Grazing-induced impacts on woody regeneration of palatable and unpalatable species for carbon sequestration

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Abstract

Australian rangelands are currently contributing to climate mitigation through nature-based solutions which include land management changes to facilitate forest [14]growth. Currently, >42 million ha of rangelands are being incentivised through the Australian Carbon Credit Unit Scheme to promote native woody forest regeneration through adoption of new grazing management regimes and removal of past suppression activities which have prevented the establishment of forest cover. These activities include the management of domestic animals by controlling the frequency, timing and intensity of grazing; control of feral animals; cessation of clearing activities; management of fire; and changes to infrastructure which allow enhanced control of grazing pressure to achieve native forest regeneration. The legitimacy of grazing management to influence woody regeneration in these arid and semi-arid environments has recently been challenged, sparking debate over the use of grazing management as a credible land management activity to underpin carbon market mechanisms.

Contrasting palatable *Acacia aneura* (mulga) and unpalatable *Eremophila sturtii* (turpentine) species are used to illustrate how grazing management activities can influence opportunities for recruitment, establishment and growth. Key biological features are identified for each species and used to guide reported or expected responses to grazing management interventions and influence the temporal patterns of carbon accumulation either directly or indirectly. The importance of initial landscape conditions to support the preconditions for grazing management to influence rates of regeneration as well as land management skills and capacity are identified as potentially important factors in determining successful use of grazing management in native forest regeneration.

Introduction

Australian rangelands are currently contributing to climate mitigation through land management which includes facilitation of forest[1] growth. Currently, >42 million ha of rangelands are being incentivised through the Australian

[14] An area of at least 0.2 hectares, dominated by trees and shrubs that are at least 2 m tall and provide crown cover of at least 20% (Australian Government 2024)

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Carbon Credit Unit Scheme. Across many projects, these land managers are undertaking native forest regeneration by removing past forest suppression activities under the Human-induced Regeneration (HIR) method. Grazing land management activities include the management of domestic livestock to control the frequency, timing and intensity of grazing, control of feral animals, cessation of clearing activities, management of fire and changes to infrastructure which allow enhanced control of grazing pressure to achieve native forest regeneration.

Criticisms challenging the ability for grazing management to influence woody regeneration are largely based on studies of woody plant encroachment. Here, over-grazing which persistently removes grasses, alters the competitive balance between trees and grass in favour of woody regeneration. This has led to conclusions that reduction or removal of herbivores will not result in increased woody regeneration or an increase in tree/shrub growth (Eldridge and Sala 2023). However, a recent study employing remote sensing showed that long-term removal of livestock does increase woody biomass, albeit small changes over long timeframes (Retallack *et al.* 2024). Other remotely sensed approaches examining more adaptive grazing management strategies have shown variation in ground cover response across multiple sites (McDonald et al. 2024). This variation in findings highlights the complexities associated with heterogeneous rangeland landscapes and management histories which may lead to complex local site characteristics providing multiple barriers, and drivers, to regeneration.

There are few studies which have directly examined the influences of grazing management on woody regeneration in the context of carbon farming. However, the circumstances under which grazing management can influence patterns of woody regeneration has been recently reviewed (Waters et al. 2025). Here, the primary driver of regeneration was identified as climate, with grazing playing a moderating role enabling the potential regeneration set by rainfall to be achieved. Further, a set of broad, evidence-based grazing principles were developed within a framework that considered three critical stages in regeneration (site condition, germination and establishment and growth and mortality) based on the biological characteristics of widely studied, palatable woody species mulga (*Acacia aneura*). Here, we compare the responses of *A. aneura* (palatable) outlined in Waters et al. 2025) with *Eremophila sturtii* (unpalatable) and predict how grazing management regime (removal of all herbivores, manipulation of herbivore type and management of grazing intensity) may influence regeneration outcomes, outlining the importance of understanding local landscape and socio-economic factors which may modify responses.

Grazing management activities

Unpalatable species are unlikely to be directly influenced by grazing unless alternative feed is unavailable during extremely dry conditions or when safe carrying capacity of livestock and/or total grazing pressure is exceeded for a protracted period (Figure 1). For both palatable and unpalatable species, grazing management may also indirectly influence regeneration by moderating the incidence of fire which will be particularly important for fire sensitive species.

Figure 1. Impact on unpalatable species, *Acacia sclerosperma* with a clear browse line (left) and browse line and re-sprouting *Eremophila mitchelli* (right) following dry periods and little alternative forage availability.

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Under all management regimes, and at all growth stages, maintaining adequate levels of ground cover is a central management outcome (Table 1). It is likely to be important in creating enhanced seedbed conditions for germination and establishment by improving landscape function through the retention of resources (water and nutrients). In the case of turpentine (*E. sturtii*), disturbance from grazing may enhance seedling germination (Robson 1995, Table 1). In the context of a carbon project, and given the infrequent rainfall driven opportunities to initiate a germination event, management aimed at enhancing seedbed would be most beneficial early in a HIR project, not just to set the trajectory of long-term plant community dynamics, but to ensure forest cover is achieved within 15 years of project commencement as required under the HIR method. Maintaining landscape function is also likely to be important later in the project to mitigate occurrence of hard setting, more compacted soils, reduced soil nutrient status/biological activities which have been reported under dense woody growth (e.g. Tighe et al. 2009). Improved landscape function can be achieved through total grazing pressure management which increases perennial ground cover through fencing and/or waterpoint management (Waters et al. 2019).

