How do different levels of grazing and fertilisation affect vegetation composition in temperate Australian grassy ecosystems?

Systematic Review and Meta-analysis

Final Report

Report to Victorian Department of Sustainability and Environment

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Front cover photos : (a) *Caesia calliantha*, a native geophyte favoured by livestock exclosure, (b) sheep grazing fertilized pasture, southern tablelands NSW, (c) aerial fertilization of native pastures circa 1965.

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Summary

The primary question asked by this review is "what components of ground layer plant diversity occur in temperate grassy ecosystems under different levels of grazing and fertilisation?" A second question posed, and one of particular interest to managers, is "How does ground layer plant diversity respond to relief from grazing and/or fertilisation?" Studies were placed within the organising framework of a modified state-and-transition (S&T) model of McIntyre and Lavorel, 2007. This S&T model was developed to provide a broad framework to describe the general effects of common land management practices on grassy vegetation structure, floristics and trait composition in temperate Australia. I extended this model by including two additional land use states (1) *Exclosed grassland*, an alternative state to *Reference grassland* but with a recent history of livestock grazing, and (2) *Past fertilised pasture*, an alternative state to *Native pasture*.

A systematic review methodology was used to find and extract data on plant abundance and composition within and among land use states. In summarizing the results of the systematic review, two separate approaches were taken. Firstly, I used the accepted studies to provide a summary of the dominant species in each of the six land use states. Secondly, I undertook meta-analyses using log response ratios of differences in individual plant species abundance among land use states.

A relatively broad interpretation of what comprised the geographic boundaries of the temperate woodlands was taken, including studies from the E1 (Mediterranean), E2 (dry Mediterranean), E3 (mostly summer dominant growth), D5 (cool, dry) and F3 (warm, wet summer) agro-climates of Hutchinson *et al.* (2005). Studies from the tropics and sub-tropics (E4 and E7), arid and semi-arid rangelands (E6, H) and alpine zones (B1, B2) were excluded. Studies from southern Queensland were also excluded and data searching was restricted to New South Wales, South Australia, Victoria, Western Australia, Tasmania and the Australian Capital Territory. For the purposes of analysis, the summer dominant rainfall, northern outlier of the D5 agroclimate zone (New England Tablelands of NSW), was identified.

After an extensive literature search 79 studies were found that met the selection criteria. Most of the research identified was undertaken in the cool wet agroclimate zone of Victoria and New South Wales (including the summer rainfall portion of the New England Tablelands). Seventy studies provided data on dominant species for one or more states within the S&T framework. Fifty seven studies had suitable data on contrasts among states. Within these studies there were 216 land use state observations and 104 land use contrast observations.

The majority of land use state observations were from grazed but unfertilised pastures (Native pasture, 90 observations) although Fertilised pastures (36 observations), Exclosed grasslands (37 observations) and Reference grasslands (44 observations) were also frequently published in the literature. The majority of contrasts among land use states were of Reference grassland to Native pasture, Native pasture to Fertilised pasture and Native pasture to Exclosed grassland.

The frequency of dominant species varied between land use states, although a small number of species, including *Austrodanthonia* (*Rytidosperma*) spp, the exotic perennial forb *Hypochaeris radicata*, and a

few exotic annual grasses (eg. *Vulpia* spp.) and legumes (*Trifolium* spp.) were frequent across most land use states. The most apparent difference in species frequencies appeared to be between Reference grassland and all other vegetation states. Reference grasslands were mostly dominated by the tall perennial grasses *Themeda triandra* and *Poa sieberiana*/*labillardierii*. These species were less frequent in Native pasture, which were often dominated by other native perennial grasses such as *Microlaena stipoides, Austrodanthonia* spp., *Bothriochloa macra*, *Aristida ramosa* and *Austrostipa scabra*. With the exception of *Hypochaeris radicata*, exotic plant species were rarely among the dominants in either Reference grasslands or Native pastures. *Themda triandra* and *P. sieberiana* were only recorded as dominant in one (2.7%) and three (8.3%) fertilised pastures respectively. *Austrodanthonia* spp (*Rytidosperma* spp), *Bothriochloa macra*, *Austrostipa scabra* and *Microlaena stipoides* tended to be the most frequently recorded native species in Fertilised pastures. In contrast to both native pastures and Reference grasslands, most of the frequently recorded dominant species in fertilised pastures were exotics. Exclosed grasslands had similar dominants to native pastures but were also sometimes dominated by robust annual grasses such as *Avena barbata* while many other typically widespread exotic annuals (eg. *Trifolium* spp. and *Vulpia* spp.) were less frequent.

Meta-analyses were undertaken of changes in plant species abundance across livestock grazing and nutrient enrichment land use contrasts using log response ratios, ln(RR). In each case I separately distinguished between the long-term imposition and removal of livestock or fertilisation.

The average response (lnRR) of native species to long-term absence of livestock was positive, but overall effects were weak. That is, average abundance in long ungrazed Reference grasslands was greater than in native pastures. These effects were most apparent in E1 (Mediterranean – WA and SA) and E3 (warm summer growing – western slopes of NSW) climates where the data suggested that grazing has had the greatest impact on vegetation, shifting composition towards exotic dominance. Cool summer wet landscapes of the New England Tablelands overall appear to have been relative tolerant of long-term livestock grazing. The estimated plant responses to removal of livestock from native pasture (exclosure) differed to those estimated for long-term absence of livestock grazing. In few landscapes were the effects of exclosure clearly beneficial (in terms of favouring native species and having negative effects on exotics) with average native responses close to 0 or negative in many cases. Individual species ln(RR) to long-term absence of grazing was only very weakly correlated with ln (RR) for recent exclosure and then only for native plant species. Some individual species were found to have opposite responses to exclosure compared to their response to long term absence of grazing.

Further analysis of the effects of excluding livestock from native pastures identified differences between native and exotic species responses, particularly with respect to mean annual rainfall and to a lesser extent tree cover, although effects were weak, uncertainty was high and species level variation was considerable. Exotic species ln(RR) was predicted to be increasingly negative at higher mean annual rainfall (indicating increasingly less abundant in exclosed grasslands compared to grazed native pasture), while native species ln(RR) was predicted to be higher when overstorey trees were present (more abundant in exclosured grasslands compared to native pastures if trees present).

The effects of nutrient enrichment (often in conjunction with livestock grazing) are clearly negative for most native plant species and the positive effects of nutrient run-down are of a similar magnitude, although less precise. Estimates of ln(RR) suggest that most exotic plant species are least abundant in non-enriched land use states and effects are consistent in all agroclimatic zones.

The data obtained strongly suggest that grazed, but not fertilised, pastures frequently support native perennial species and so play an important role in the conservation of native plant diversity in grassy woodlands. The dominant species of native pastures do however differ from Reference grasslands and many native plant species decline in abundance as a result of long-term livestock grazing. However, exclosure of native pasture does not consistently result in an increased abundance of native plant species and declines in the abundance of exotics. Exclosure of native pastures is often undertaken for the purposes of plant conservation. The meta-analyses described here suggest that the conservation benefits of removing livestock are highly variable and in most agro-climatic regions rarely result in significant improvements in groundlayer cover and compisition.

The meta-analysis suggests that a plants response to long-term livestock grazing is a poor predictor of response to livestock exclusion. As a result only in a few situations could livestock exclusion be expected to lead to increases in the abundance of native species relative to exotics, let alone reverse the vegetation changes that have occurred owing to long-term livestock grazing. While livestock exclosure can have positive outcomes for some native species, results are variable and hard to predict. Basing current decision making (whether or not to exclude livestock) on plant species abundances in Reference grasslands, could lead to unexpected outcomes.

The current understanding of how livestock grazing and fertilisation affects groundlayer plant composition is primarily derived from studies that rely on contrasts among sites with differing land use history. Most of our current knowledge therefore reflects the long-term, historical effects of these management practices. In this context the vegetation changes owing to livestock grazing of Reference grassland or fertilisation of native pasture are relatively well described. In contrast there were very few studies that explicitly examined exclosure of fertilised grasslands or the run-down of available nutrients in previously fertilised pastures. Information about the vegetation of these land-use states and respective transitions is required to assist managers in allocating limited conservation resources. A greater emphasis on experimental studies, supported by appropriately designed natural experiments, is needed to address our understanding of these land use states and respective land-use transitions.

Some previous syntheses of livestock grazing impacts on grassland vegetation have not separated between the long-term effects of livestock grazing and livestock exclosure and rather treated them as both representing the effects of grazing. Hence, these studies assume grazing related vegetation changes fit a classical succession framework. The available evidence suggests that studies examining the imposition of grazing, and possibly fertiliser, would generate different estimates than those studies based on relief from these practices, supporting S&T models of vegetation that include irreversible or alternative states. Likewise, the results also strongly suggest that failure to account for fertiliser history will bias estimates of the effects of livestock grazing. Previous studies and syntheses have often examined vegetation changes along grazing gradients that also co-varied with nutrient enrichment, without explicitly attempting to distinguish between the two. To further our scientific knowledge of these ecosystems, avoid confusion when comparing results among studies and to better inform management it is essential that future studies carefully distinguish between land use states.

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1. Introduction

Globally, subhumid and Mediterranean grassy ecosystems have been largely converted to intensive agriculture (Sala et al. 2000; Woodward, Lomas, & Kelly 2004). In many regions where soils are not sufficiently arable these landscapes primarily support livestock grazing (Ramankutty et al. 2008) and have been subject to widespread exotic plant invasions and nutrient enrichment (Steinfeld et al. 2007; Reid et al. 2010). Conserving the biodiversity of grazed temperate grasslands presents a significant challenge and it is fundamentally important to understand how different plant species respond to livestock grazing, livestock exclusion and soil nutrient enrichment.

The understorey vegetation of Australia's temperate grassy ecosystems has been substantially modified by a recent history (~160 – 190 years) of livestock grazing and associated management practices (e.g. fertilisation, pasture sowing, cultivation) (Whalley, Robinson, & Taylor 1978; Yates & Hobbs 1997; Dorrough et al. 2004; Kirkpatrick et al. 2005; McIntyre & Lavorel 2007). Temperate grassy ecosystems occur across a range of climates, soils and landscapes throughout south-eastern Australia and with some isolated occurrences in south-western Australia (Yates & Hobbs, 1997). These grasslands evolved under the influence of frequent fire, light to moderate levels of non-ungulate herbivore grazing, a variable climate and generally low fertility Nitrogen- and Phosphorus-limited soils (McIntyre 2011). They have been classified by Milchunas & Lauenroth (1993), Diaz et al. (2007) and Cingolani, Noy-Meir, & Diaz (2005) as having a short evolutionary history of grazing by large herbivores. Despite the broad distribution of these ecosystems, management activities such as livestock grazing and fertilisation, are thought to have relatively consistent impacts on plant species composition(Moore 1970; McIntyre & Lavorel 2007). However, the degree of susceptibility to conversion from native to exotic plant dominance appears to vary regionally, with the pre-agricultural system being most resilient in northern summer dominant rainfall regions (Whalley, Robinson, & Taylor 1978; McIntyre & Martin 2001) and least resilient in southern Mediterranean grasslands and woodlands (Pettit, Froend, & Ladd 1995).

