Is shrub removal an appropriate management strategy in shrub-encroached woodlands?

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Abstract

Encroachment of shrubs into open woodland is a global phenomenon affecting drylands worldwide. Encroachment generally reduces pastoral productivity by reducing grass cover for livestock. Consequently, a range of mechanical methods such as ploughing have been used in an attempt to remove encroaching shrubs. Apart from the high cost, ploughing has been shown to have deleterious and often inconsistent effects on woodland ecosystems. Our work showed that soil under shrub patches contain generally higher levels of nutrients and are preferred sites of animal disturbance. However, ploughing and grazing reduced the number of vegetated patches, altered landscape heterogeneity, and often had species-specific effects, potentially leading to a dominance of ploughing- or grazing-resistant shrub species. With ploughing resulting in reductions in soil nutrients, long–term increases in shrub density rather than reductions, and the lack of sustained grass cover, we suggest that mechanical shrub removal is an inappropriate method for managing shrub-encroached woodlands. In the context of pastoralism, alternative approaches such as time-controlled grazing or rotational grazing (similar to transhumant systems) would be more appropriate management strategies. An alternative perspective, which is increasing in popularity, is to value encroached woodlands in terms of the ecosystem benefits they provide. These include habitat for animals, sinks for carbon dioxide, ecotourism and water supplies.
Keywords: ploughing, grazing, arid, shrubs, soil disturbance, woodland, Australia, spatial distribution, land management.

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1 Introduction

Since European settlement, Australian vegetation has experienced substantial changes, from a matrix of grassland and woodland, to dense shrubland. This has mainly been due to overgrazing and the lack of wildfire. The density of these woody shrubs suppressed perennial grasses and reduces livestock-carrying capacity. There have therefore been many attempts to transform shrublands back to their original grassland–woodland matrix. These techniques have ranged from destocking and exclosure, to various mechanical, biological and chemical techniques.

Mechanical shrub removal is particularly expensive (A$40-$85 ha^{-1} in early 1990s; [1]), but its use has been encouraged by authorities such as Catchment Management Authorities [2]. It typically results in only short–term changes in plant community structure [3], often stimulates shrub regrowth, leading to the eventual persistence and dominance by woody shrubs [4]. Post–treatment management of stocking rates is rarely considered by land managers, and many failures could arise from the suppression of grass growth as a result of overgrazing [5]. Therefore, the negatively-held perception of woody shrubs as weeds is highly context-dependent [6] and based largely on the effects that shrubs have on reducing pastoral productivity in an agricultural, production-based framework. It remains unclear, however, whether shrubs *per se* or interactions between grazing and climate change (e.g. more erratic rainfall and increasing CO_2 level) are responsible for the putative reductions in pastoral productivity of these shrublands.

Notwithstanding those putative negative views, there is increasing recognition among ecologists that shrubs are important for improving a range of ecosystem services because they influence micro–climate, reduce erosion and nutrient loss, increase water holding capacity, maintain soil structure and stability, and act as habitat for a range of organisms [7, 8]. Shrubs have even been recognized for their role in reversing desertification processes, even conserving and restoring degraded arid lands that was previously linked to the phenomenon of shrub encroachment itself [7]. It is important therefore, that we understand the effects of different land management treatments such as ploughing and grazing on the density and composition of vegetation and animal disturbance, as well as on soil nutrient properties.

Here we report on the ecological costs of mechanical shrub removal (ploughing) and potential alternatives to manage shrubs at our study site. Our site is typical of encroached woodland in eastern Australia and characterized by dense native shrubs, sparse perennial grasses, and an extensive cover of bare, eroded soil. We examined four treatments which represent different degrees of disturbance and reflect how managers and conservation agencies in eastern Australia manage shrubs within the context of both pastoral production and conservation. The most common option is the 'unploughed-grazed', which involves stock grazing and no shrub removal. More than 50% of landholders fell within this category, while approximately 25-50% of the remaining landholders adopted the 'ploughed-grazed' treatment, which involved ploughing followed by the maintenance of current grazing practices. The ‘ploughed-ungrazed’ involves the removal of livestock and ploughing in order to meet some specific conservation objectives such as altered habitat for key plant or animal species. All of these treatments involved some degree of disturbance, except for the ‘unploughed-ungrazed’ treatment, a strategy practiced by managers of national parks and conservation reserves whereby livestock are removed but shrubs are not ploughed [9].

