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Supplementary material

Limited evidence for the use of livestock for the conservation management of exotic plant cover

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Appendix S1. Description of the three communities

Table S1. Mean (± s.e.) for the cover and abundance of exotic plants and a range of biotic and abiotic attributes, plant richness and dung loads for different herbivores across the three plant communities

Sheep dung includes sheep + goats; rabbit grazing includes rabbits + European hares. Within a row, different superscripts indicate a significant difference at $P < 0.05$ (one-way analysis of variance). Aridity = (1 – Aridity Index)

Attribute	Black box		Cypress pine		Red gum	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
Exotic plant cover (%)	7.14[a]	0.93	13.3[b]	1.17	17.2[b]	1.70
Exotic plant abundance (number m^{-2})	22.6[a]	2.63	59.7[b]	4.59	36.9[c]	3.24
Rainfall (mm $year^{-1}$)	385[a]	3.2	460[b]	4.6	441[b]	3.2
Aridity	0.26[a]	0.004	0.32[b]	0.005	0.39[c]	0.005
Sand (%)	24.0[a]	0.65	60.0[b]	0.98	14.4[c]	0.37
Silt (%)	56.7[a]	0.88	27.1[b]	1.01	71.7[b]	0.49
Clay (%)	19.3[a]	0.68	12.9[b]	0.82	13.9[b]	0.33
Soil total C (%)	2.75[a]	0.10	2.08[b]	0.06	4.84[c]	0.11
Soil total N (%)	0.205[a]	0.005	0.152[b]	0.003	0.307[c]	0.006
Soil available P (ppm)	51.86[a]	2.31	14.38[b]	0.689	61.08[a]	2.02
Exotic plant richness (125 m^2)	7.7[a]	0.37	9.6[b]	0.36	11.9[c]	0.53
Native plant richness (125 m^2)	27.5[a]	0.65	26.8[a]	0.88	19.0[b]	0.51
Cattle dung (kg ha^{-1})	28.8[a]	4.2	142.0[b]	39.1	17.8[a]	4.1
Sheep or goat dung (kg ha^{-1})	3.4[a]	0.7	12.1[b]	3.2	0.2[a]	0.1
Rabbit dung (kg ha^{-1})	2.2[a]	0.4	12.2[b]	2.4	1.0[a]	0.5
Kangaroo dung (kg ha^{-1})	18.9[a]	1.7	52.7[bc]	3.4	33.2[c]	2.4

Appendix S2.

Table S2. Description of attributes used to develop an index of soil health and their relevance (*sensu* Tongway 1995)

Attribute	Interpretation and relevance
Surface roughness	Surface microtopography. Rougher surfaces have a greater ability to retain abiotic and biotic resources; qualitative; visual assessment.
Crust resistance	The ability of the soil to resist erosion; qualitative.
Crust brokenness	Extent to which the soil crust is broken. Broken crusts are more susceptible to erosion. Cracks may be indicative of potential microsites for seeds to settle; qualitative; visual assessment.
Crust stability	The degree to which surface soil aggregates maintain their stability when wetted; qualitative; assessed with the Emerson slake test (Tongway 1995)
Surface integrity	100 minus the cover of erosional features (e.g. rills, scalds, pedestals); qualitative, visual assessment.
Deposited materials	Extent and nature of materials deposited on the surface from upslope; quantitative, visual assessment.
Biocrust cover	Cover of biological soil crusts, which protect the soil against erosion, fix nutrients and provide habitat for seeds and soil biota; quantitative, visual assessment.
Litter cover	Indicates the potential for decomposition of plant material and protects the soil against erosion; quantitative; visual assessment.
Litter origin	Assesses if litter has been transported from elsewhere; qualitative; visual assessment.
Litter incorporation	The extent to which litter is incorporated into the soil; qualitative; visual assessment

Soil surface attributes used as health indicators

The attributes described in in the table above were assessed within the five small quadrats (0.25 m^2) at each site. This procedure is derived from the Soil Survey Analysis methodology component of Landscape Function Analysis (Tongway 1995). Soil surface roughness is a measure of the surface microtopography and is assessed by noting the difference between the lowest and highest points of the soil surface. Soil surface roughness defines the ability of the soil to capture and retain resources such as water and organic matter. Crust resistance is a measure of the ability of the soil to resist erosion and is measured on dry soil. It involves assessing the ease with which the soil can be disturbed, producing material suitable for erosion by wind or water. Crust brokenness is a measure of the extent to which the surface crust is broken. A more detached crust is likely to indicate material prone to movement by erosion but can also relate to the provision of potential microsites for the collection of seeds. Crust stability, which relates to the stability of soil fragments, is measured using the Emerson Slake Test (Tongway *et al*. 2003). Surface integrity is the cover of uneroded surface, i.e. 100 minus the cover of wind or water erosion, assessed by measuring features such as rills, water sheeting, scalds, terracettes and pedestals. Deposited material is material that is deposited by wind or water erosion and derived from elsewhere. Cover of biocrusts provides a useful measure of surface stability because of the tendency of cryptogams to stabilise surface soils (Eldridge *et al*. 2011). The cover of litter was assessed, as well as its origin, whether it is derived from local plants or transported from elsewhere, and its degree of incorporation into the surface, i.e. how well the litter and soil are mixed together.

