Agriculture, Ecosystems and Environment 179 (2013) 125–132

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Herbaceous vegetation response to grazing exclusion in patches and inter-patches in semi-arid pasture and woody encroachment

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ARTICLE INFO

Article history:
Received 4 May 2013
Received in revised form 7 August 2013
Accepted 12 August 2013
Available online 8 September 2013

Keywords:
Landscape function
Groundcover
Plant cover
Australia
Rangelands

ABSTRACT

Semi-arid rangelands have strong feedbacks between vegetation and abiotic factors (rainfall and soil), which manifest at the small patch/inter-patch scale. The effects of excluding grazing at the small patch scale have not been studied in these systems, despite fine-grained patch/inter-patch mosaics determining landscape-scale ecosystem function and productivity. We established small (1 m × 1 m) grazing exclosures and monitored change in herbaceous vegetation cover quarterly over 2 years, in grazed and ungrazed patches (high herbaceous vegetation cover) and inter-patches (low herbaceous vegetation cover), in woody encroachment and pasture sites in semi-arid eastern Australia. Prior to excluding grazing, herbaceous groundcover in pasture patches (63–67%) was significantly greater than in woody encroachment patches (15–16%) or inter-patches in both vegetation states (0–1%). The effect of grazing exclusion on herbaceous cover varied between patch type and vegetation state. In the absence of grazing, herbaceous cover was significantly greater in pasture patches than in woody encroachment patches at every monitoring time. Initial differences in herbaceous cover between woody encroachment patches and pasture patches was significantly less pronounced with continued grazing pressure, indicating that grazing pressure can negatively influence the positive effect of a lack of woody plants on herbaceous growth in pastures. Grazed pasture patches had significantly less herbaceous cover than ungrazed pasture patches at every monitoring time, whereas in woody encroachment, grazed patches had less herbaceous cover than ungrazed patches on only two occasions in the second year. Inter-patches in both vegetation states failed to respond to grazing exclusion in the 2-year study period. Herbaceous cover change in semi-arid rangelands is a function of grazing, rainfall and woody plant incidence. If grazing pressure in pasture patches is not carefully managed to maintain herbaceous cover, the positive effects of high rainfall and low woody plant abundance on herbaceous cover can rapidly diminish. Improving herbaceous groundcover overall will require an interventionist approach to overcome barriers to plant establishment in inter-patch areas such as the lack of resource retention.

1. Introduction

Semi-arid vegetation is strongly structured by abiotic factors, such that resource patchiness is often reflected in vegetation patchiness (Schlesinger et al., 1990; Aguiar and Sala, 1999). Strong feedbacks between vegetation and soil resources are common in these systems, and are most evident in cover, particularly herbaceous cover, which is typically patchy at small spatial scales (up to several metres in diameter). Patches and inter-patches regulate resource movement between runoff (inter-patch) and runon (patch) zones (Ludwig et al., 2005; Bisigato et al., 2009; Muñoz-Robles et al., 2011b). The size, orientation and other properties of patches and inter-patches determine the magnitude of resource movement (Aguiar and Sala, 1999; Ludwig et al., 2000). Landscape function in semi-arid regions is strongly linked to the spatial scale at which this patchiness and resource movement occurs (Ludwig and Tongway, 1997; Muñoz-Robles et al., 2011b). Semi-arid systems have an optimum ratio of patches to inter-patches at which productivity is maximised (Noy-Meir, 1973; Tongway and Ludwig, 1994; Aguiar and Sala, 1999). Inter-patch areas allow the concentration of resources (such as seeds and organic matter) and surface runoff in down-slope patches, resulting in higher overall biomass production than if resources and surface runoff were spread uniformly across an area (Ludwig et al., 2005). However, once inter-patches become too large or too contiguous, the net productivity of the system decreases (Noy-Meir, 1973; Tongway and Ludwig, 1994).

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0167-8809/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agee.2013.08.002

Livestock grazing alters cover and patchiness in semi-arid systems (Milchunas and Lauenroth, 1993; Adler et al., 2001; Asner et al., 2004; Kefi et al., 2007; Bisigato et al., 2009; Villagra et al., 2009) and changes in herbaceous vegetation cover when grazing is removed can be unpredictable (Fuhlendorf et al., 2001; Seymour et al., 2010). The effects of increased grazing pressure on the stability of patchy ecosystems has been well studied (Kefi et al., 2007), but the reversibility of these changes is less well understood (Asner et al., 2004). Hence, investigating the response of patches and inter-patches to grazing removal is a necessary first step in developing strategies for managing resource-limited semi-arid rangelands.

Soil moisture is generally the most limiting resource in semi-arid ecosystems, thus rainfall is an important predictor of vegetation change. The response of herbaceous plants to rainfall is an indicator of semi-arid ecosystem function (Ludwig and Tongway, 1997), which can be altered by rangeland management, particularly grazing (Snyman, 1998). Through high rates of biomass removal and selective removal of palatable species, excessive grazing can: (1) increase the occurrence and extent of sparsely vegetated inter-patches, increasing runoff and reducing resource retention; (2) reduce the availability of resources such as seeds and litter reserves, and (3) alter the proportions of plant life-forms, each of which may respond differently to rainfall (Ludwig and Tongway, 1997; Snyman, 1998). Therefore, the relationship between grazing, rainfall and herbaceous vegetation is complex (Fuhlendorf et al., 2001; Searle et al., 2009). Indeed, it is likely that the response of herbaceous vegetation to rainfall varies with different grazing regimes and patch/inter-patch configurations.

