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Long-term impacts of rabbit and cattle grazing on carbon sequestration in arid rangelands

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Abstract
One of the claimed multifunctional characteristics of degraded pastoral landscapes is their ability to sequester carbon in woody biomass. But what is the actual potential for this, and at what rate may this occur over time? Due to slow growth rates, intermittent droughts, and heterogeneous landscapes, it may require many years of data collection from across multiple site locations to answer such questions. For an arid calcareous landscape in central Australia that had been degraded through overgrazing by cattle and rabbits, we used multiple, disparate, data sources to estimate change in above-ground woody biomass over 40 years. From a very low density of live trees and shrubs in 1981, regeneration occurred in 1-ha plots when protected from grazing by rabbits and large herbivores ('rabbit-exclosed'). There was lesser regeneration in adjacent plots that excluded only cattle grazing ('cattle-exclosed') and minimal establishment in control plots that were grazed. Hyper-spatial satellite images available from Google Earth were classified to estimate multi-temporal woody canopy cover for each plot between 2004 and 2023. Plot-based above-ground biomass (AGB, dry weight) of live trees and shrubs was estimated from the density and cover data using allometric functions from studies conducted elsewhere. Finally, AGB was accurately estimated in all plots in late 2022 using ground-based allometry data. AGB increased by 1.92 tonnes / ha within the rabbit-exclosed plots between 1981 and 2022, with lesser increases on the cattle-exclosed and control plots (0.69 and 0.63 tonnes / ha, respectively). Although maximum AGB after 40 years was still small (1.97±0.303 tonnes / ha), separate analysis of satellite data has shown that woody canopy cover elsewhere in this recovering landscape has reached ~50%, equivalent to ~4 tonnes / ha AGB. Such woody thickening can potentially reduce herbage growth and adversely impact beef production, bringing to focus the multifunctional balance between pastoralism and carbon sequestration.

Introduction

Altered grazing management to facilitate carbon sequestration, above- and below-ground, is progressively being implemented in parts of the Australian rangelands, both demonstrating their multifunctional value (Stringer et al. 2012) and providing an additional income stream for pastoralists (Hacker and McDonald 2021). The potential to sequester carbon may be greatest where formerly productive landscapes have been degraded through loss of perennial vegetation and erosion (Baumber et al. 2020, Henry et al. 2024).

Owen Springs pastoral lease near Alice Springs, Northern Territory (NT), is an exemplar of variably degraded rangeland in arid central Australia. The area has a summer-dominant mean annual rainfall of ~280 mm but with high interannual variability (minimum, 67 mm; maximum, 782 mm; 84-year record, Alice Springs Airport). The lease was first stocked in 1873 with grazing by cattle continuing until 2002 when the lease was resumed and all cattle and feral horses removed. Part of the lease became the Old Man Plains (OMP) research station (522 km^2) which was progressively restocked from 2005 at between three and six animal equivalents (AE) / km^2. Prior to that, cattle grazing pressure on calcareous shrubby grasslands, the most preferred pastoral land type, was estimated at ~12 AE / km^2 (Bastin et al. 2023). Feral horses (unknown number) and rabbits (densities as high as 20 / spotlight km, Foran et al. 1985) added to total grazing pressure. This sustained grazing pressure, particularly during drought, had caused extensive degradation (Pickup and Chewings 1994, see also Fig. 4 in Bastin et al. 2023) including widespread death of browsed shrubs (Fig. 1), a phenomenon previously described by Friedel (1985). High rabbit densities are especially pernicious during drought because rabbits will ringbark stems in their search for water. They will then browse seedlings that may germinate following high rainfall preventing the successful regeneration of woody vegetation.

Figure 1. Extensive shrub death on an OMP calcareous shrubby grassland associated with cattle and rabbit browsing. The 1982 photo also shows a rabbit warren in the foreground and part of a netted rabbit exclosure. Photo: Barney Foran, CSIRO.

The continuing security on present-day OMP of replicated rabbit- and cattle-proof exclosures constructed in 1981 and archived tree- and shrub-density data from that time (Foran et al. 1985) have provided the opportunity to retrospectively monitor change in woody biomass over the past four decades. In this paper, we combine multiple, disparate, data sources to estimate change in above-ground woody biomass since the early 1980s.