Links between the composition of understorey vegetation, traits of the vegetation and subsequent ecosystem functions have also been identified (McIntyre & Lavorel 2007; McIntyre 2008). These links suggest that there are clear trade-offs between the agricultural production values of the understorey vegetation and environmental attributes such as soil protection and biodiversity preservation. If consistent changes in the composition of understorey vegetation can be identified then predictions can be made for how management will modify conservation values and functional attributes of understorey vegetation.

There has been one quantitative review of plant responses to livestock grazing within Australia (Vesk & Westoby 2001), and data from Australia's temperate grassy ecosystems was also included in a meta-analysis of global effects of grazing on vegetation (Diaz et al. 2007). A review of the potential effects of grazing exclusion on plant diversity in Australian grassy ecosystems has also been published (Lunt et al. 2007). Both Vesk & Westoby (2001) and Diaz *et al.* (2007) did not consider potential interactions with soil enrichment through fertilisation although in both cases some of the included studies described apparent livestock grazing gradients that were confounded with nutrient enrichment. Neither review distinguished between long-term historical impacts of grazing, and the effects of more recent livestock exclosure, as suggested by Lunt et al (2007), although both types of study were included in analyses. While Lunt *et al.* (2007) did consider how the effects of grazing exclusion on vegetation may vary according to soil nutrient enrichment and level of site degradation they did not undertake a quantitative assessment of available literature.

A systematic review methodology (Pullin & Stewart 2006) was used to examine the effects of livestock grazing and fertilisation on plant composition in Australian temperate grassy ecosystems. Discussion with government investors (Land & Water Australia and the Victorian Department of Sustainability and Environment) and land management agencies also indicated a strong desire for quantitative evidence about the effects of various interventions on the direction and rate of restoration in grassy ecosystems. There is considerable interest in how ground layer plant diversity responds to relief from grazing and/or fertilisation.

Variation in land use practices and management histories is expected to impose considerable complexity on the assessment of evidence. For this reason a modified version of the state-and-transition model described by McIntyre and Lavorel (2007) was used as an organising framework for the review (Fig 1). This S&T model was developed to provide a broad framework to describe the general effects of common land management practices on grassy vegetation structure, floristics and trait composition in temperate Australia.

Two additional land use states were included to differentiate states owing to exclusion of livestock or fertilisation after long-term exposure, that is to (a) differentiate Exclosed grasslands (State 6), with a history of livestock grazing since European settlement until recent removal (typically <50 years), from Reference grasslands (State 1), which have not been open to livestock grazing for 100 to 150 or more years, and (b) differentiate Past fertilised pastures (State 7), which have been previously fertilised, but fertilisation has ceased and soil fertility has run-down to levels similar to Native pastures, from Native pastures (State 2) which have never been fertilised. Using this framework the two key interventions of livestock grazing and soil nutrient enrichment were used in their binomial form. Evidence surrounding the effects of varying the frequency, intensity or timing of these interventions was not examined.

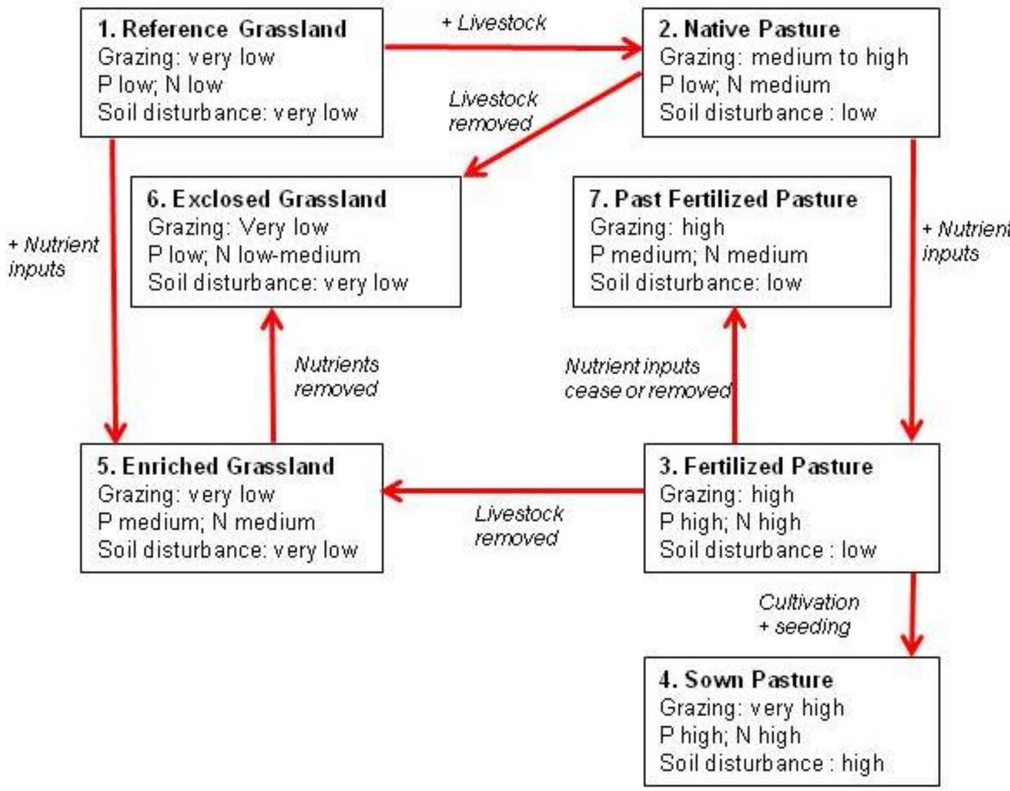

Fig. 1. State-and-transition model for understorey vegetation in temperate grassy ecosystem showing key management interventions (adapted from McIntyre and Lavorel, 2007). .

3. Objectives

3.1 Primary objective

The objective of the review was to determine the effect of different levels of grazing and fertilisation on plant species composition in Australian temperate grassy ecosystems. Studies were placed within the organising framework of a modified form of the state-and-transition model of McIntyre and Lavorel, 2007. To better capture the effects of management history on vegetation, an additional two states were included (see above).

The two primary questions asked by this review are “what components of ground layer plant diversity occur in temperate grassy ecosystems under different levels of grazing and fertilisation?” and “how do different levels of grazing and fertilisation affect plant abundance?”

3.2 Secondary objective

Conservation managers currently desire information to inform decision making about whether or not to provide incentives for relief from grazing and/or fertilisation. A third question of particular interest to managers is “How does ground layer plant diversity respond to relief from grazing and/or fertilisation?”

4. Methods

4.1 Question formulation

The broad topic was formulated by Land & Water Australia (LWA) as one of two trial systematic reviews (see also Review No. 44) and was more recently refined through discussions with the Victorian Department of Sustainability and Environment (DSE). The topic, scope and questions were initially refined and developed through discussions with LWA, prior to development of the review protocol, and subsequently extended to meet the needs of DSE. Feedback on the primary and secondary questions was sought through peer review of the review protocol. Reviewers included leading researchers, catchment managers and federal and state policy officers involved in grassy woodland conservation.

4.2 Search strategy

a. Electronic databases

The following electronic databases were searched:

1. ISI Web of Knowledge
2. Directory of Open Access Journals
3. Scirus
4. ScienceDirect
5. Agricola
6. Australian Agriculture and Natural Resources Online (AANRO)
7. Australian Natural Resources Index
8. Australian Natural Resources Index Archive
9. Agris
10. Cambridge Scientific Abstracts (CSA) – Natural Sciences
11. Australian Digital Theses Program

Searches were also undertaken using the internet-based search engine Google Scholar. The first 100 word document or PDF hits were examined for appropriate data.

General search terms were developed (see below). Preliminary searches indicated that several of these were likely to yield large result sets. In these cases study exclusion terms were used with "NOT" statements (e.g. NOT tropical, NOT arid), where the database allowed for this.

<u>Subject only</u>
1. Grass* & Woodland* & Australia
2. Temperate & Grass* & Australia
4. Botanical composition & Woodland & Australia
5. Temperate & Pasture* & Australia OR NSW, Victoria, Tasmania, South Australia

<u>Intervention and subject</u>
1. Plant* & Graz* & Australia
2. Vegetation & Graz* & Australia
3. Pasture & Graz* & Australia

3. Plant* & Nutrient* & Australia
4. Vegetation & Nutrient* & Australia
5. Plant* & Fertil* & Australia
6. Vegetation & Fertil* & Australia
7. Pasture & Fertil* & Australia
8. botanical composition & Fertil* & Australia
9. botanical composition & Graz* & Australia

b. Specific Authors

Our previous collective examinations of the literature identified a number of potential key authors (listed below). I searched Web of Science for each of these authors using the author field tag (i.e. to exclude multiple citations).

Allcock, K.G
Badgery, W. B.
Benson, J. S.
Biddiscombe, E.F.
Boulton, A.
Bridle, K. L.
Bruce, S.
Chalmers, A. C.
Chapman, D. F.
Chilcott, C.
Clarke, P. J.
Cole, B. I.
Davison, E. A.
Doing, H.
Dowling, P. M.
Eldridge, D. J.
Facelli, J. M.
Fensham, R. J.
Foreman, P. W.
Fox, M.
Frood, D.
Garden, D. L.
Gibson, N.
Gilfedder, L.
Groves, R. H.
Hamilton, S.
Hyde, M. K.
Kemp, D. R.
King, W. M.
Kirkpatrick, J. B.
Lange, R. T.
Langford, C. M.

Leigh, J. H.
Li, J.
Lodge, G. M.
Lunt, I. D.
Magcale-Macandog, D. B.
Michalk, D. L.
Moore, R. M.
Morgan, J. W.
Munnich, D. J.
Nott, R.
Odgers, B. M.
Parsons, R. F.
Petit, N.
Prober, S. M.
Rehwinkel, R.
Reid, N.
Reseigh, J.
Robinson, B. B.
Rodgers, R. W.
Roe, R.
Scarlett, N. H.
Semple, W. J.
Simpson, P. C.
Stuwe, J.
Trémont, R. M.
Whalley, R. D. B.
Williams, O. B.

In addition, known active researchers were contacted with a request for refereed manuscripts in press and Masters or PhD theses relevant to the review topic.

c. Existing libraries

I also compiled extensive personal lists of research papers and theses. These were scanned for additional references that met the study inclusion criteria.

d. Specific journals

The table of contents of all issues of the following journals were also searched for possible relevant studies:

Australian Journal of Experimental Agriculture (now Animal Prodution Science)
Australian Journal of Agricultural Research (now Crop and Pasture Science)
The Rangeland Journal
Pacific Conservation Biology
Cunninghamia

Bibliographies of all articles viewed at full text stage (see below) were also searched.

