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Long-term recovery of carbon stocks in *Acacia aneura* (mulga) woodland following thinning

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Key words: live biomass; standing dead; coarse woody debris; litter; regrowth management

Abstract

Management of woody vegetation in grazed woodland systems has important implications for livestock production, carbon (C) sequestration and biodiversity. Many of Australia's C sequestration projects are in grazed woodlands dominated by the fodder tree *Acacia aneura* (mulga), requiring management of competing priorities, particularly livestock production and C stocks. Partial clearing or thinning of mulga regrowth can be used to increase pasture (and therefore livestock) production. This paper will focus on the impact of thinning mulga woodlands on the recovery of woody C stocks.

Three experimental sites in Queensland were established in the 1960s to study the impact of thinning of mulga woodlands. From an initial density of 1900-5600 trees ha⁻¹, three replicated thinning treatments were implemented at each site: 40, 160 and 640 trees ha⁻¹. We remeasured the sites after 50-60 years and estimated woody biomass, litter and coarse woody debris C stocks. Over this time, all treatments demonstrated additional pastoral productivity relative to uncleared woodlands (Bray *et al.* this conference).

After 50-60 years, woody biomass and debris C stocks were similar among the three thinning treatments. Although there were no significant differences in C stock in live or total aboveground biomass, standing dead C stock was significantly lower in the 40 trees ha⁻¹ treatment.

Our findings indicate that mulga woodlands have the capacity to recover over 50-60 years and reach similar C stocks after thinning to low stand densities. Thinning of mulga should be considered in the context of regulatory guidelines and whole property management to balance multiple values. Further work is warranted to explore the potential of ecological thinning in mulga regrowth as a tool by which land managers could optimise their production-carbon-biodiversity goals.

Introduction

Management of woody vegetation in grazed woodland systems has important implications for livestock production, carbon (C) sequestration and biodiversity (MLA 2006; Thomas *et al.* 2025; Waters *et al.* 2025). Clearing of woody regrowth for pasture management has typically included broadscale mechanical or chemical clearing (England *et al.* 2026, this conference). Partial clearing, or thinning, offers a potential alternative management tool to balance production-carbon-biodiversity goals. However, there is limited information on the long-term impacts of thinning of woody regrowth on these values.

In Australian woodlands, altered management practices can promote undesirable monocultures of dense regrowth which impact ecosystem structure and function. Recent studies of thinning in woody regrowth have assessed its potential to restore historical or ecologically desirable ecosystem structure and processes in *Acacia harpophylla* (brigalow, Dwyer *et al.* 2010) and *Callitris glaucophylla* (white cypress pine, Waters *et al.* 2018) dominated ecosystems. This may also be relevant to many of Australia's C sequestration projects in *Acacia aneura* (mulga) woodlands, where cessation of clearing and destocking of livestock is common. Thus, the aim of this study was to assess how partial thinning of mulga woodlands impacts the long-term recovery of woody C stocks.

Methods

The study area was the Mulga lands bioregion of SW Queensland, Australia. Three thinning trial sites were established in the 1960s to study the effect of thinning of *Acacia aneura* (mulga) woodlands to different tree densities on ecosystem productivity. The vegetation at all sites was woodland dominated by mulga, with a population of woody shrubs (mainly *Eremophila*) at Monamby (Beale 1973; Pressland

1976). From an initial density of 1900-5600 trees ha⁻¹, at each site three replicated thinning treatments were implemented: 40, 160 and 640 trees ha⁻¹ in a randomised block design (Table 1).

Table 1. Details of long-term thinning trials in SW Queensland and treatments measured in 2022-2023.

Site	Lat. (°)	Long. (°)	Start year	Age ¹ (yrs)	Plot size (ha)	N plots	Treatments
Boatman	-27.24	146.98	1963	59	0.39-0.54	21	Thinned 40, 160 & 640 trees ha ⁻¹ , 7 replicates
Monamby	-26.64	145.38	1965	58	0.16	21	Thinned 40, 160 & 640 trees ha ⁻¹ , 7 replicates
Charleville	-26.42	146.28	1970	53	0.12	9 ²	Thinned 40, 160 & 640 trees ha ⁻¹ , 3 replicates

¹ At measurement in 2022 or 2023; ² Excluding uncleared, fire treatment and full clearing plots.