What is less clear is whether the removal of all herbivores (destocking) will constrain or increase rates of woody regeneration and result in the occurrence of high stem density cohorts. In this situation, the ability to manipulate competition between perennial grasses and seedling growth during germination and establishment phases will have been removed. A lack of herbivory may limit the capacity to achieve maximum attainable carbon carrying capacity by creating high stem density vegetation patches which may slow rates of woody biomass accumulation compared to more open vegetation (Waters et al. 2017, Table 1). Finally, a lack of herbivory may also reduce the ability to manage fuel loads and wildfires which can reduce or preserve accumulated biomass. While destocking may be an option for conservation land use, maintaining pastoral land use as well as the delivery of carbon sequestration has been shown to benefit pastoral enterprises and regional communities (Baumber et al. 2020). The management of herbivore type and grazing intensity will create opportunities for multi-use, integrated landscapes. Here, focusing on woody regeneration at the germination and establishment stages to incorporate periods of rest to promote recovery from grazing (controlling forage utilization and retaining ground cover) will enable seedlings to achieve heights above browse height (1.2 to 1.5 m) for palatable species.

Waters et al. (2025) outline the importance of land manager capacity (knowledge, skills and resources) in effective implementation of grazing management. However, local landscape features such as terrain will influence the stability of infrastructure in managing total grazing pressure. Drainage channels pose a risk of fence breaches in high rainfall events. Examples of alternative practices include fence alignment to high terrain, avoiding watercourses, adoption of low impact earth works, or minimising disruptions to natural movement to soil surface hydrology from linear surface disturbances such as vehicle tracks, fence line clearing and animal pads (Pringle 2019).

Conclusions

In areas where management can improve land condition for seedbed enhancement (soil condition and water availability), management has been shown to indirectly influence regeneration (Waters et al. 2025). In those areas, management aimed at improving site condition and germination appears critical for both palatable and unpalatable species. It is proposed that ensuring that pasture utilization does not negatively impact establishment and growth stages of unpalatable species during periods of protracted drought and limited forage availability is critical.

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Table 1. The potential influence of different grazing regimes on site condition and growth stages of woody regeneration for palatable and unpalatable species. [1.] References within Waters et al. 2025.

Growth stage	**Palatable species** (mulga, *Acacia aneura*)[1.]	**Unpalatable species** (turpentine, *Eremophila sturtii*)
Removal of all herbivores		
Site condition	Maintain or improve levels of perennial ground cover and improve landscape function. Increased ground cover, soil water infiltration, nutrient retention potential to create ideal seedbed conditions.	Seedling germination enhanced with soil disturbance such as blade ploughing (Robson 1995); Maintain or improve levels of perennial ground cover and improve landscape function. Increased ground cover, soil water infiltration, nutrient retention potential to create ideal seedbed conditions.
Germination & Establishment	May remove the ability to manipulate competition between perennial grasses and seedling growth which may result in slower rates of regeneration.	Greater seedling emergence occurs under high shrub densities (approx. 32 to 6% higher) compared to open landscapes (Booth et al. 1996).
Growth & mortality	Areas of high stem density cohorts may limit capacity to achieve maximum attainable carbon carrying capacity.	Areas of high stem density cohorts may limit capacity to achieve maximum attainable carbon carrying capacity. (Waters et al. 2017).
Manipulation of herbivore type		
Site condition	Management of total grazing pressure plays a critical role in maintaining or restoring landscape function through maintaining or improvement of ground cover.	Management of total grazing pressure plays a critical role in maintaining or restoring landscape function through maintaining or improvement of ground cover (Hacker, McDonald 2021).
Germination & Establishment	Sheep, Dorpers and goats may prevent recruitment directly through herbivory. Under deteriorating seasonal conditions and lack of alternative available forage, kangaroos as well as sheep, Dorpers and goats may impact germination and recruitment. Cattle less likely to impact regenerating Mulga.	Sheep and goats will not reduce establishment unless extremely heavy goat grazing pressure (Harrington 1979). Under protracted drought, when alternative forage unavailable Dorpers and goats may impact seedling establishment.
Growth & mortality	Sheep, Dorpers and goats can prevent growth (density and height). Cattle are less likely to impact regenerating mulga, Kangaroos little impact on mature trees.	Sheep, Dorpers, goats and cattle are unlikely to impact growth (density and height) of mature turpentine unless under extreme grazing pressure by goats or when feed demand outweighs feed supply (little alternative available forage) during periods of drought.
Managing grazing intensity		
Site condition	Management of total grazing pressure plays a critical role in maintaining or restoring landscape function through maintaining or improvement of ground cover.	Management of total grazing pressure plays a critical role in maintaining or restoring landscape function through maintaining or improvement of ground cover (Hacker, McDonald 2021)
Germination & Establishment	Direct impact of herbivory from sheep, Dorpers and goats may result in higher levels of seedling mortality. Overgrazing will reduce seedling growth rates and expose cohorts to a greater susceptibility to drought, potentially amplifying mortality events.	Regulate the level of competition between perennial grasses and seedlings in the first summer after germination to increase regeneration (Waters et al. 2025)
Growth & mortality	Direct impact of herbivory from cattle, sheep, Dorpers and goats may result in reducing plant height as well as removal of branches above browse height, lowering potential carbon accumulation. This may be amplified when alternative forage unavailable.	Sheep, Dorpers, goats and cattle are very unlikely to directly impact growth (density and height) of mature Turpentine unless under extreme grazing pressure by goats or when feed demand outweighs feed supply (little alternative available forage) during periods of drought.

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