2 Methods

The study was conducted at ‘Wapweelah’, an extensive grazing property about 35 km west of Enngonia near Bourke in north-western New South Wales, Australia (29º 16’S, 145º 26’E). In 1990, three blocks of 200 m x 400 m, separated by distances of 1–5 km, were established and divided into four equal plots 100 m wide by 200 m long. The two central plots were then enclosed in a grazer–proof 6 m tall fence, and half of the area was ploughed and the other unploughed. Similarly one of the two unfenced plot (grazed) sections was ploughed and the other unploughed. The grazed plots then were subject to grazing by sheep, goats, cattle, kangaroos, rabbits and camels.

In August 2008, 18 years after ploughing and fencing, we established a 50 m transect in the centre of each plot in order to measure the density and composition of different patches in each treatment. Along this transect we recorded the total number, length and width of shrub hummocks and surface debris where shrubs have been removed or fell over naturally (i.e. log mounds) which together represent sites of potential resource capture, and the distance between the patches (interspaces), which represent sites of resource shedding. We recorded separately the number of shrubs by species, along 100 m x 2 m transect on each plot. We also recorded all evidence of animal activity found along this transect as well as the animal that likely created the structure (i.e. ant, termite, spider, scorpion, cicada, goanna, or echidna) and the types of patch (i.e. shrubs, log mounds or interspaces) under or on which the animal disturbance was found.

The data were analysed using a mixed-model ANOVA to examine possible microsite effects on animal disturbance and treatment effect on landscape level parameters (e.g. patch, animal disturbance and shrub density). The first stratum considered block and treatment effects from the most disturbed to the least disturbed (ploughed-grazed, ploughed-ungrazed, unploughed-grazed and unploughed-ungrazed), while the second stratum microsite effects (i.e. shrub hummock vs log mound vs interspace) and their interactions with treatment. All data were checked for normality and homogeneity of variance (Levene’s test) prior to analyses and *post-hoc* differences in means were examined using Least Significant Difference testing. Similarly, PERMANOVA analyses were used to explore the possible differences in the composition of shrub and animal disturbance using the same design as the ANOVA.

We established separately, for each treatment (except for the ploughed-ungrazed site as it would unlikely be applied by land managers), one 10 m x 10 m

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plot and sampled the surface on a coarse 2 m grid (n=36) as well as a finer grid of points that were spaced at distances of 25 cm apart (n=72) across the plot. For each sampling point, litter cover was estimated using a 10 cm x 10 cm quadrat of 25 grid points. Soil, sampled to 7 cm depth, was collected at each of the 108 points, and soil pH was derived from those samples. The pH was determined using 1:5 soil:water suspension. We used the GS+ geostatistical package to examine the nature of the spatial scaling of the litter cover and pH at spatial scales ranging from 0.25 to 14 m. Semi-variograms were examined to look for trends in spatial patterning in relation to the disturbance gradient.