4.3 Study inclusion criteria

- **Relevant subject(s):**

Relevant subjects were any plant species or plant functional group that occur in the understory / ground layer of temperate grassy ecosystems. A relatively broad interpretation to what comprised the geographic boundaries of the temperate woodlands was taken, including studies from the E1 (Mediterranean), E2 (dry Mediterranean), E3 (mostly summer dominant growth), D5 (cool, dry) and F3 (warm, wet summer) agro-climates of Hutchinson et al. (2005). This excluded studies from the tropics and sub-tropics (E4 and E7), arid and semi-arid rangelands (E6, H) and alpine zones (B1, B2). All studies from southern Queensland were excluded and the search was restricted to New South Wales, South Australia, Victoria, Western Australia, Tasmania and the Australian Capital Territory.

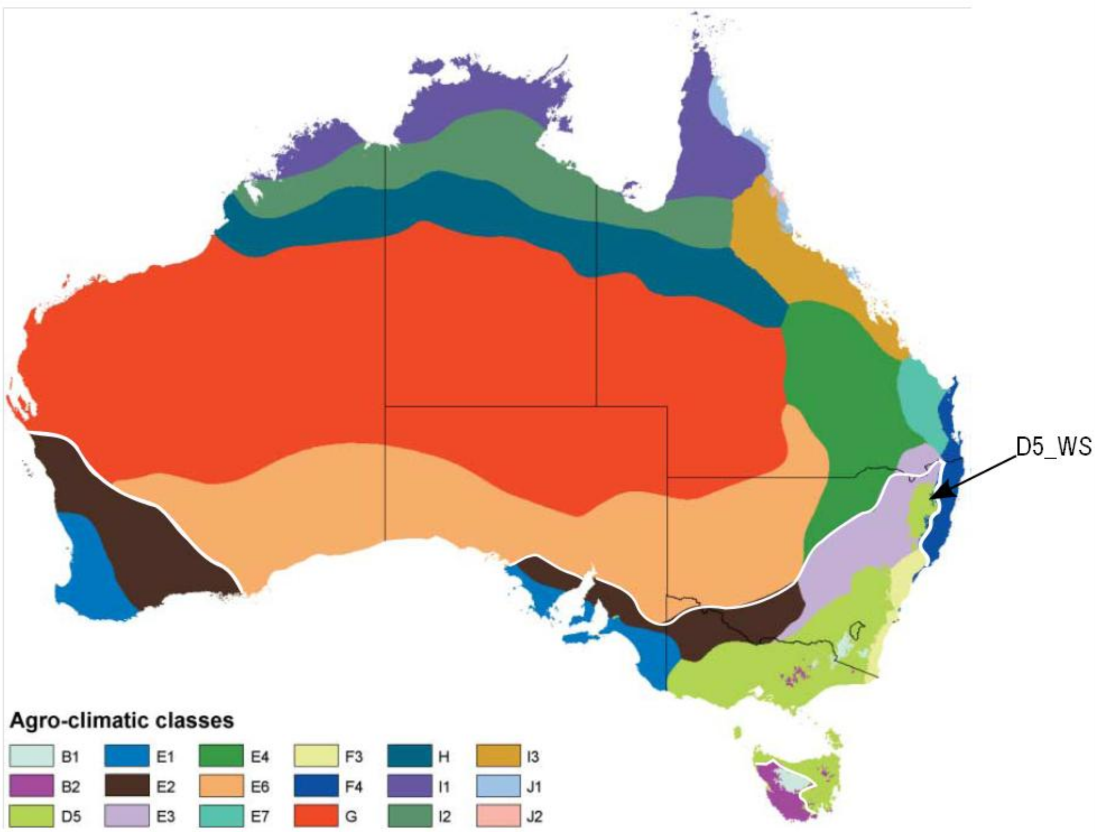

Fig. 2 Eighteen agro-climatic classes mapped by Hutchinson et al (2005).
This review was restricted to classes D5, E1, E2, E3 and F3. The outlying northern D5 zone, around the New England Tablelands, with a summer dominant rainfall, was treated as a separate climate class (annotated as D5_WS). From Hutchinson et al (2005).

In many circumstances it is difficult to determine whether a study specifically applied in terms of the vegetation envelope (ie. as a temperate grassy ecosystem). Native and sown pastures can be derived from woodlands, grasslands or forest. Further, tree structural attributes (cover, density and height) are dynamic and spatial and temporal gradients between grassland, woodland and forest boundaries can increase difficulties regarding delineating the appropriate ecosystem. Additionally a number of studies collectively examine grassy ecosystems, and include cleared woodland, grassy woodland, grassland, and grassy forest. The literature search excluded research in wet forests, wetlands (and associated vegetation types such as sphagnum bogs, sedgelands, although seasonally wet grasslands such as those dominated by *Poa labillardierii* were included), heathlands and dry schlerophyll forests with a shrub dominant understory. A further complication is the dynamic nature of shrub cover in many grassy ecosystems. Shrub invasion into temperate grasslands and woodlands is widely described in the literature, typically post relief from grazing and fire. Studies that provide evidence of recent shrub invasion into grassy dominated temperate ecosystems will provide the exception to the rule of current grassy dominance.

- **Types of intervention:**

Primary interventions considered were nutrient enrichment and commercial levels of livestock grazing. This included sheep and cattle grazing but excluded goat, horse, native animal or feral animal grazing and experimentally applied artificial grazing (eg. hand clipping of plants). Nutrient enrichment could be either through fertiliser input (Phosphorus or Nitrogen), enrichment through livestock camping or nutrient run-on. This excluded atmospheric soil nutrient enrichment. Where possible, levels of enrichment and grazing were assigned. Categorical descriptions, based on land use, are prevalent and these tend to correspond to the six land use states (Table 1). Often land use descriptions include information about both fertilisation and grazing (see Table 1). If land use descriptions were not adequate to assign a observation to either Fertilised pasture or Native pasture, these were excluded unless data on soil nutrient availability were provided. In this later case I used a colwell available soil Phosphorus of >15ppm (>20ppm in basalt derived soils) to separate nutrient enriched from never enriched (see Table 3 for equivalent Bray and Olsen P test values).

Table 1. Relationships between land use descriptions and interventions

Land use	Intervention
1. Reference grasslands	long-ungrazed, never enriched
2. Native pasture	+ grazing, never enriched
3. Fertilised pasture (incl. livestock camping)	+ grazing, + enrichment
6. Exclosed grassland	Ex grazing, never enriched
5. Enriched grassland	Ex grazing, past enriched
7. Past fertilised/Degraded pasture	+ grazing , past enriched

To address the secondary questions that related to relief from grazing or fertilisation, the previous land use state provided the necessary context for analysis of the intervention (eg. Table 2). I contrasted the vegetation responses owing to the *addition* of either grazing or fertilisation with their *removal* (Table 3). In all cases studies were not longitudinal, rather they compared species abundances across land use categories simultaneously, whether experimentally or using available land use contrasts.

Table 2. Interventions, and current and prior land use for analyses for state transitions owing to grazing and/or fertilisation. For the purposes of data analysis I did not distinguish between contrasts 6 & 7 as preliminary analyses showed these to have similar effect sizes.

Contrast	Prior Land use State	Intervention	Current Land use State
1	1. Native pasture	Livestock removal	6. Exclosed grassland
2	3. Fertilised pasture	Livestock removal	5. Enriched grassland
3	3. Fertilised pasture	Fertiliser ceased	7. Past fertilised pasture
4	5. Enriched grassland	Nutrients removed	6. Exclosed grassland
5	1. Reference Grassland	+ Livestock	2. Native pasture
6	2. Native pasture	+Nutrients	3. Fertilised pasture
7	1. Reference Grassland	+Nutrients	5. Enriched grassland
8	1. Reference Grassland	+ Livestock, + Nutrients	3. Fertilised pasture

It is important to note that all Reference grasslands would have been subject to some livestock grazing immediately after settlement until fencing was introduced. While the date at which fencing excluded livestock from areas such as cemeteries, rail lines, roadsides and crown reserves (the most common forms of Reference grasslands) varied regionally (typically the mid to late 19th century) I assume they all have an equivalent prior level of grazing. In most cases Reference grasslands would have been fenced from frequently grazed pastures prior to (1) widespread sowing of perennial pastures and annual legumes, (2) peaks in livestock numbers in the late 19th and early 20th century that coincided with severe drought conditions and (3) a later peak associated with widespread superphosphate application (1950's-1970's). Reference grasslands cannot therefore be considered equivalent to permanent grazing refuges that have never been subject to livestock grazing (Fensham & Skull 1999). However, while some changes in vegetation may have occurred early in European settlement, comparing the vegetation between these areas and native pastures will provide best estimates of the long-term, historical effects of imposing livestock grazing on temperate grassy ecosystems and incorporates both past and current grazing impacts (Lunt et al. 2007). In contrast, the removal of livestock from native pastures (represented by the Native pasture to Exclosed grassland contrast) provides information on the effects of removal of livestock from long grazed areas.

- **Types of outcome:**

Studies needed to include measures of, or changes in, individual species or plant functional group cover, biomass or frequency. Studies that only reported indices of diversity or richness were excluded. The exception was in cases where the raw data used to develop the indices could be obtained from the author/s.

- **Types of study:**

Studies included raw data or summaries of raw data - qualitative assessments based on supposition or personal/collective experience were excluded.

The search strategy focused on peer-reviewed data for quality control purposes but also due to time constraints. Thus refereed journal articles and externally examined theses (Masters and PhD) were included and in only a few circumstances honours theses. Specific searches for unpublished reports and conference proceedings were not undertaken, but if they were found during other searches they were included only if they had a minimum study quality of II-2 (see 3.4 below). Raw data sets were accepted only if they formed the basis for peer-reviewed manuscripts.

The author assessed relevance by excluding articles with obviously irrelevant titles. Subsequently, the abstracts, where available, of the remaining studies were examined with regard to possible relevance. Where there was insufficient information to make a decision regarding study inclusion when viewing titles and abstracts, then relevance to the next stage of the review process was assumed. A second reviewer independently assessed a random subset of 121 articles at the abstract stage to estimate the potential repeatability of the inclusion methodology.

- **Potential reasons for heterogeneity:**

There are numerous possible reasons for heterogeneity in how plants respond to grazing and/or fertilisation. These include variation in:

1. Type of grazing animal and variation over time
2. Grazing intensity
3. Grazing season and frequency
4. Spatial variability of nutrient enrichment
5. Type of fertiliser (e.g. single super phosphate, rock phosphate, urea) or dominant nutrient (e.g. nitrogen, phosphorus, potassium)
6. Method of enrichment (e.g. run-on, fertiliser, livestock accumulation)
7. Landscape position
8. Tree cover
9. Pasture sowing history
10. Spatial scale of the study
11. Recent rainfall, soil moisture, drought
12. Time since fertilisation or grazing
13. Soil disturbance
14. Soil/substrate
15. Agro-climate zone
16. Mean annual rainfall and seasonality of rainfall
17. Composition of local weed flora
18. Original vegetation composition

These potential reasons for heterogeneity were considered when developing the data extraction forms (see 3.5 below). However, owing to time and resource constraints the sources of heterogeneity were largely used to provide additional assessment of study validity and were not considered further in analyses presented in this review.