An overall index for each quadrat was derived as the sum of the 10 scores shown in Table S2 and expressed as a percentage of 43, the maximum possible score. Indices based on these surface attributes have been used widely to assess different landscapes worldwide and are known to be related with laboratory and field measurements of their related processes (e.g. Tongway 1995; Maestre and Puche 2009; Eldridge *et al*. 2011).

Appendix S3. Structural equation model procedures and the *a priori* model

The process of constructing structural equation models typically involves model specification, model identification, parameter estimation, testing model fit, and, model re-specification (Malaeb *et al*. 2000; Iriondo *et al*. 2003). This requires the use of theoretical knowledge to develop a hypothetical systems model. Then, numerical data that represent variables within the model are gathered, the value of unknown parameters estimated (Iriondo *et al*. 2003), and model tested for goodness of fit. The testing of model fit is then repeated under the final process of re-specification.

In the present study, model fitting was evaluated using a maximum likelihood χ^2 goodness-of-fit test, Joreskog's goodness of fit index (GFI), and the normed-fit index (NFI). Under the χ^2 test, a good model should have a P value > 0.05. A better model fit therefore has a larger P value. The GFI value provides additional assessment of the results obtained from the χ^2 goodness-of-fit test through examining the variances and co-variances accounted for in the model, thereby showing how closely the model replicates the data. The GFI statistic ranges from 0–1 and typically does not exceed 0.9. The NFI assesses the model by comparing the χ^2 value of the model to the χ^2 value of the null uncorrelated model. The NFI ranges from 0 to 1 with values exceeding 0.90 being indicative of a good model fit. Consistent with SEM procedure, we used expert knowledge to develop an *a priori* model (Fig. S1) and the mechanisms underpinning this model are shown in Table S1.

Appendix S4. Species model for the river red gum community

Analyses

To further delve into the significant result from the Structural Equation Model (SEM), we used generalised linear mixed modelling (GLMM) to assess the effects of our different measures of grazing on the cover of individual species. We expected that grazing sensitive species would be strongly reduced by historic livestock and recent cattle in line with the results from the SEM.

The model included fixed effects of our four herbivores (cattle, sheep, kangaroo, rabbit) and our measure of historic livestock grazing (tracks), which were all $\log_{(x+1)}$ transformed and standardised before modelling. The random components included random intercepts for individual species which had slopes which were allowed to vary for each of our five grazing measures. Using the lme4 package (Bates *et al*. 2015) we ran this model three times using binomial (*glmer* function), negative binomial (*glmer.nb* function) and normal (*lmer* function) model distributions within R (R Foundation for Statistical Computing, Vienna, Austria). We then used Akaike's Information Criterion (AIC) to compare these distributions and select the final model, the normal distribution using the *AIC* function in the MuMIn package (Nakagawa and Schielzeth 2013). The plot of residuals *v.* fits for this model was also superior to the other two distributions with no obvious outliers. Confidence intervals (CI) around the model parameters (fixed and random) were estimated using bootstrapped confidence intervals (500 simulations; Bates *et al*. 2015).

Results

We found only one significant effect of grazing on weed cover, partially supporting our expectations. Livestock tracks significantly reduced the cover of shrub species overall (Figure S1a). Across all species, the reduction in cover was greatest for the cover of *Lolium rigidum* and *Bromus diandrus* (Figure S1). The relatively high variability amongst the responses of individual species (Figure S1b) explains the weak and variable effects of the remaining measures of grazing (Figure S1a). For example, Cattle grazing has an overall neutral effect on weed species cover, but this is due to stark contrast in species responses, with *Lolium rigidum* and *Bromus diandrus* strongly increase in cover with greater cattle grazing, while *Ehrharta longiflora* is strongly reduced by increases in cattle grazing (Figure S2).

Appendix S5.