We remeasured the trials in 2022-2023, 53-59 years post-thinning, and estimated woody biomass C stocks. In each plot, stem diameter of all trees/shrubs at heights of either 130 cm or 10 cm, species and health score (Piper *et al.* 2026) were recorded. Live aboveground biomass (ABG, Mg dry matter (DM) ha⁻¹) and standing dead aboveground mass (Mg DM ha⁻¹) were calculated by applying plant functional type allometrics (Paul *et al.* 2016; Paul and Roxburgh 2024), with corrections for health scores (Piper *et al.* 2026). Total AGB was calculated as the sum of live AGB and standing aboveground dead mass. All dry-mass values were converted to carbon mass by multiplying live biomass by 0.5 (Gifford 2000). At Boatman and Monamby, litter (diameter <25 mm) and coarse woody debris (CWD; diameter ≥25 mm) C stocks were also measured using the methods described by Forrester *et al.* (2025), with the sum of transect lengths for CWD in each plot measuring 150 m.

Data were analysed using R software (R Core Team 2025). We used linear mixed-effects models to test the effect of thinning on C stocks using the R package *nlme* (Pinheiro *et al.* 2018). The model structure included 'Site' and 'Treatment' with 'Block' (replicate) included as a random effect. Post-hoc pairwise comparisons among treatment levels were made using estimated marginal means (R package *emmeans*, Lenth 2025), with Tukey-adjusted *p*-values for multiple comparisons. For CWD C, a natural logarithmic transformation was applied so that the residuals were centred at zero and approximately normally distributed.

Results

Across all sites and thinning treatments in these Mulga woodland systems, C stocks in live AGB and standing dead mass ranged from 24.3-37.3 and 2.0-6.0 Mg C ha⁻¹, respectively. CWD and litter ranged from 1.7-3.3 Mg C ha⁻¹ and 2.0-4.8 Mg C ha⁻¹, respectively.

Woody biomass and debris carbon stocks within sites were generally similar among the three thinning treatments (Figure 1). Live AGB C, standing dead C, total AGB C and litter C stocks differed significantly among sites ($F = 2.25-53.45$, $p = 0.01-<0.0001$) but interactions between site and thinning treatment were not significant ($F = 0.48-2.26$, $p = 0.08-0.69$). CWD C stocks did not differ among sites ($F = 0.41$, $p = 0.53$) and site × thinning interactions were not significant ($F = 0.16$, $p = 0.85$). There was no effect of thinning treatment ($F = 0.83-2.15$, $p = 0.13-0.45$) on live AGB C, total AGB, CWD C or litter C stocks. By comparison, there was a significant effect of thinning treatment on standing dead C stock ($F = 7.44$, $p = 0.002$), which was significantly lower in the 40 trees ha⁻¹ treatment at Boatman, but not at Monamby or Charleville (Figure 1b).