For most analyses I did however examine how responses varied according to agro-climate, while variation in responses to livestock exclosure were analysed with respect to mean annual rainfall, tree cover, rainfall seasonality (ratio of cool season rainfall, April-September, to warm season rainfall, October-March), time since livestock exclosure and site fertility. Direct measures of site fertility were rarely available and so where data were available I estimated a fertility ranking with five levels based on either substrate and land use or available soil phosphorus (see Table 3).

Table 3. Fertility Ranking levels, phosphorus thresholds and qualitative levels based on substrate, landscape position and land use.

Fertility Ranking	Phosphorus (colwell)	Description
Very Low	<4mg/kg (Olsen <3, Bray <4)	Ridgetops, eroded slopes, not fertilised, may have naturalized legumes. Sediments and sandstones
Low	4-15mg/kg (Olsen 3-6, Bray 4-8)	non-eroding mid and lower slopes with no or very light old fertilisation. Metasediments and granites
Moderate	16-24mg/kg (Olsen 7-9, Bray 9-14)	Unfertilised basalt and alluvium, moderately fertilised sediments, metasediments and granites with sown legumes
High	25-45mg/kg (Olsen 10-15, Bray 14-25)	Moderately fertilised basalt, alluvium, heavily fertilised sediments and granites.
Very High	>45mg/kg (Olsen >15, Bray >25)	Basalt or alluvium with heavy fertilisation and sown legumes, livestock camps

4.4 Study quality assessment

Articles that meet study inclusion criteria were assessed at full text stage according to a hierarchy of evidence based on that developed by Pullin & Knight (2003) (see Table 4). Only studies assessed as having a quality between **I** and **II-3** were retained in the review.

Table 4. Hierarchy of evidence based on the experimental design of research undertaken. From Pullin and Knight (2003).

Quality of evidence – Conservation	
I	Strong evidence obtained from at least one properly designed; randomised trial of appropriate size. Includes either (a) well designed and replicated experiments spatially replicated at >3 sites (separated by minimum 1km) and of 5 or more years duration and (b) well replicated (> 10 observations per treatment) space-for-time studies of broad spatial extent (>100km 2)
II-1	Evidence from well designed controlled trials of moderate spatial and or temporal extent. Includes (a) well designed and replicated experiments at 2-3 sites and of minimum 3 years duration or (b) moderately replicated (6-10 observations per treatment) space-for-time studies of moderate spatial extent (50 -100 km 2)

II-2	(a)Well designed and replicated experiments with minimum 2 years duration or longer experiments at a single site (b) minimally replicated (min. 3 observations per treatment) space-for-time study
II-3	Evidence obtained from multiple time series or from dramatic results in uncontrolled experiments. Includes non spatially replicated experiments (ie multiple replicates in single block) and multiple samples at a single site.
III	Opinions of respected authorities based on qualitative field evidence, descriptive studies or reports of expert committees.
IV	Evidence inadequate owing to problems of methodology e.g. sample size, length or comprehensiveness of monitoring, or conflicts of evidence.

A large proportion of studies obtained through this review provided adequate information on the subject and interventions but only for a single study location. Although these studies singly are inadequate as a description of the vegetation of a land use state, as a whole they represent an important body of evidence. I retained such observations and scored them as II-3.

4.5 Data extraction

For each study accepted into the final review, the study characteristics (subject, intervention, and outcomes measured), study quality, sources of heterogeneity, and results were recorded in a relational database.

Where sufficient data were provided I ranked the five most abundant species in each land use state. Species with the same estimate of abundance were considered ties and given the same rank. This method of ranking follows the philosophy of the dry-weight rank method (Mannetje & others 2006).

Where possible I also estimated the mean abundance and standard deviation of (a) all species/species groups if only a select number were reported or (b) frequent species (those species present in minimum of 20% of observations within a single study or 30% within a single land use state). Where alternative measures of abundance were provided, those that provided information on density were preferred over visual estimates of biomass or cover. In cases where manuscripts reported changes in species abundance over several years I only used data for the last season of observation. In many cases I obtained raw datasets from authors as required data were not available in the published papers.

For each species included in the database I classified its origin (native or exotic in temperate Australia), longevity (annual/biennial or perennial) and also its growth form (grass, sedge, forb, geophyte, shrub). Geophytes were predominantly monocots, but also included a few dicots (eg. *Drosera peltata*, *Microseris lanceolata*). In a small number of cases, a species assignment to origin or longevity was uncertain. Unless specific note was made by authors of a study these were classified as potentially being of either level. Species with uncertain assignments were excluded from some analyses.

Ten genera were often only identified to genus level (*Austrodanthonia* spp., *Austrostipa* spp, *Trifolium* spp., *Vulpia* spp. *Bromus* spp., *Lolium* spp., *Hypochaeris* spp, *Briza* spp., *Carex* spp., *Glycine spp.*) and two species of *Poa* were often not distinguished (*Poa labillardierii*, *Poa sieberiana*). For these groups of taxa I summarised their occurrences as individual species, where these data were available.

4.6 Data synthesis

All quantitative data were compiled for each species or plant functional group. Two separate compilations were undertaken. Firstly I calculated the frequency of each abundant species (ranked 1-5) across all studies (see above), within each of the land use states. Secondly I estimated effect sizes, as response ratios (Hedges, Gurevitch, & Curtis 1999) of individual plant species and plant life-history group responses (using estimates of mean abundance) across contrasts between the asigned land use states as per Table 2. The effect was estimated as the natural log (ln) of the response ratio (RR):

$$lnRR = ln\frac{\bar{X}_a}{\bar{X}_b}$$

Where $\bar{X}_a$ is the mean species measure of abundance in either the ungrazed (ie. Reference grassland or exclosed) or non-enriched (not fertilised or nutrient run-down) observation while $\bar{X}_b$ is the mean abundance of the grazed or enriched observation. Hence lnRR is **positive** when plants are most abundant in the ungrazed (relative to grazed) or unfertilised (relative to fertilised) land use states.

In many cases species were very rare or absent from one level of an observation, yielding a zero value. While response ratios cannot be estimated when one level is zero, the absence of a species is of considerable ecological significance and elimination of such data would have potentially large effects on predicted effects of grazing or nutrient enrichment. To correct this, rather than adding a constant value (eg. 1) to all observations prior to estimating lnRR, I followed the methodology of Viola et al. (2010) and added the lowest non-zero abundance observed within a study to all observations for that study. While this correction yields a conservative estimate of the log response ratio for extremely rare or absent species, it does allow information about their response to be included in analyses. One dataset reported negative values from logit estimates of likelihoods of occurrence and these were treated in the same way (the smallest observed absolute value was added to all estimates to ensure they were non-zero).

Although study variance was estimated where suitable data were available, I only present results for unweighted analyses. While weighted meta-analyses are often considered optimal (Hedges, Gurevitch, & Curtis 1999; Stewart 2010) there is increasing use of un-weighted meta-analysis in ecology, that is, treating the variance around each study as equivalent (Borer et al. 2005; Marczak, Thompson, & Richardson 2007; Darling & Côté 2008). Weighted meta-analyses place greater emphasis on highly replicated, often small-scale experimental studies, or well replicated space-for-time studies with narrow geographic extent and hence often less within species variance. Equal weighting allows the use of a greater proportion of published data (in our dataset 75% of grazing observations and 71% of nutrient enrichment observations had estimates of variance), hence reducing the likelihood of review Type 1 errors (Englund, Sarnelle, & Cooper 1999; Lajeunesse & Forbes 2003). Rather than limiting the number of studies to just those with estimates of variance, all studies were included in analyses.

The analyses focused on how effect sizes varied:

(a) Among species
(b) Between native and exotic species
(c) Between native and exotic species according to each land use contrast
(d) Between native and exotic species among agroclimatic zones.

For the analysis of agroclimatic zones an *a priori* decision was made to separate the D5 (cool wet) class into two groups, (a) those with average annual rainfall >700m and predominantly in the warmer months (70% or more rain falling between Oct and Mar) and (b) remaining areas with lower rainfall and generally a more even rainfall distribution. This separated studies conducted in the New England Tablelands area from the remainder of the D5 zone (Figure 2).

In two cases I grouped results for two or more land use contrasts where the interventions were considered equivalent and mean ln(RR) were similar. In the first case I grouped contrasts 6 & 7 and in the second I grouped contrasts 3, 6 & 7.

Analyses were undertaken using the MetaWin 2.1 statistical program (Rosenberg, Adams, & Gurevitch 2000) with a random effects structure, with individual species by study observation specified as the random effect. Mean effect sizes and bootstrapped 95% confidence intervals, corrected for bias for unequal distribution around the original value and from 5000 permutations, were estimated in each case (Rosenberg, Adams, & Gurevitch 2000).

I also conducted a separate analysis of all grazing exclusion data (ie those with recent removal of livestock grazing) using linear mixed models (LMM) with fixed and random effects structures. I hypothesized that the outcomes of livestock exclusion would be affected by site productivity (total mean annual rainfall and fertility ranking), time since exclosure and the presence or absence of overstorey trees. I also included rainfall seasonality in models. Total annual precipitation is a major determinant of primary production (Sala et al. 1988), although can be modified locally by differences in available soil nutrients. The seasonality of precipitation was also predicted to be important as it may influence the relative abundance of exotic and native species owing to differences in the proportion of annuals and perennials among their flora. Because enriched and exclosed pastures had similar effect sizes I combined both groups of studies and rather used the fertility ranking (Table 3) and mean annual rainfall to describe variation among exclosure studies. While the fertility ranking is largely a qualitatively determined measure of site productivity, relying only on quantitative data (eg. soil nutrient analyses, plant productivity) would have restricted analyses to a very limited data set. Because only one exclosure study had a fertility ranking of high (and none had very high), I combined moderate and high. Initial analyses also suggested little difference in response coefficients between very low and low and these to were combined so that the final variable had two levels (very low- low and moderate – high).

The hierarchical LMM was fitted with restricted maximum likelihood (REML) (Welham & Thompson 1997). The model included all environmental variables described above and their interactions with species' origin as fixed effects. Hence the effect of each environmental variable was allowed to vary according to whether a species was native or exotic. The continuous variables were all centered to their mean values:

e.g.

$$Precipitation\ (centered) = log(Precip.) - \frac{\sum log(Precip.)/n}{2 \times sd\ (log(Precip.)}$$

The random effects component of the model included Observation and Species, although the slope and intercept for each species were allowed to vary according to the environmental variables for a particular observation. The modeling approach taken is essentially the same as that described by Pollock, Morris, & Vesk (2012). The model was fitted using the lme4 package (Bates, Maechler, & Bolker 2011) in the R statistical environment (R Development Core Team 2012).

