even mild fire, and fire can lead to mulga shrublands moving temporarily to an expression where mulga are absent or sparse (i.e., grassland and/or sparse mulga expressions). The term 'expression' is used here in alignment with Richards et al. (2020) to recognise transient and reversible dynamics within states that differ substantially in one or more ecosystem attributes, relative to other expressions.

Modified states reflect key differences in ecosystem condition for biodiversity and pastoral value, along gradients of degradation and regeneration (Figure 2). The key drivers of degradation are overgrazing and associated hydrological dysfunction as grazing impacts worsen. Mulga harvesting, fire, drought and heatwaves, and isolated hail damage also contribute to ecosystem condition decline, leading to the removal and/or death of the mulga overstorey. As grazing pressures increase, the most palatable component of the flora declines (good to fair condition) and then disappears (fair-poor to poor condition). Less palatable grasses such as *Eriachne helmsii* become more common in grassy areas, and bare ground and exposed hardpan increase in cover. Unpalatable shrubs also increase in abundance (e.g., *Eremophila clarkei* and. *Acacia tetragonophylla*) and the overstorey shifts from healthy with good cover, to sparse with strong browse lines to collapsed (Figure 2). At the extreme, landscape hydrology becomes so dysfunctional that it can no longer support Mulga. This "collapsed" state (collapsed Mulga with collapsed understorey) is characterised by dying and dead trees and an understorey dominated by sparse annuals.

Recovering states with regenerating mulga overstorey (Figure 2, dashed boxes) were included to recognise the long timeframes for recovery of mulga overstoreys, including an approximately 50 year period from seedling

establishment (defined at approximately 3 years since germination). Within this period, two distinct states of overstorey recovery we considered useful to recognise:0.3-2 m mulga and 2-3 m mulga. Given these long timeframes, understorey was considered to shift from collapsed to fair-poor and potentially to fair over this period, depending on management. The potential for the mulga understorey to recover to good condition was considered more likely over a 60-year timeframe, with the ongoing removal of grazing and natural recruitment.

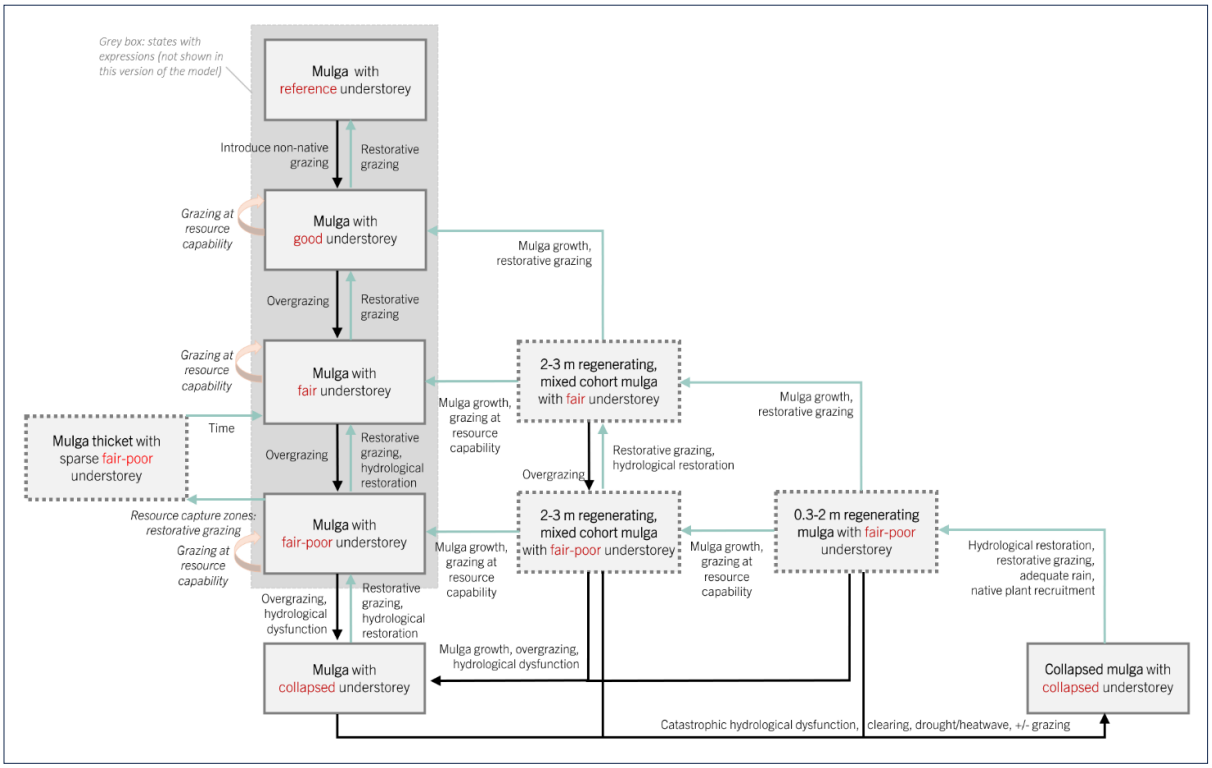

Figure 2. Simplified state and transition model for WA shrub-grass mulga showing degradation (black arrows) and restoration (teal arrows) transitions. Curved arrows (orange) indicate drivers that maintain a state in its current condition. Boxes with solid borders show reference and modified states, while boxes with dashed borders are regenerating (i.e. transitional) states. Text on arrows describe the drivers that are causing transitions between two states.