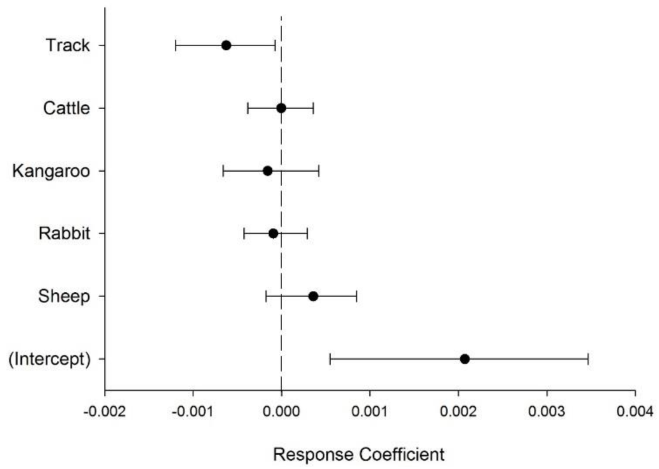

Figure S1. Response coefficients (model slopes) and their bootstrapped confidence intervals (CI) for the explanatory variables and model intercept. Significance is determined when confidence intervals do not intersect the x = 0 (vertical dashed line).

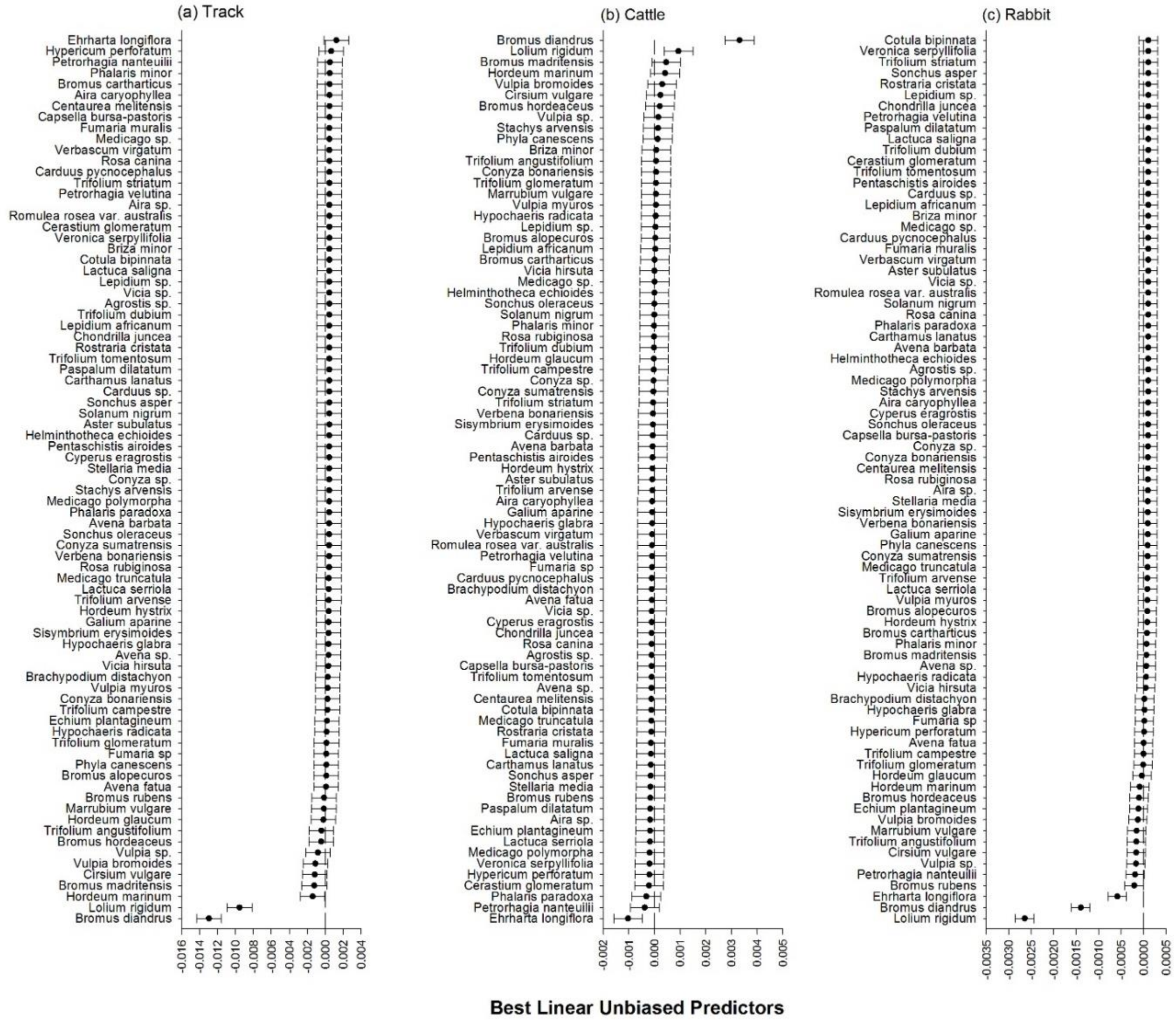

Figure S2. Best Linear Unbiased Predictions (BLUP) of the random effects for each plant species (*y*-axis) for each measure of grazing (a) tracks, (b) cattle, (c) rabbit, (d) kangaroo, (e) sheep, and the