5. Results

5.1 Review statistics

The electronic database search extracted a large number of studies (>25,000) indicating the poor specificity of the search terms, even with the extensive use of "NOT" terms (Table 5). Approximately 1% of these were judged as relevant based on title and abstract assessment. Both reviewers independently examined 121 randomly selected references at the abstract stage and the agreement was substantial (K=0.72). The selection or exclusion of references at this stage of the review process was fairly conservative to ensure relevant references were not excluded. Only 40 references, obtained through electronic sources, remained after full text viewing (Table 5). Of these only ten were not already in the personal databases held by the author and colleagues. An additional 39 references were obtained from other sources, primarily from personal databases of the author or colleagues and searching the table of contents of specific journals. The majority of studies included multiple observations. That is they included multiple land use states and/or land use contrasts. From the 79 studies (Appendix 1), 70 studies provided data on dominant species in each land use state and 57 studies had suitable data on contrasts among land use states (Appendix 2). Within these studies there were 216 land use state observations and 104 land use contrast observations.

Table 5 Search statistics

Electronic Searches	Number of Studies
References identified through electronic searches after removal of duplicates	>25,000
References remaining after relevance assessment at title and abstract stage	391
References remaining after full text viewing	40
Unique references (not already held within authors private databases)	10
Other sources (excluding duplicates)	
Bibliographies, specific journals, authors databases	39
Total references assessed as meeting criteria	**79**
Total observations meeting criteria	**216/104**

5.2 Data synthesis – Species composition within land use states

The majority of observations were from grazed but unfertilised native pastures (90 observations) although Fertilised pastures (36 observations), Exclosed grasslands (37 observations) and Reference grasslands (44 observations) were also frequently published in the literature (Appendix 3). Very few studies have examined the vegetation in Enriched grasslands (past grazed and fertilised pastures from which grazing has been excluded) or Past fertilised pastures (grazed pastures where fertilisation has ceased and nutrient levels allowed to run-down). These later vegetation states are difficult to assign owing to a frequent lack of available information on the history of fertiliser use prior to a study. However, it may also be that researchers have not attempted to obtain this information or not recognised the need to restrict their studies to sites where such data are available. As a result some observations may have been miss-classified as Exclosed grassland or Fertilised pasture. Many of the past fertilised pasture observations were descriptions from single paddocks.

Appendix 3 provides a list of all species ranked as dominant in at least one study observation. While the data suggests there is considerable overlap in dominant species among reference, native pasture and fertilised pastures there are some notable patterns. With the exception of *Hypochaeris radicata* , exotic plant species were rarely among the dominants in either Reference grasslands or Native pastures. The most frequent dominants in Reference grasslands were the grasses *Themeda triandra, Poa sieberiana and Microlaena stipoides*. These species were also frequent in Native pastures, along with other native grasses such as *Austrodanthonia* spp., *Bothriochloa macra*, *Aristida ramosa* and *Austrostipa scabra* and the exotics *Hypochaeris radicata*, *Vulpia spp* and *Trifolium* spp. However, *T. triandra* and *P. sieberiana* were only recorded as dominant in one and three Fertilised pastures respectively. *Austrodanthonia* spp (Rytidosperma spp), *Bothriochloa macra*, *Austrostipa scabra* and *Microlaena stipoides* tended to be the most frequently recorded native species in Fertilised pastures. In contrast to both Native pastures and Reference grasslands, most of the frequently recorded dominant species in Fertilised pastures are exotics. Exclosed grasslands had similar dominants to native pastures but were also often dominated by robust annual grasses such as *Avena barbata*.

As few Enriched and Past fertilised pastures were documented in the literature few conclusions can be made regarding those species likely to dominate. However, exotic species (eg. *Avena barbata* and *Phalaris aquatic)* were most frequently dominants in Enriched pastures while both native (primarily cool season perennial grasses) and exotic species were often dominant in Past fertilised pastures.

5.4 Data synthesis – Meta-analysis of species abundances across land use contrasts

Eighty one study observations and 1575 individual species observations were compiled describing the contrasts relating to livestock grazing and livestock exclosure (Fig 3). Thirty three study observations and 541 individual species observations were compiled for contrasts describing fertilisation or the run-down/tying-up of available nutrients (Fig 9).

Livestock grazing and livestock exclosure contrasts

Overall the absence of livestock had a weakly negative effect on average abundance across all species and observations (Fig 3). However, for the contrast between Reference grassland and Native pasture, native and exotic species had opposing responses, with native species tending to be more abundant in the absence of livestock (Fig 3). Differences between exotics and natives were minimal for the contrast between native pasture and exclosed pasture, as the overall response of native and exotics were both weakly negative (declined in response the absence of livestock). The predicted ln(RR) of native and exotics for the contrast between Fertilised pasture and Enriched grassland were similar to that of

Reference and Native pasture but uncertainty was considerable, owing to a small number of observations but also suggesting highly variable responses (Fig 3).

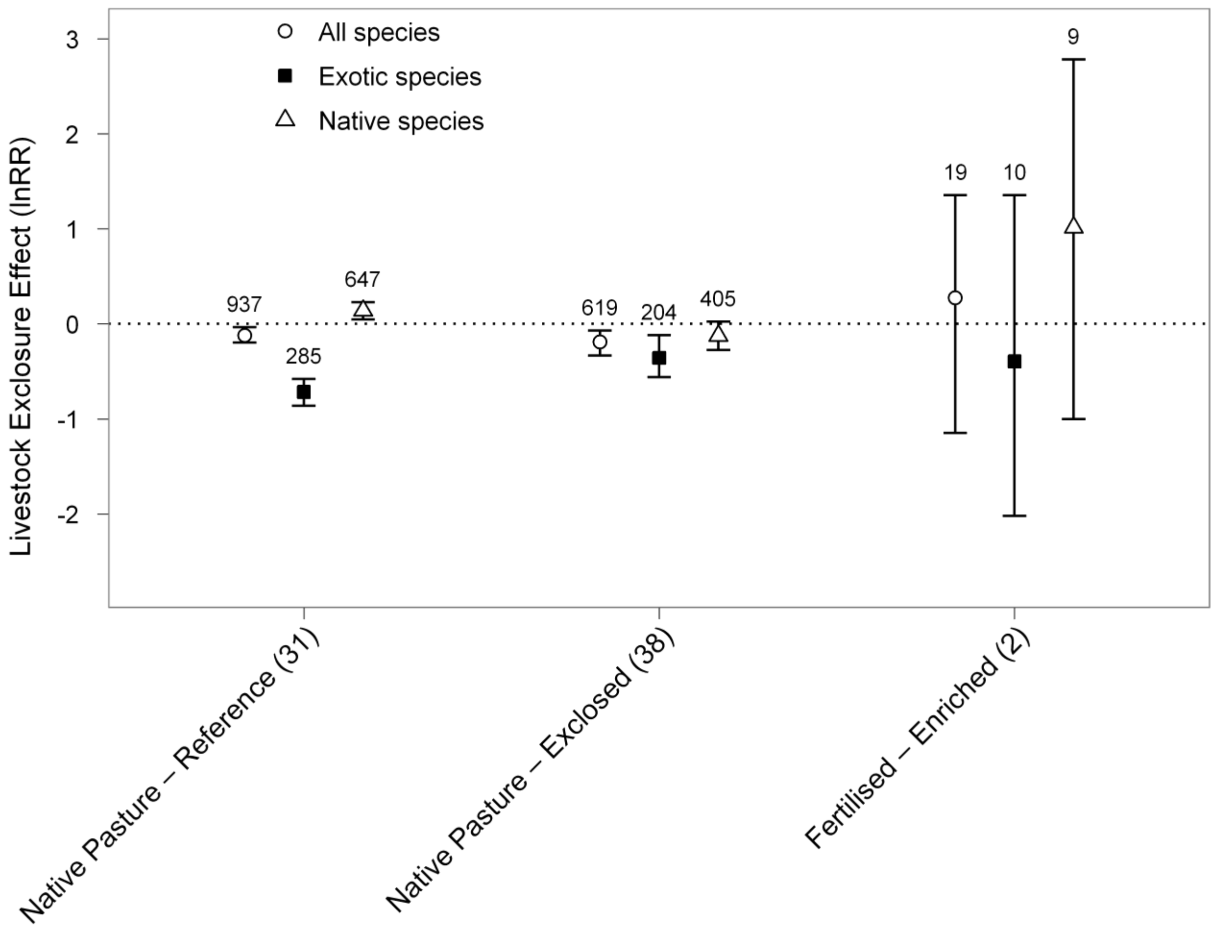

Fig. 3 Mean (+/-95% CI) of ln(RR) for all species, native species and exotic species grouped for each of three different land use contrasts.
Numbers in brackets are the number of land use contrast observations. The numbers above the mean values are the number of individual species observations.

Responses to the long-term absence of livestock (Reference grassland and Native pasture contrast) varied among agroclimatic classes (Fig 4). The difference in response between native and exotic species was greatest in E3 (Warm, summer growing) and in E1 (Mediterranean) climate zones, suggesting that livestock grazing has most modified vegetation composition within those climate zones. Although native species responses overlapped 0 in the D5 climate zone, the negative responses of exotics also suggest that overall livestock have probably resulted in some degree of replacement of native vegetation with exotics within that climate region as well. In contrast, overall effects are predicted to be quite weak in the D5_WS (cool with wet summers) climate zone. Based on these results I would predict that in the summer rainfall New England Tableland the average abundance of native and exotic species in Reference grasslands and Native pastures are relatively similar.

Response ratios for the native pasture and exclosed pasture contrast suggest that while in most climate zones the more recent removal of livestock from native pastures results in the decline of exotic species abundance (in D5_WS, F3 and possibly in E1 and D5), average responses of native species are also likely to be negative in D5_WS, E2 and F3. Even in D5, where the most data is available, responses of native species overlap with 0. No data were available to assess the responses to removing livestock from native pastures within the E3 climate zone.