The stability of patches and inter-patches and their responsiveness to grazing exclusion and rainfall depends on their ability to trap resources such as organic matter, propagules and water. Patches are less 'leaky' than inter-patches: rainfall results in greater sediment, runoff and organic matter loss from sparsely vegetated inter-patches than from vegetated patches, as well as the transfer of these resources from inter-patches to patches (Muñoz-Robles et al., 2011b). Seed banks are therefore concentrated in vegetated patches in these two-phase systems (Bisigato et al., 2009), rainfall should result in a greater increase in herbaceous vegetation cover in patches than inter-patches, and exclusion of vertebrate grazing should result in an increase in herbaceous cover in patches, because established plants can grow without being eaten. In inter-patches, however, few plants occur prior to grazing exclusion, and an increase in herbaceous cover will only occur if plants can first establish.

Woody plants have increased in abundance in semi-arid and arid ecosystems globally (Graz, 2008; Eldridge et al., 2011). The consequences of woody encroachment vary widely among ecosystems, but one consistent effect is a decrease in herbaceous biomass (Eldridge et al., 2011). This is likely to be a direct consequence of woody plants competing for resources with groundstorey plants (Scholes and Archer, 1997; Archer et al., 2000), a phenomenon that is likely to be compounded by grazing pressure.

In this study, we assessed change in herbaceous cover in patches (generally with relatively high herbaceous cover and/or other indicators of active resource retention, defined in Table A1) and inter-patches (generally with relatively low herbaceous cover and little indication of resource retention, defined in Gibbons et al., 2009; Table A1) in semi-arid eastern Australia. We measured the response of herbaceous vegetation cover to the exclusion of grazing in paired sites with and without woody vegetation. We predicted that: (1) pasture patches would contain more herbaceous cover than woody encroachment patches irrespective of grazing exclusion, due to the overriding negative effect of woody plant presence; (2) patches would be more responsive to grazing exclusion than inter-patches; (3) rainfall would explain more variation in herbaceous cover change in patches than in inter-patches, due to the greater cover of plants that can respond to rainfall, and greater resource and propagule accumulation, and (4) patches would contain more germinable seed in the soil seed bank than inter-patches due to the ability of patches to capture more litter and propagules than inter-patches.

Supplementary data associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.agee.2013.08.002.

2. Materials and methods

2.1. Study region

The study sites were on the Cobar Pediplain in semi-arid New South Wales, Australia (Fig. 1). Long-term average rainfall varies from 440 mm at Nyngan in the east to 350 mm at Cobar in the west (Australian Bureau of Meteorology, 2012) spread evenly throughout the year but with high intra and inter-annual variability. The geology, soils and vegetation of the study region are described in Tighe et al. (2009) but the soils can broadly be described as hard-setting 'red earths'. The two vegetation states, 'woody encroachment' and 'pasture' that were investigated were defined in accordance with recent studies (see Table A1 in Supplementary Information) and can be summarised as follows: the woody encroachment sites were either dense *Callitris glaucophylla*, *Eremophila* spp. or *C. glaucophylla*–*Eremophila* spp. associations with 700–12 300 stems ha^{-1}, with an overstorey of large *Eucalyptus populnea, E. intertexta* or *C. glaucophylla*. Pastures were a mixture of annual and perennial herbs, comprising native and introduced grasses and forbs, and that had undergone periodic cultivation to introduce new pasture seed and disturb the soil surface to reduce surface sealing and promote infiltration, as well as being infrequently cropped. Further site and management details can be found in Tighe et al. (2009) and Muñoz-Robles et al. (2011a,b).

2.2. Experimental design

Eight paired sites were selected across three grazing properties (Fig. 1). At each paired site, a woody encroachment site was paired with an adjacent pasture site from which shrubs had been removed 16–40 years previously. Each site comprised a mosaic of patches and inter-patches, which ranged in diameter from <1 m to several metres. Total herbaceous cover (all vascular plants <1 m tall) and visual indicators of resource retention/resource loss were the primary visual differences between patches and inter-patches (see Table A1 for further description). The two patch types – patch and inter-patch – were identified at each pasture and woody encroachment site using the visual assessment methods described by Tongway and Hindley (2004). One grazing exclusion cage (1 m × 1 m × 1 m) was established in a patch and an inter-patch at each site, and an ungrazed plot, 0.5 m × 0.5 m, established within each. The cages were formed of rigid 5.0 × 7.5-cm wire mesh including a mesh cover, which excluded all large grazing mammals (including rabbits) but not invertebrates. In a patch and in an inter-patch at each site, a caged plot was paired with an adjacent control (grazed) plot (0.5 m × 0.5 m) with very similar proportions of initial total herbaceous and litter cover (Table 1). The control plot remained grazed for the duration of the study. A total of 64 plots was established – eight replicates of each of the eight treatment combinations of vegetation state (pasture vs woody encroachment) × patch type (patch vs inter-patch) × grazing management (grazed vs ungrazed).

Soil and landscape position were similar within and between paired sites. All sites had surface soils prone to both biological and physical crusting and sealing. Two properties practised set-stocking of cattle and sheep (paddocks grazed continuously by