3 Results

3.1 Ploughing triggers erosion and homogenizes surface soils

At the landscape scale, there was a significant treatment effect on patch density per 50 m of transect. The undisturbed (unploughed-ungrazed) plot had approximately two- to seven-times more patches (mean=9.3 patches) than the other plots, whose means ranged from 1.3 to 3.3 patches. Mean distance between patches also varied significantly in relation to different treatment, which were two- to fourfold greater in the disturbed (maximum mean=20.72 m) than undisturbed plots (4.47 m; [9]). These findings are not surprising given the numerous studies that have recorded that disturbances such as grazing are associated with the removal of vegetated patches [10]. Loss of resource-accumulating patches, in combination with the increasing distance between those patches, always increases erosion risk either by wind or water at the disturbed sites. Moreover, the severe destruction of cryptogamic crusts and the significantly low number of patches due to ploughing, even under exclosure [9] suggest that two decades are insufficient for the landscape to recover. Indeed, recovery in arid landscape due to prolonged human disturbance is protracted, and requires up to a century for cryptogamic crusts to recover from severe disturbance [11].

We also found that the distribution of soil nutrients at the landscape scale differed greatly among the treatments. At the most disturbed (ploughed-grazed) plot, we did not find any spatial patterning of litter cover or pH, which suggested that the distribution of those properties was homogenous across the landscape. Conversely, the pattern was clearer in the intermediately–disturbed plot (unploughed-grazed), with a distinct spatial patterning in the undisturbed plot, which corresponded to the average diameter of shrub canopies (Figure 1). The undisturbed plot, which had a higher density of vegetated patches and thus shorter distance between patches, accumulated more resources than the disturbed plots as a result of lower erosion risk. These results indicate, therefore, how differences in the number of resource-accumulating (vegetated) patches could lead to a different distribution of resource accumulation at the landscape level.

Significant patterning or accumulation of organic matter and litter under the shrubs, but only at the unploughed-ungrazed plot, indicates that grazing and ploughing reduce the spatial heterogeneity of soil properties. While heterogeneity is critical to maintain the productivity of arid landscapes [12], homogenization of organic matter suggests that resources are not localized, for example, under the shrub canopy. Rather, they could be seared across the landscape, making them vulnerable to movement by wind or water erosion. Loss of patchiness, and the negative feedback due to erosion, would eventually result in a low input of organic matter. Consequently, further reductions in water infiltration and soil protection might occur, resulting in higher radiation and surface temperature [13].

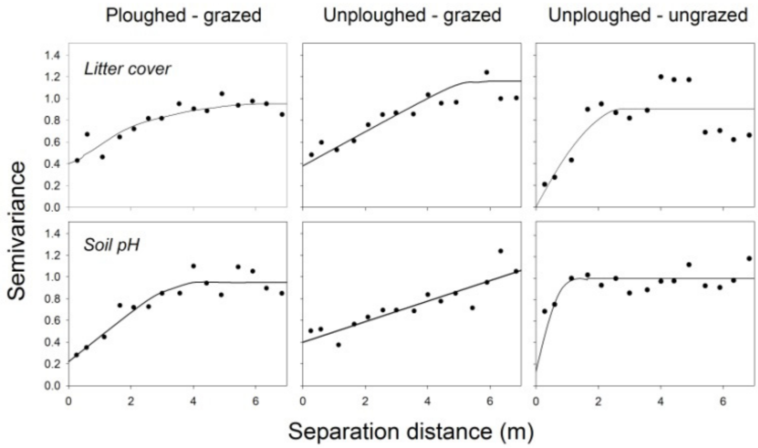

Figure 1: Semi-variograms of litter cover and soil pH in relation to treatment.

Vegetated patches are therefore important for maintaining the heterogeneity and functioning of arid landscapes as they may enhance nutrient cycling even beyond their canopies [14]. In semi-arid systems, shrubs act not only as a source of organic matter but also as ionic pumps. Generally, there would be an increase in pH at the surface from accumulation of litterfall or wind and water deposition [15] under the canopy compared with the bare interspaces. Declines in soil fertility, infiltration and eventually productivity result from homogenization of soil chemical and physical properties. Thus, any treatment such as ploughing, which destroys those fertile patches, would be expected to lead to degradation of the soil surface.