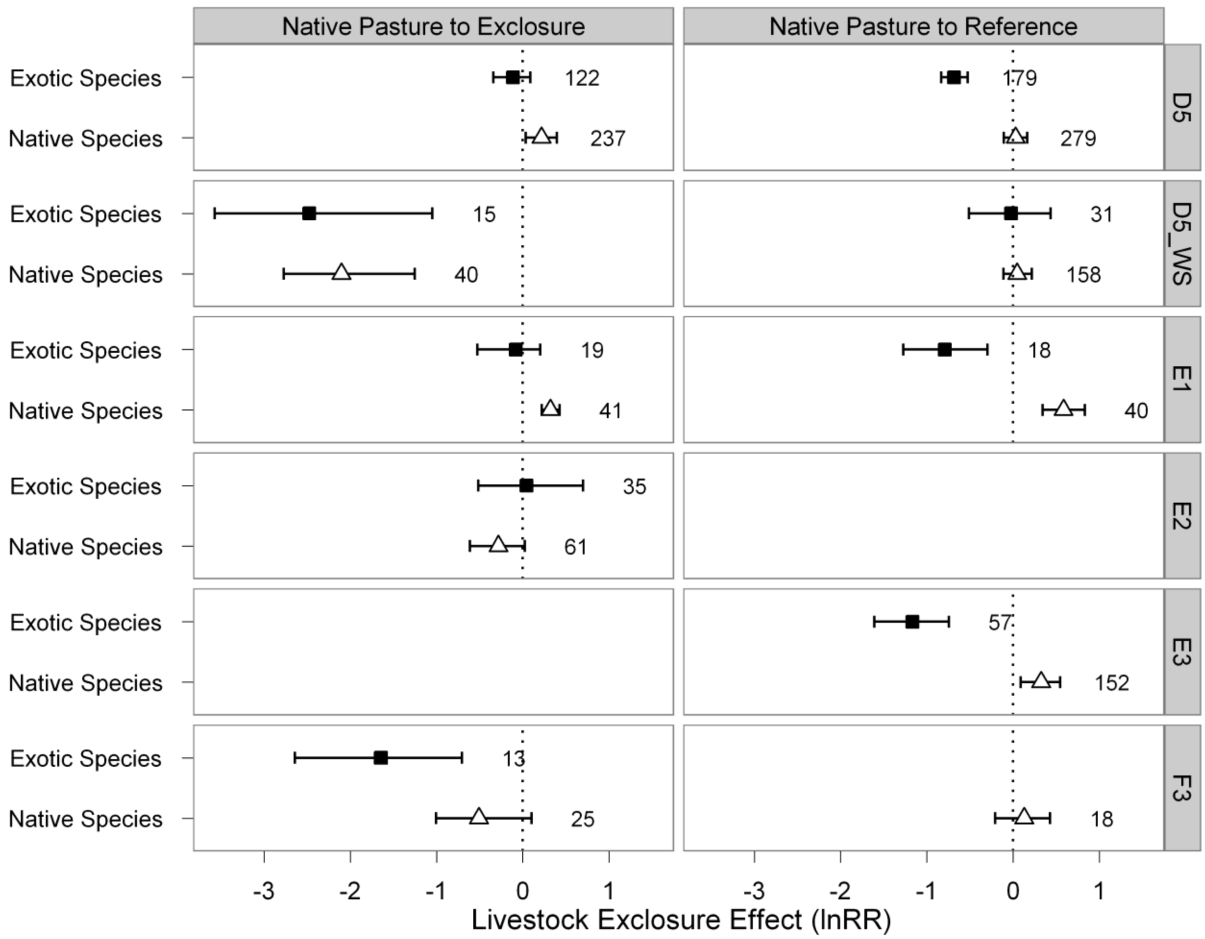

Fig. 4 Mean (+/-95% CI) of ln(RR) of all species, native species and exotic species across Native Pasture - Exclosure and Native Pasture – Reference Grassland contrasts within each Agroclimate class.

The individual species response ratios suggest that most native species are either more abundant or at least equally abundant in Reference grasslands compared to Native pastures (Fig 5). However , there is also a small group of native species that are less abundant in Reference grasslands (eg. *Aristida ramose*, *Daucus glochidiatus, Euchiton involucratus, Solenogyne* spp., *Sporobolus creber*, *Wurmbea dioica*, *Fimbristylis dichotoma*). In contrast all except seven exotic species have negative mean ln (RR) values (least abundant in long ungrazed Reference grasslands), and only one exotic species has a positive response ratio with a 95% confidence interval that does not cross 0 (*Medicago minimia*). Such differences between native and exotic species are not as readily apparent when the abundance of individual species are contrasted between native pastures and exclosed pastures as there are similar proportions of native and exotic species with negative and positive mean response ratios (Fig 5).

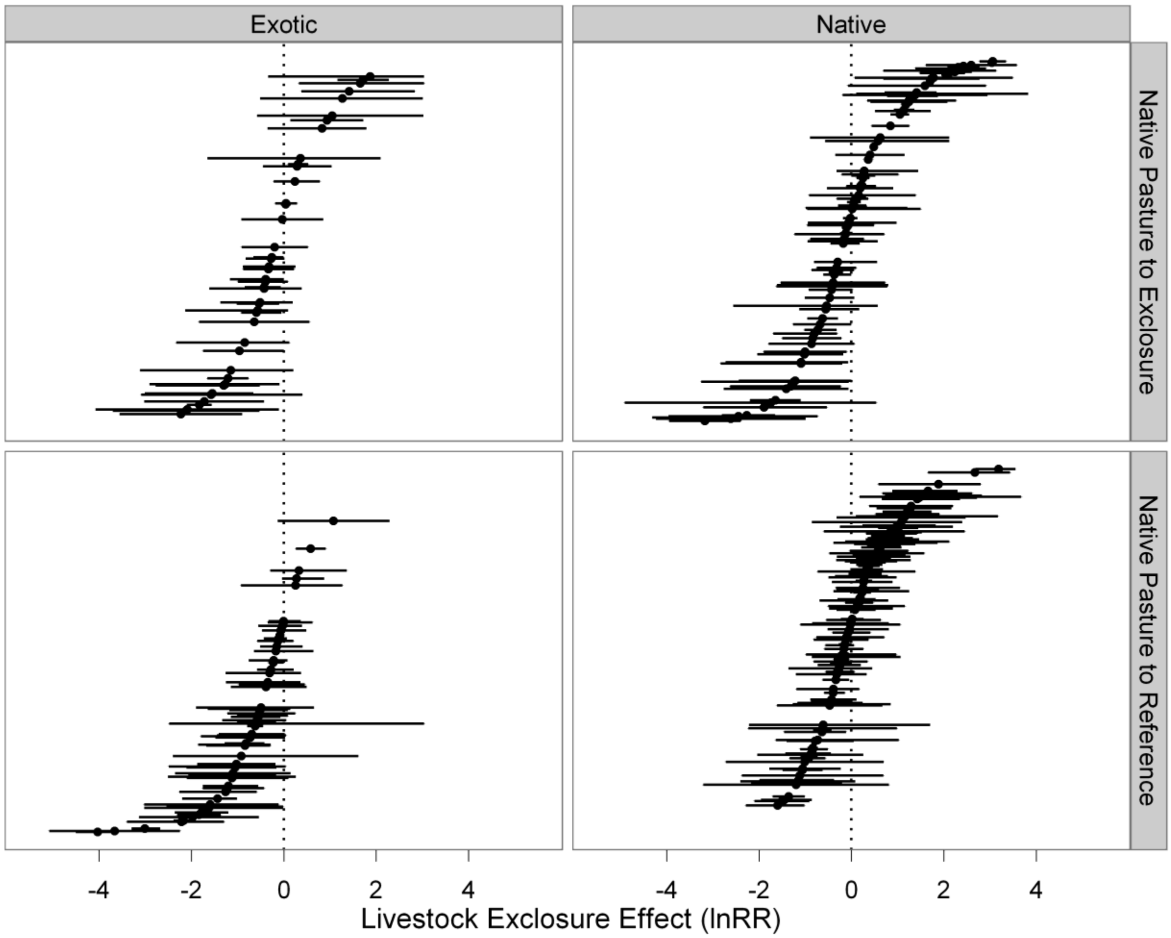

Fig. 5 Individual exotic and native species mean (+/-95% CI) ln(RR) in each of the two grazing contrasts.

Generally the individual species response ratios for the Reference grassland - Native pasture contrast are a poor predictor of a plant species response to removing grazing from native pasture (as indicated by lnRR for the native pasture and exclosed pasture contrast), particularly for exotic plant species (Fig 6). Some individual species have strongly contrasting responses. For example the exotics *Avena barbata*/spp and *Cirsium vulgare* both have a negative ln(RR) for the Native pasture – Reference grassland contrast but a positive ln(RR) for the Exclosed – Native pasture contrast while the native species *Leptorhynchos squamatus* and *Schoenus apogon* have a positive ln(RR) for the Native pasture – Reference grassland contrast but a negative ln(RR) for the Exclosed – Native pasture contrast (Appendix 4). A number of native forb species with weakly negative, or neutral responses to the long-term absence of livestock have strongly negative responses to livestock removal from Native pasture (eg. *Triptilodiscus pygmaeus, Crassula sieberiana*). Others such as *Senecio quadridentatus* have greater (positive) response ratios following exclosure when compared to long-term absence of livestock grazing.

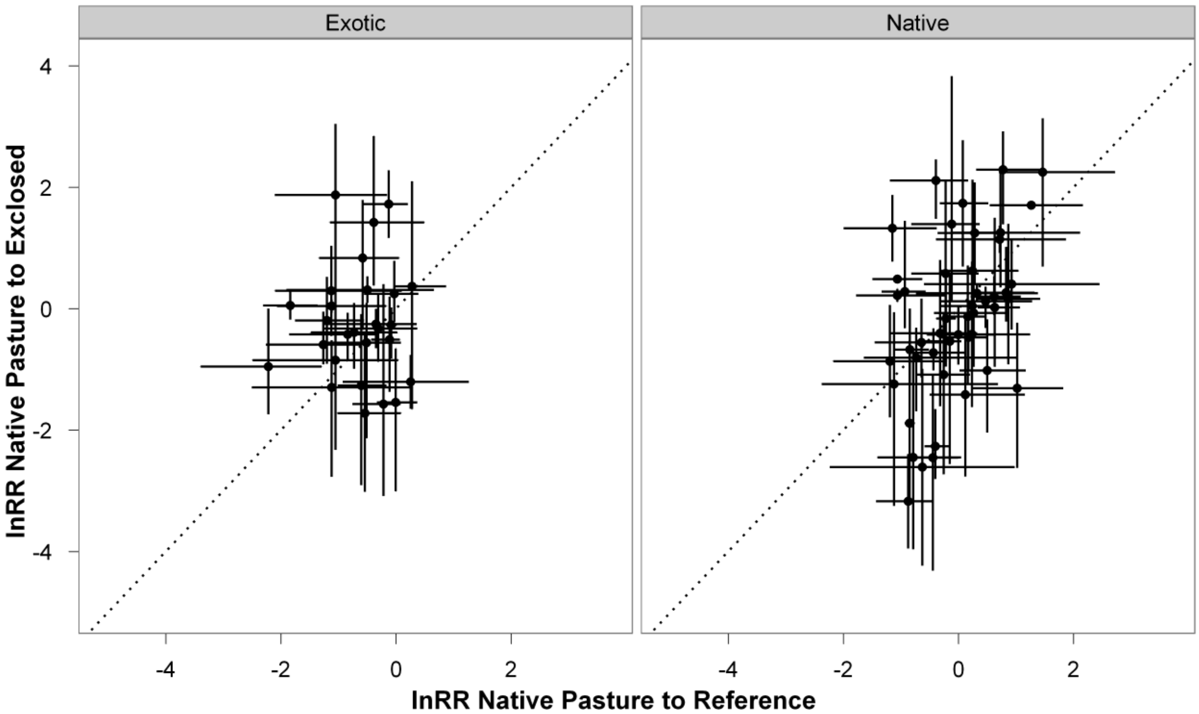

Fig. 6 Relationship between mean ln(RR) of individual species for each of the livestock grazing land use contrasts.