intercept (f) for each species. Data presented here supports this model's fixed effects (Figure S1), with $x = 0$ (dashed lines) representing the average response across all species for each model component (Figure S2). Significant deviations of an individual species from the average species response are determined when the confidence interval does not intersect $x = 0$. The species shown here are only a subset of all species.

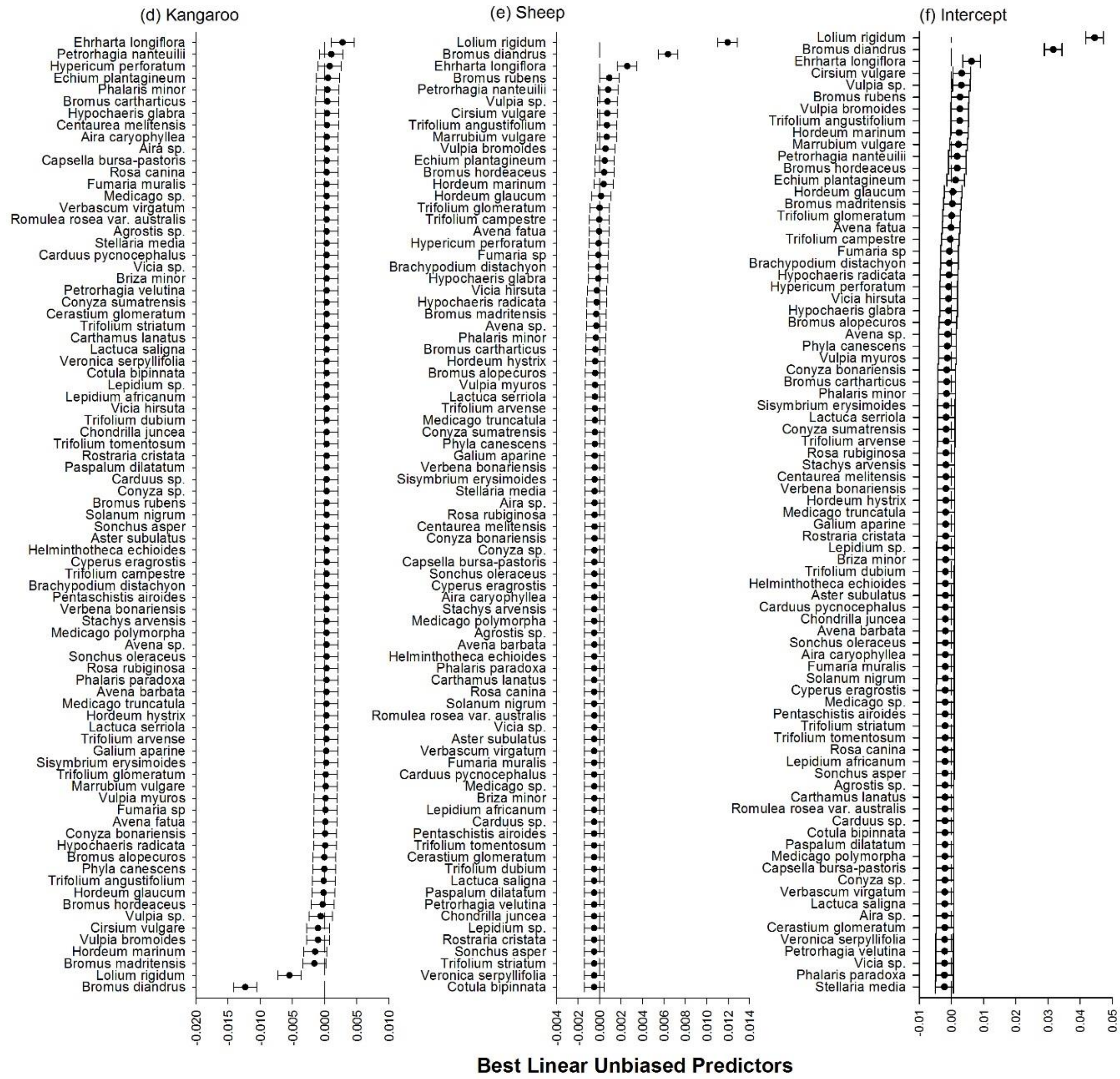

Figure S2. (*Cont*.)

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