3.2 Ploughing may lead to monospecific shrub stands

Although we failed to detect significant differences in total shrub density among treatments, there were approximately 1.5–times more shrubs on the ploughed-grazed plots (5750 shrubs ha^{-1}) than the ploughed-ungrazed (3400 shrubs ha^{-1}) plots, and twice as many on the unploughed-grazed plots (2300 shrubs ha^{-1}). We attribute the lack of significant difference to the low statistical power arising from only three replicate plots [9]. The lack of a significant ploughing effect on the reduction of shrub density after two decades was consistent with other studies of altered shrub density [16]. It also suggests that abiotic factors at regional scales (e.g. rainfall, atmospheric CO_2) might be driving shrub re-growth rather than small-scale shrub manipulations such as ploughing or grazing exclusion. Variable rainfall, which occurs more frequently due to a changing climate, as well as increasing level of CO_2 favour C_3 shrubs over C_4 grasses. The ability of shrubs to withstand drought, fire, salinity and frost as well as grazing and ploughing [17] allow them to maintain their dominance once established [18]. The failure of perennial grasses to recover even decades after disturbance [19] suggests that shrub removal is ineffective in the long-term. Though shrub removal might increase pasture production in the short-term (<10 years [20]), long-term studies (~30 years) suggest otherwise [21]. The imposition of grazing shortly after ploughing might retard the recovery of these systems and deplete grass soil seedbanks.

We found, however, significant differences in shrub composition among treatments, suggesting that the effects of ploughing and grazing on vegetation were highly species-specific [9]. The combination might therefore lead to the domination of grazing- and/or ploughing-tolerant species such as *Eremophila sturtii* over intolerant species such as *Acacia excelsa*. In general, differences among treatments were generally due to the dominance of particular shrub species: *Acacia excelsa* in unploughed-ungrazed plots, *Eremophila sturtii* in all unploughed plots, *Eremophila longifolia* in the ploughed-ungrazed plots, and *Dodonaea viscosa* in all of the ploughed plots (Figure 2). Eventually, ploughing in combination with grazing might lead to the extinction of some species and a long-term reduction in shrub diversity.

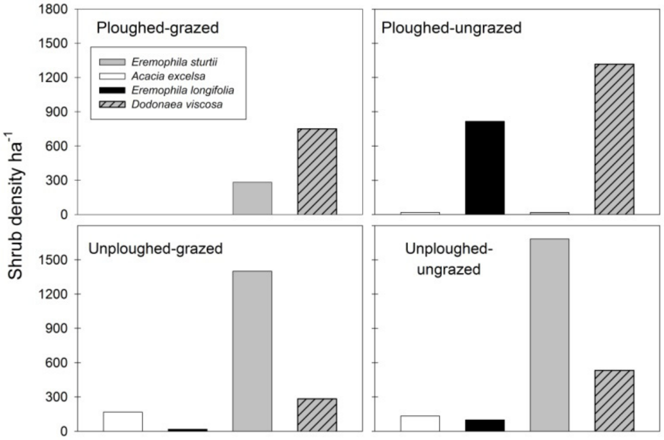

Figure 2: Shrub density (plants ha^{-1}) under the four different ploughing and grazing treatments.

3.3 Shrubs provide habitat for soil–disturbing fauna

We found more animal disturbances in the resource–accumulating (shrubs) patches than would be expected given the low percentage of area occupied by shrubs (Figure 3). Ant nest density was greater in both the interspaces and shrub hummocks than on the log mounds ($F_{2,16}$=28.93, P<0.001). Our findings on the distribution of ant nest could be ecologically important as ants have been known as central foragers, moving resources from resource-rich areas (e.g. under the shrubs) to their nests. With significantly high number in the interspaces, the presence of ant nests might partially offset the ploughing- and grazing-induced reduction in soil nutrients as ant nests became micro fertile-patches in these resource-shedding areas. Ant nests have been known to accumulate organic matter, improve infiltration [22] and enhance the germination of various plants [23].