Exotic annual grasses, forbs and sedges and exotic perennial shrubs and forbs tend to be least abundant in Reference grasslands with long-term absence of livestock, while native perennial shrubs, grasses and forbs have an opposing response (Fig 7). Patterns differ slightly following exclosure of livestock from Native pasture – native perennial geophytes have a strongly positive response, while the responses of exotic annual species still tend to be negative following short-term exclosure, but mean effect sizes are smaller (Fig 8). Also notable is that the response of native perennial grasses and forbs reverse under short-term exclosure compared to long-term absence of livestock (Fig 8).

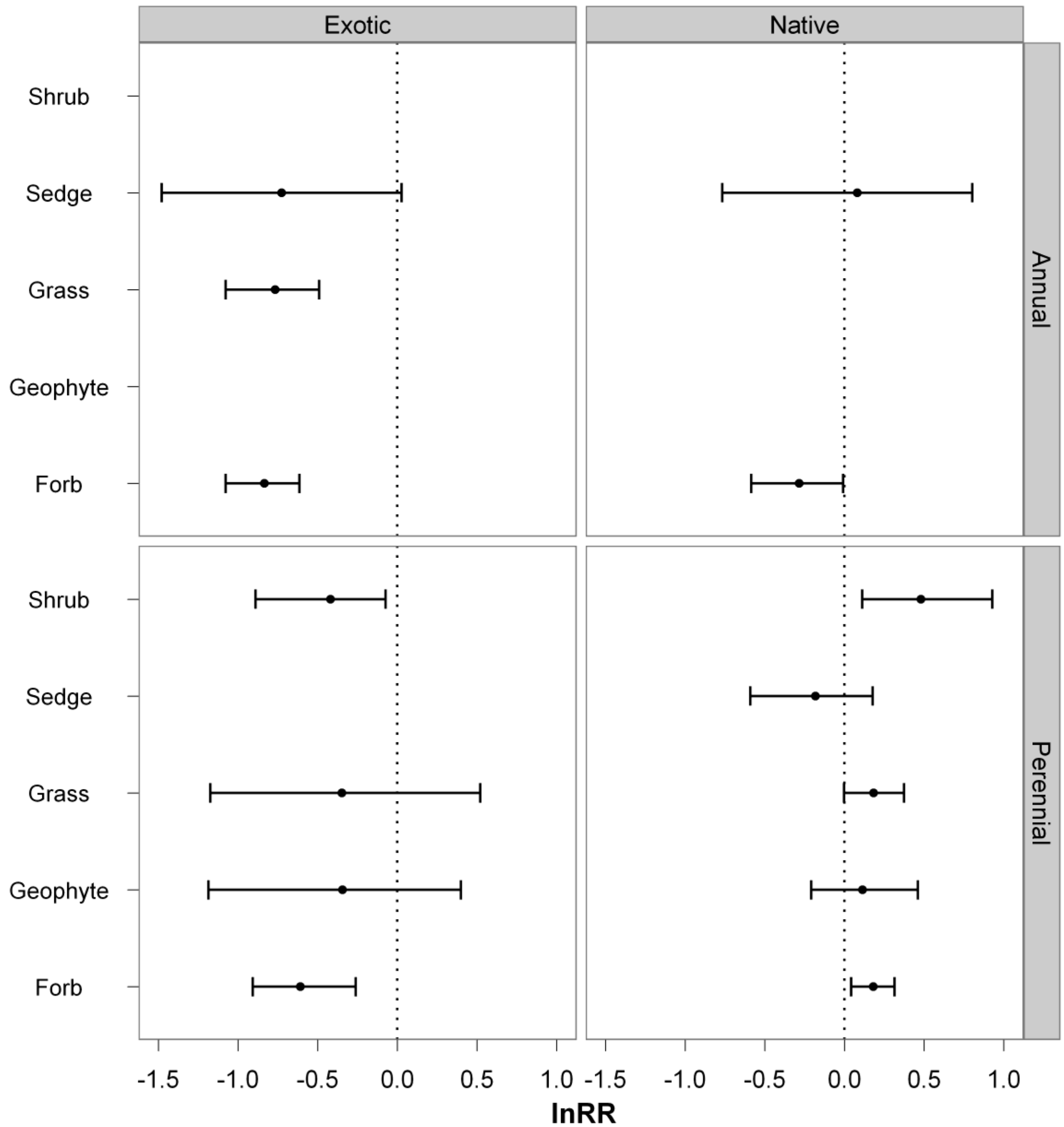

Fig. 7 Mean (+/-95% CI) ln(RR) of different plant growth forms for the long-term absence of livestock grazing (Native pasture to Reference grassland contrast).

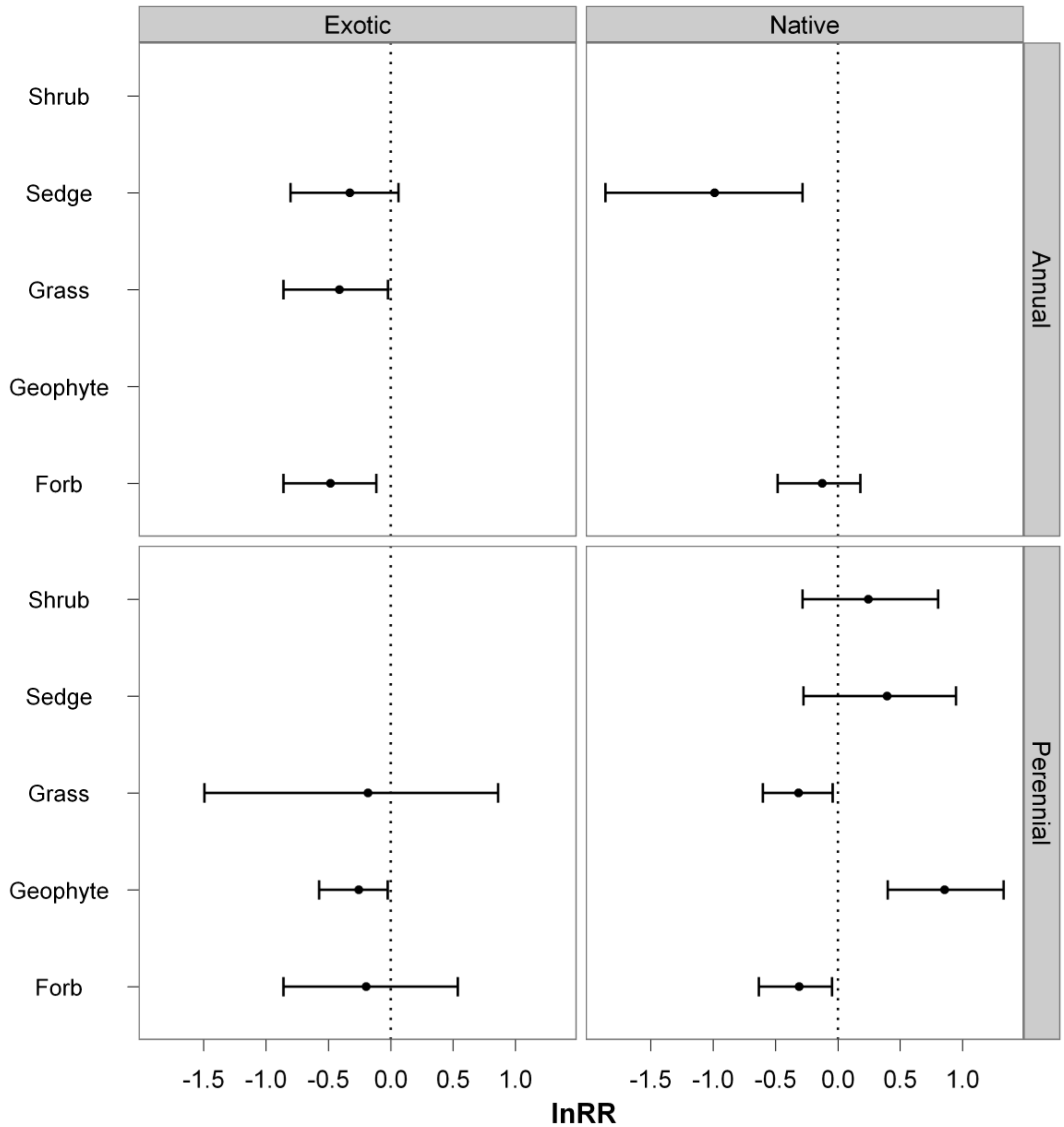

Fig. 8 Mean (+/-95% CI) ln(RR) of different plant growth forms for the contrast between native pasture and exclosed pasture

Linear mixed models of short-term livestock exclosure

The random effects components of the LMM suggested large individual species level variation in lnRR, particularly in relation to mean annual rainfall (σ = 1.12, SD = 1.06) and when site fertility was moderate-high (σ = 2.26, SD = 1.50). Overall the model predicted an overall negative lnRR for exotic species (ie. the "average" exotic plant response) and a weak positive lnRR for native species, although standard errors were substantial (Table 7). While estimates of AIC suggested little support for removal of model variables (data not shown), coefficients and their standard errors suggest that some variables (time since exclosure, rainfall seasonality and fertility ranking) had weak or highly uncertain effects on average species lnRR (Table 7). Only the presence or absence of trees and mean annual rainfall appeared to consistently affect native and exotic plant species lnRR. The model suggested a negative effect of increasing mean annual rainfall on average exotic lnRR, that is exotic plant abundance was less in exclosed pastures relative to native pastures, particularly at high mean annual rainfall. The response of native species to annual rainfall was close to neutral. Native species were predicted to have slightly higher lnRR in those studies where woodland trees were present and when fertility ranking was low, although standard errors were substantial. Overall the model predicts that differences in lnRR between native (natives tending towards positive lnRR) and exotic species (negative lnRR) will be most apparent at high precipitation, when trees are present and fertility is low (Table 7). However, the models although ability to predict is very poor, in part due to large among species variation.

Table 7 LMM coefficients for fixed effects for a model of plant responses to livestock exclosure.