Restoration and regeneration in the mulga rangelands are largely implemented through grazing management and where soil surface condition has been degraded, through hydrological interventions to increase water infiltration. A range of restoration interventions were identified by the workshop participants, falling into two categories: tools to manage total grazing pressure (e.g., water point management, reduced dingo control, and rest-based grazing strategies), and tools to expedite recovery of landscape hydrology (e.g., water ponding with grader and bulldozer-built banks). Finally, a set of potential indicators for monitoring ecological recovery in the WA mulga rangelands were identified. They include indicators from Tongway and Hindley (2004) Landscape Functional Analysis procedure (e.g., soil cover, litter cover, cryptogam and perennial grass basal cover, and microtopography) and additional ecosystem attributes like the ratio of increaser:decreaser species, invertebrates and plant recruitment.

Discussion & Conclusions

The simplified STM presented above provides an expert-led synthesis of ecosystem dynamics for WA shrub-grass mulga (Figure 2). It integrates and organises information from experts and the current WA Department of Primary Industries and Regional Development (DPIRD) pasture condition assessment system (Waddell *et al.* 2023) to build a model of ecosystem function. This includes distilling the key drivers that either maintain the ecosystem in its

current state, or lead to degradation or recovery - explicitly relating the intensity and/or duration of grazing pressure to different ecosystem condition states. While not presented here for brevity, each state includes a description of dominant species, and ground cover, hydrology and soil attributes alongside quantitative data where available. The STM provides a synthesised, coherent model of WA shrub-grass mulga ecology that is accessible to both experts and non-experts. General applications include supporting DPIRD to develop rangelands monitoring and condition standards. For restoration, the STM will assist with planning appropriate management interventions and their correct timing and scale. It also provides an estimate of recovery timeframes for regulatory purposes. These factors can support land managers to access emerging nature markets, including with the development of restoration plans and the measurement of outcomes using indicators.

Acknowledgements

The development of WA mulga STMs is a collaboration between CSIRO and the WA Department of Primary Industries and Regional Development. We would like to acknowledge the generous contribution of time and knowledge by the experts that participated in the three-day workshop. The restoration component of the study was supported by funding from the Valuing-Sustainability Future Science Platform. Ethics and privacy approvals obtained for this study are **075/23** and **084/24**.

References

Bestelmeyer, B.T., Ash, A., Brown, J.R., Densambuu, B., Fernández-Giménez, M., Johanson, J. *et al.* (2017). State and transition models: theory, applications, and challenges. *Rangeland systems: Processes, management and challenges*, 303-345.

DCCEEW (2005). Outback Australia - the rangelands. Available at: https://www.dcceew.gov.au/environment/land/rangelands Last accessed 5/12/24.

DCCEEW (2023). Interim Biogeographic Regionalisation for Australia (IBRA) Version 7 (Subregions). (ed. Department of Climate Change, E, the Environment & Water).

Landsberg, J., James, C.D., Morton, S.R., Müller, W.J. & Stol, J. (2003). Abundance and composition of plant species along grazing gradients in Australian rangelands. *Journal of Applied Ecology*, 40, 1008-1024.

Richards, A., Dickson, F., Williams, K., Cook, G., Roxburgh, S., Murphy, H. *et al.* (2020). The Australian ecosystem models framework project: A conceptual framework. *CSIRO. https://doi. org/10*, 25919, f61q-1386.

Richards, A.E., Abbott, B., Sudmeyer, R., Fletcher, M., Ryan, K., Prober, S. *et al.* (2023). State and transition models for tussock grasslands and woodlands of the Kimberley: final project report.

Tongway, D.J. & Hindley, N.L. (2004). *Landscape function analysis manual: procedures for monitoring and assessing landscapes with special reference to minesites and rangelands*. CSIRO Sustainable Ecosystems Canberra, Australia.

Waddell, P., Thomas, P., Fletcher, W., Ryan, K., Foster, J., Stretch, J. *et al.* (2023). Pasture condition guides for the southern rangelands, including the Gascoyne, Murchison and Goldfields-Nullarbor. Department of Primary Industries and Regional Development Perth.

Westoby, M., Walker, B. & Noy-Meir, I. (1989). Opportunistic management for rangelands not at equilibrium. *Rangeland Ecology & Management/Journal of Range Management Archives*, 42, 266-274.

WWF (2021). New Data Shows Rangelands Make Up Half the World's Land Surface – and Present a Severely Underutilized Opportunity to Address the Climate and Biodiversity Crises. Available at: https://www.worldwildlife.org/press-releases/new-data-shows-rangelands-make-up-half-the-world-s-land-surface-and-present-a-severely-underutilized-opportunity-to-address-the-climate-and-biodiversity-crises.