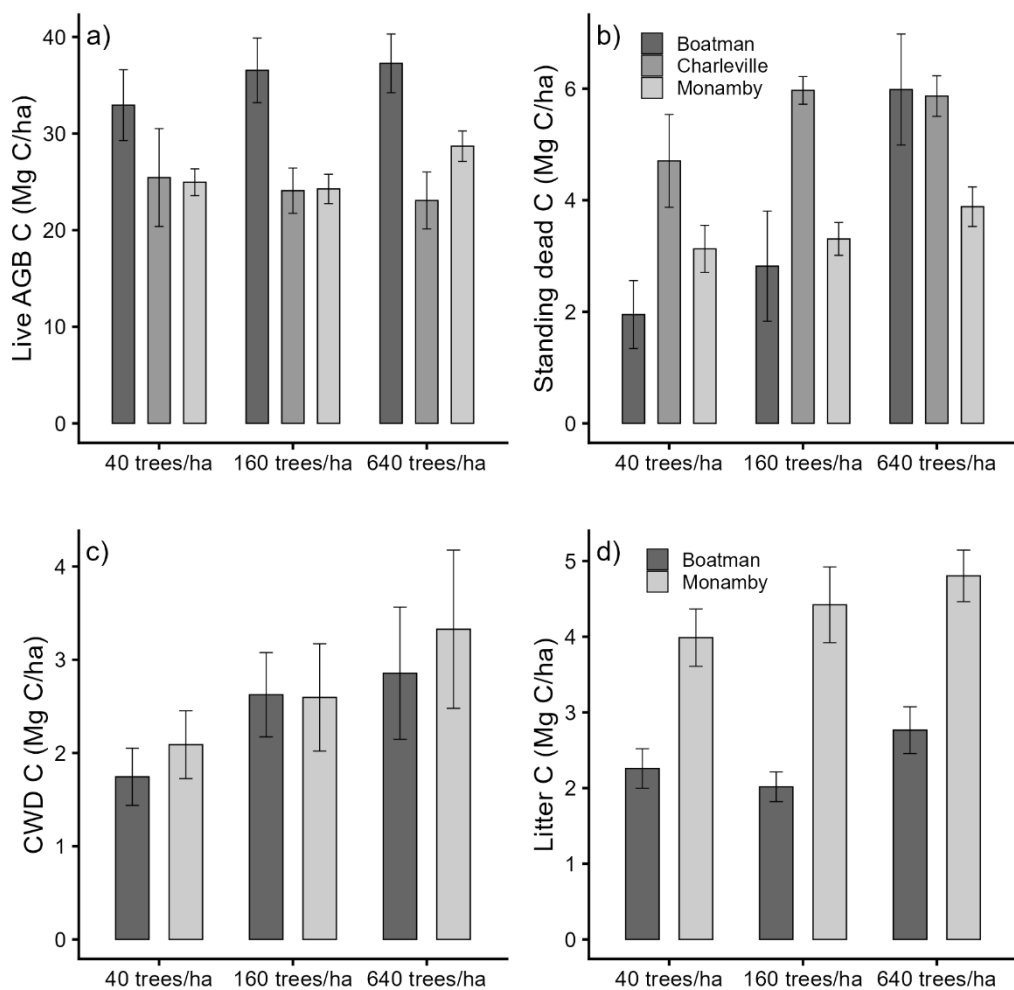


Figure 1. Comparison of mean $\pm$ SE: a) live AGB C stocks, b) standing dead C stocks, c) CWD C stocks, and d) litter C stocks among thinning treatments (40, 160 and 640 trees ha⁻¹) and sites. Note: CWD and litter C were only measured at Boatman and Monamby.

Discussion

After 53-59 years post-thinning, we found no effect of thinning on live or total AGB C, although standing dead C stock was significantly lower in the highest thinning intensity treatment. These results agree with modelling simulations for a thinning study of brigalow (Dwyer *et al.* 2010) where all thinning treatments reached asymptotic live AGB values within the 50-year simulation period, first the more intense treatments (40-44 years after thinning) and then the least intense treatments (48-50 years after thinning), although initial and thinning densities were much higher than the present study. We found no significant differences in CWD or litter C stocks among thinning treatments 53-59 years post-thinning. While not significant, there was a trend of higher CWD stocks with thinning intensity. This trend agrees with a chronosequence study of time since thinning in the Pilliga (Waters *et al.* 2018) where the post-thinning reduction in woody vegetation was accompanied by an initial increase in the volume of CWD, with higher CWD stocks in older thinned stands (21-40 years post-thinning). The lack of significance in the present study may be related to the longer time since treatment.

Our findings indicate that mulga woodlands have the capacity to recover over 50-60 years and reach similar carbon stocks after thinning to low stand densities. Over the same period, all treatments demonstrated additional pastoral productivity relative to uncleared woodlands (Bray *et al.* 2026, this conference). Thinning of mulga should be considered in the context of regulatory guidelines and whole property management to balance multiple values. Further work is required to explore the potential of ecological thinning in mulga regrowth as a tool by which land managers could optimise their

production-carbon-biodiversity goals, including whether thinning can promote the establishment of other tree species and increase overstorey diversity.

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