Methods

Three 1-ha plots (netted to exclude rabbits, fenced to exclude cattle and open to all grazing) were replicated at six sites in 1981 on calcareous shrubby grasslands approximately ~40 km south west of Alice Springs. The density of shrubs and trees (dead, mature or juvenile) was collected annually in four belt transects (10 m by 50 m) at each plot between 1982 and 1988 (see Foran et al. 1985 for further detail).

Individual stem diameters (at 10 cm) and crown area (as an ellipse) were measured for all trees and shrubs within all exclosures in October 2022. The same data were collected in adjacent 1-ha grazed plots (which may have been different to the original 'controls' as their precise locations were unknown). Health scores of the canopy and stem wood for all individuals were also recorded (Piper, pers. comment). Above-ground biomass (AGB, kg dry weight per individual) was calculated using the generalised shrub allometry of Paul et al. (2016). Plot-level canopy cover was calculated by summing the individual crown areas corrected for health divided by the plot area. Individual AGBs corrected for health were summed and divided by plot area to calculate plot-level AGB. These data were combined with those collected from another 430 sites in the Australian rangelands to develop generalised stand-level canopy cover – AGB relationships (by structural vegetation class) (Pasut, pers. comment) with the shrub equation used to calculate plot-level AGB (tonnes / ha) for the OMP sites in years where canopy cover was estimated using remote sensing.

Publicly available, high spatial-resolution satellite images available between 2004 and 2023 on Google Earth were saved as red-green-blue (RGB) composites with a nominal pixel size of 0.25 m for each site area. Twenty classes were generated for each site-time using ISO Cluster unsupervised classification. Those classes best representing identifiable tree and shrub canopies, plus associated shadow, were grouped to estimate multi-temporal percent canopy cover. Plot-level AGB was then estimated as above.

Results

From a notional low level of woody biomass in the 1980s*, AGB increased by a factor of 12 (cattle-exclosed) to 75 (grazed) by the early 2000s. The rabbit-exclosed treatment had consistently higher biomass, followed by cattle-exclosed (Fig. 2). Remotely-sensed estimates of AGB in 2021 and 2023 were higher for all treatments than the more accurate estimates in late 2022 using ground-based allometry data.

Assuming a consistent increase in AGB between 2004 and 2023, linear regressions fitted to the data suggested an annual increase of 34 kg / ha for the rabbit-exclosed plots ($R^2 = 0.77$, $P<0.01$), 21 kg / ha for the cattle exclosed treatment ($R^2 = 0.21$, ns) and 17 kg / ha for grazed plots ($R^2 = 0.28$, ns).

Discussion

The field-measured AGB of trees and shrubs in 2022 was low compared with other studies in the arid rangelands (e.g. Williams et al. 2023, Pasut, pers. comment). Nevertheless, the other data sources used here indicate that woody AGB started from a very low base on degraded land in the 1980s and may have accumulated at an annual rate of up to 34 kg / ha from the early 2000s onwards. The 'grazed' rate of 17 kg / ha / year extrapolates to an annual AGB accumulation of ~288 tonnes between 2004 and 2023 for the 169 km^2 of calcareous shrubby grassland on OMP. We acknowledge these increases are small and may have large estimation errors due to limited spatial sampling and no validation of the remote sensing analyses.

Initial establishment and growth of seedlings was only successful within rabbit exclosures (Foran et al. 1985, and 1988 data in Fig. 2). Successful regeneration of shrubs in cattle-exclosed and grazed plots probably dates from about 1996 when the rabbit population was substantially reduced, and subsequently maintained at a low level, through rabbit haemorrhagic disease (Edwards et al. 2002). Exceptional rainfall in 2000-2001 combined with destocking promoted vegetation growth (Bastin et al. 2023) and likely facilitated further successful shrub establishment. Thereafter, resumed grazing at a more conservative stocking rate combined with periodic spelling, and further years of above-average rainfall help to explain the gradual increase in remotely-sensed canopy cover and derived AGB.

* There was an initial low density of mature shrubs (predominantly Acacia kempeana, see Table 3 in Foran et al. 1985) and individuals were given a notional AGB of 35 kg (dry weight). Juvenile shrubs were similarly allocated a biomass of 1 kg each.