We did not detect any treatment effect on the density nor the composition of animal disturbance, indicating a consistent effect of patch across the different grazing and ploughing regimes. Our study demonstrates, therefore, that shrub hummocks provide habitat for soil-foraging animal species as there were more disturbances in the resource-accumulating patches than in the resource-shedding patches (Figure 3). This trend is not surprising given that plants provide nesting, perching and foraging sites as well as shelter against predators.

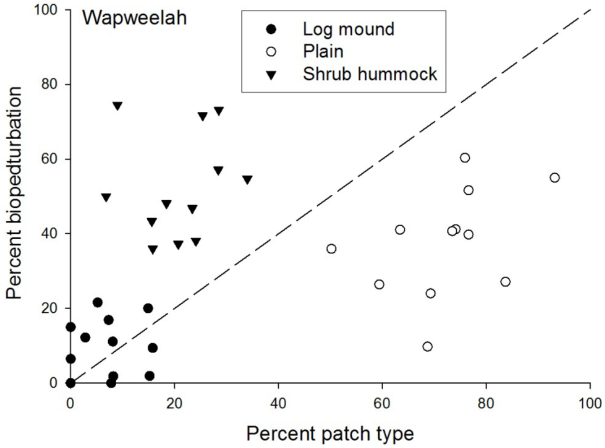

Figure 3: Percentage of animal disturbances as a percentage of available patch type. The broken line represents a 1:1 relationship.

4 The cost of ploughing versus the benefits of maintaining shrubs

Overall, apart from being expensive and having only short-term production benefits [3], the ecological cost of ploughing is high. We suggest that ploughing is inappropriate for reducing shrub densities in encroached Australian semi–woodlands and encourage the adoption of alternative strategies. The use of alternative grazing animal such as goats, rotational grazing, adjusting livestock numbers during productive (La Niña) or unproductive (El Niño) periods, and control of total grazing pressure are more appropriate than ploughing. An alternative perspective, which is gaining traction worldwide, is to value these encroached shrublands in terms of the ecosystem benefits that they can provide for communities such as fresh water, habitat, fuel wood and sinks for carbon dioxide [8, 24]. Under average seasonal condition, livestock production could produce a net carbon sink of 0.5t CO_2 equivalents ha^{-1} $year^{-1}$ and under these alternative grazing regimes, designed to both enhance carbon sequestration and increase individual animal performance, the opportunity cost of reducing emission was around A$20-30 t^{-1} CO_2 equivalents. However, land managers benefit from selling emissions only if the price of carbon credits is high (e.g. > A$50 t^{-1} CO_2 equivalents). Therefore, the development of carbon-management systems requires a regional planning system that includes incentives or compensatory payments, particularly if there is conflict between land-managers and greenhouse abatement [25]. However, we acknowledge that the shift will likely adversely impact livelihoods of producers at a time when they are attempting to the recoup the costs of these new strategies.

5 Conclusions

Retaining shrubs has various ecological and potential economic benefits. Firstly, productivity of semi-arid rangelands depends on the presence of shrubs, as they maintain landscape heterogeneity by acting as resource sinks. Shrubs in productive rangelands can also minimize resource loss by reducing erosion and acting as biodiversity hot-spots. Shrubs also have the potential for inclusion in emission trading and sequestration programs by enhancing land-based sinks for greenhouse gases [25]. Treatments such as ploughing could therefore significantly increase the emission of greenhouse gasses by enhancing decomposition rates and potentially reducing both the amount of carbon sequestered [26], as well as soil carbon [27]. A changing climate, in particular, will provide many challenges for scientists and land managers attempting to adapt their current land use practices. However, with the potential opportunity for managing carbon stocks and maintaining ecosystem processes, we argue for a change in emphasis from removal of shrubs to one of seeking alternative uses for shrub–encroached woodlands. Given the trend of increasing cover of shrubs worldwide with increasing atmospheric CO_2 [24], enterprises based on shrub retention are likely to enjoy longer–term economic and ecological benefits.

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