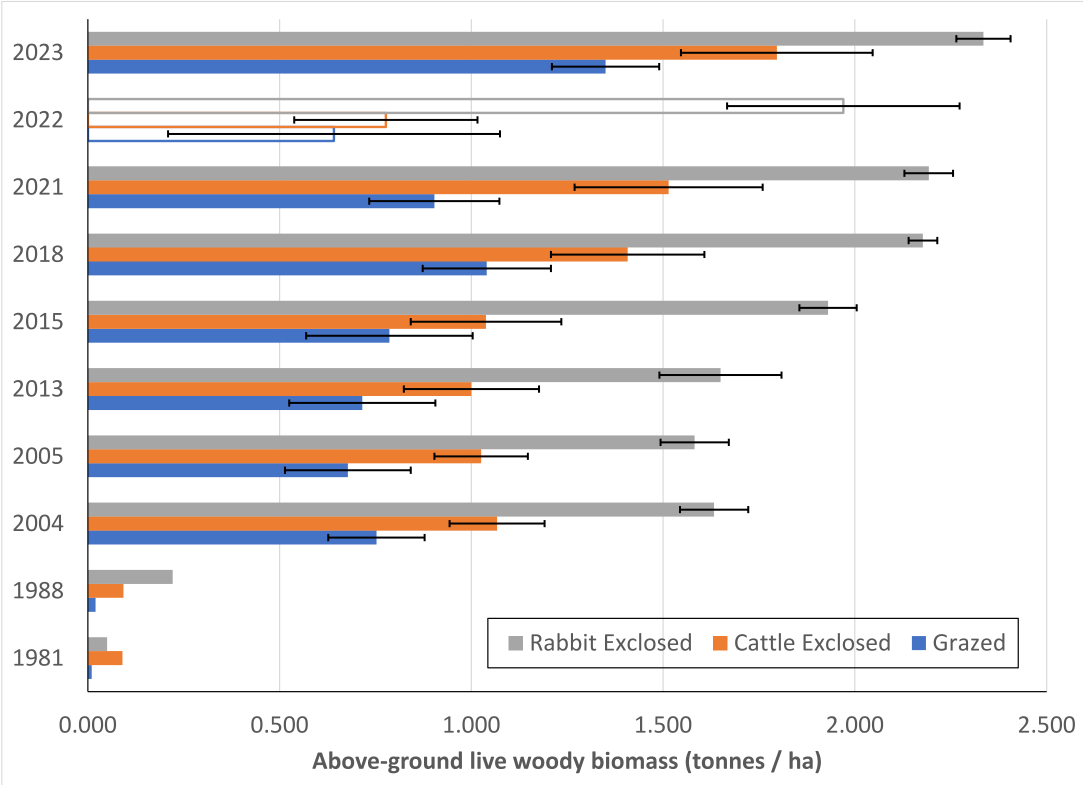

Figure 2. Estimated mean above-ground biomass of trees and shrubs for grazed, and rabbit- and cattle-exclosed treatments at six sites on Old Man Plains between 1981 and 2023. The standard error of each mean from 2004 onwards is also shown. Solid columns between 2004 and 2023 show remote sensing-based estimates with the open columns representing the 2022 field data.

The monitored increase in AGB, excluding the 2022 field data, is indicative rather than absolute due to the assumed relationship between density and AGB in the 1980s and probable errors associated with image processing in accurately discriminating canopy cover. The notional AGB of 35 kg assigned to each of the very few mature *A. kempeana* was based on the mean dry weight of 254 similar individuals harvested in a neighbouring paddock in 2012 (Bastin 2014). The density of juvenile shrubs in the rabbit-exclosed treatment increased through the 1980s but we argue their contribution to woody AGB was minimal regardless of their assigned small biomass value. The RGB images saved from Google Earth had reduced radiometric resolution compared with their source data. Further, we did not radiometrically calibrate the multi-temporal images to correct for different sensors, and sun-angle and atmospheric effects. Woody canopies were best discriminated when there was good spectral contrast between their grey-green foliage and the background soil and a senescent herbage layer; actively growing (green) pasture confounded successful classification. Despite these limitations, the Google Earth images did provide a free and convenient method for retrospectively monitoring change in canopy cover.

Regeneration of trees and shrubs across this calcareous landscape varies according to the nature and severity of past degradation (Stafford Smith and Pickup 1990). Woody canopy cover in some areas has reached ~50%, equivalent to ~4 tonnes / ha AGB. Such woody thickening can potentially reduce herbage growth and adversely impact beef production, without substantially contributing to carbon sequestration. This brings to focus a probable imbalance between the multifunctional values of continued successful pastoralism and meaningful long-term removal of carbon dioxide from the atmosphere.

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