Model Terms	**Estimate**	**S.E.**
Intercept	-0.525	0.357
Time Since Exclosure	-0.2883	0.4082
Rainfall	-0.9753	0.3929
Rain Season	0.2987	0.3314
Trees		
Present	-0.1619	0.3866
Fertility Ranking		
Moderate	0.1464	0.5844
Origin		
Native	0.3711	0.3091
Interactions		
Time Since Exclosure: *Origin* Native	0.2642	0.3259
Rainfall : *Origin* Native	0.9738	0.3476
Rain Season : *Origin* Native	0.1031	0.2737
Trees Present : *Origin* Native	0.4701	0.3292
Fertility Moderate : *Origin* Native	-0.4607	0.5385

Nutrient enrichment contrasts

Native species were on average more abundant in unfertilised Native pastures and in Exclosed grasslands where nutrients have been experimentally rundown through carbon additions (Fig 9). Exotics demonstrated the reverse pattern. Average effects sizes were also large relative to effects sizes observed in the grazing transitions – native species were approximately twice as abundant in unfertilised native pastures than those that had been fertilised (average lnRR = 0.73) while exotic species were approximately 1.8 times more abundant in fertilised pastures (average lnRR=-0.52). The larger effect size suggests greater transformation of vegetation composition as a result of changes in nutrient availability than from grazing. The magnitude of effects are predicted to be similar in both fertilisation and nutrient run-down contrasts, although uncertainty are substantial, particularly around effects of nutrient run-down on native species, and confidence intervals overlap zero.

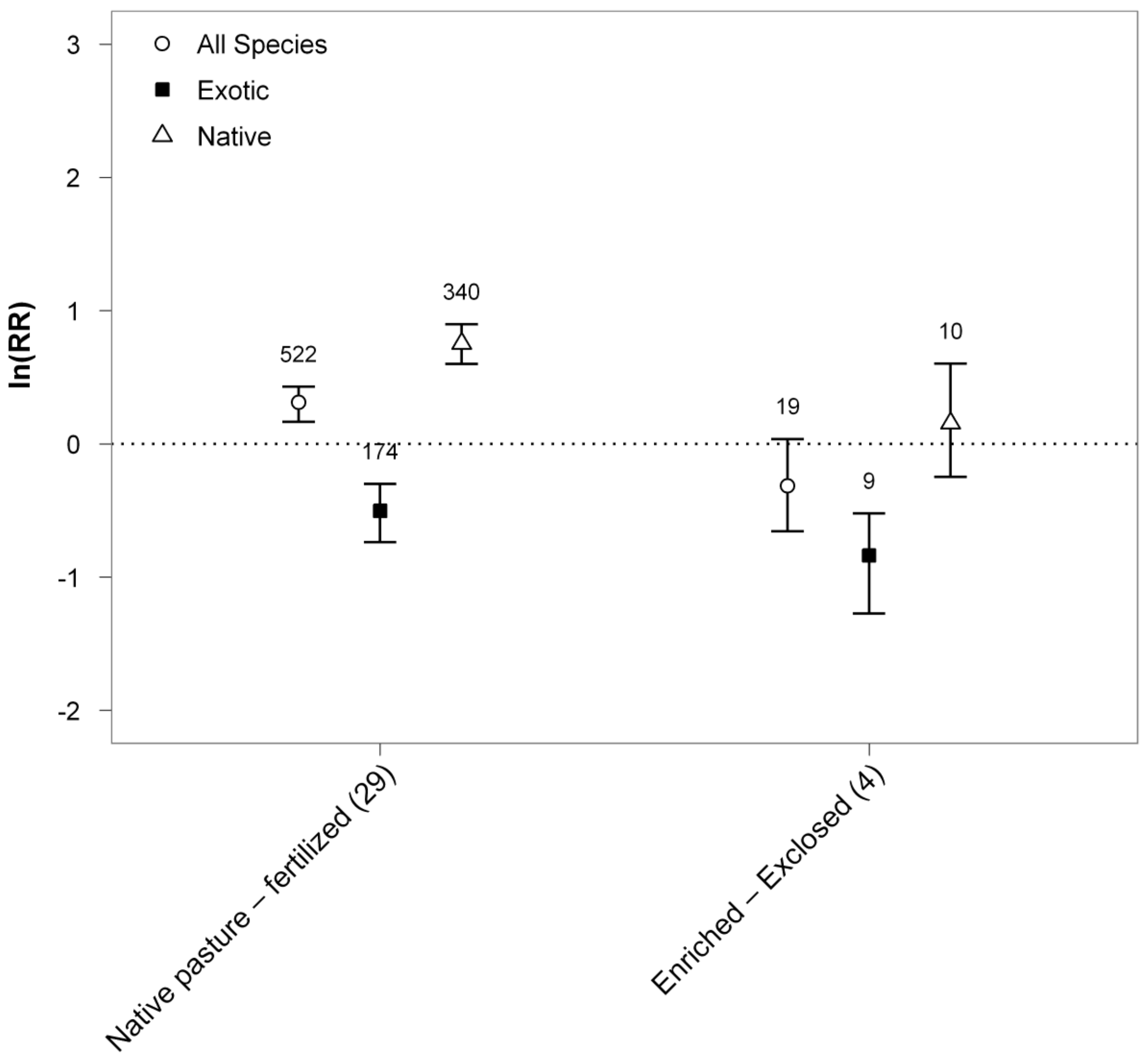

Fig. 9 Mean (+/-95% bias corrected CI) of ln(RR) of all species, native species and exotic species across Native Pasture to Fertilised pasture and Enriched grasslands to Exclosed grasslands contrast.
In all cases this later transition was achieved through experimental manipulation of nutrient availability (nitrate) through carbon addition (sugar) in the absence of livestock. No contrasts between fertilised pastures and past-fertilised pastures were obtained from the literature. The Native pasture – Fertilised pasture contrast also includes one Reference grassland – Enriched grassland contrast (ie. addition of nutrients to Reference grasslands). Note that ln(RR) is positive when plant species are more abundant in the non-enriched state.

Because there were few nutrient run-down studies and because the 95% bias corrected CI's for their effect sizes tended to overlap with the native pasture – fertilised pasture contrast, the following analyses treat both contrasts as simply between enriched and non-enriched.

In contrast to the effects of the long- and short-term exclosure of livestock, the absence or not of nutrient enrichment appears to have substantial effects on the relative abundance of native and exotic species in all climate zones (although data was lacking in F3), but particularly in the cool wet and cool wet summer climate zones (Fig 10).

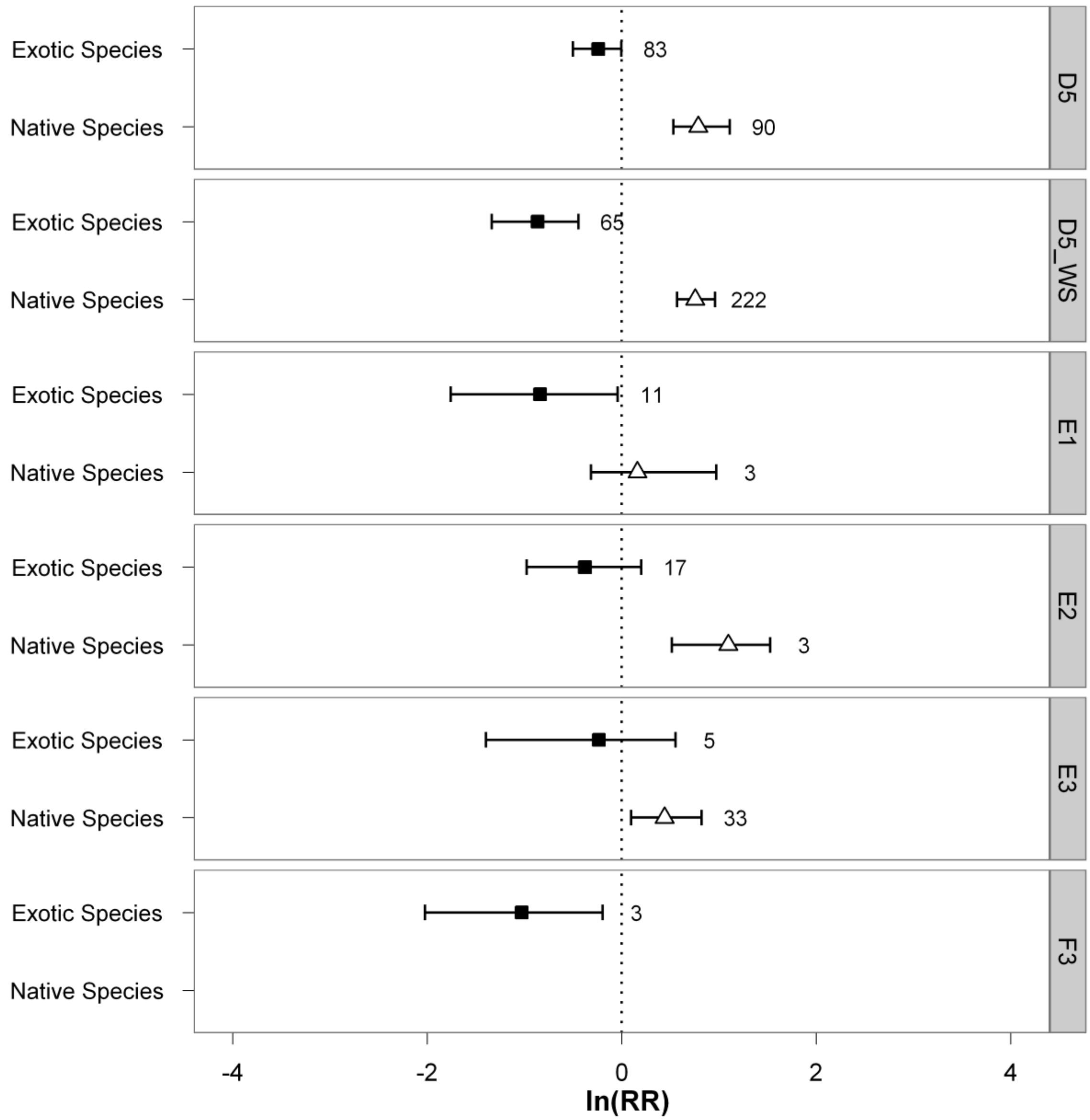

Fig. 10 Mean (+/-95% bias corrected CI) of ln(RR) of all species, native species and exotic species in each of six agroclimatic zones for the contrast between nutrient enriched and non-enriched land uses.
Note positive effect sizes indicate greater abundance in low fertility, non-enriched land use states. These predictions average across contrasts between both native pasture and fertilised and exclosed and enriched land use states.

Most exotic species are least abundant in low fertility land use states (8.6% of exotic species have positive lower 95% bias corrected CI's *cf*. 34% of exotic species with negative upper 95 bias corrected CI's) (Fig 11). There are a few native species that have apparently been favored by nutrient enrichment (eg. *Eragrostis leptostachya* 95% bias corrected CI = -1.50 to -0.42, *Rumex brownii* 95% bias corrected CI = -3.22 to -0.45; *Carex gaudichaudiana* 95% bias corrected CI = -3.43 to -0.96) but the majority are most abundant when nutrient availability is low (52% have 95% bias corrected CI's that are positive *cf.* 8% with negative 95% bias corrected CI's).

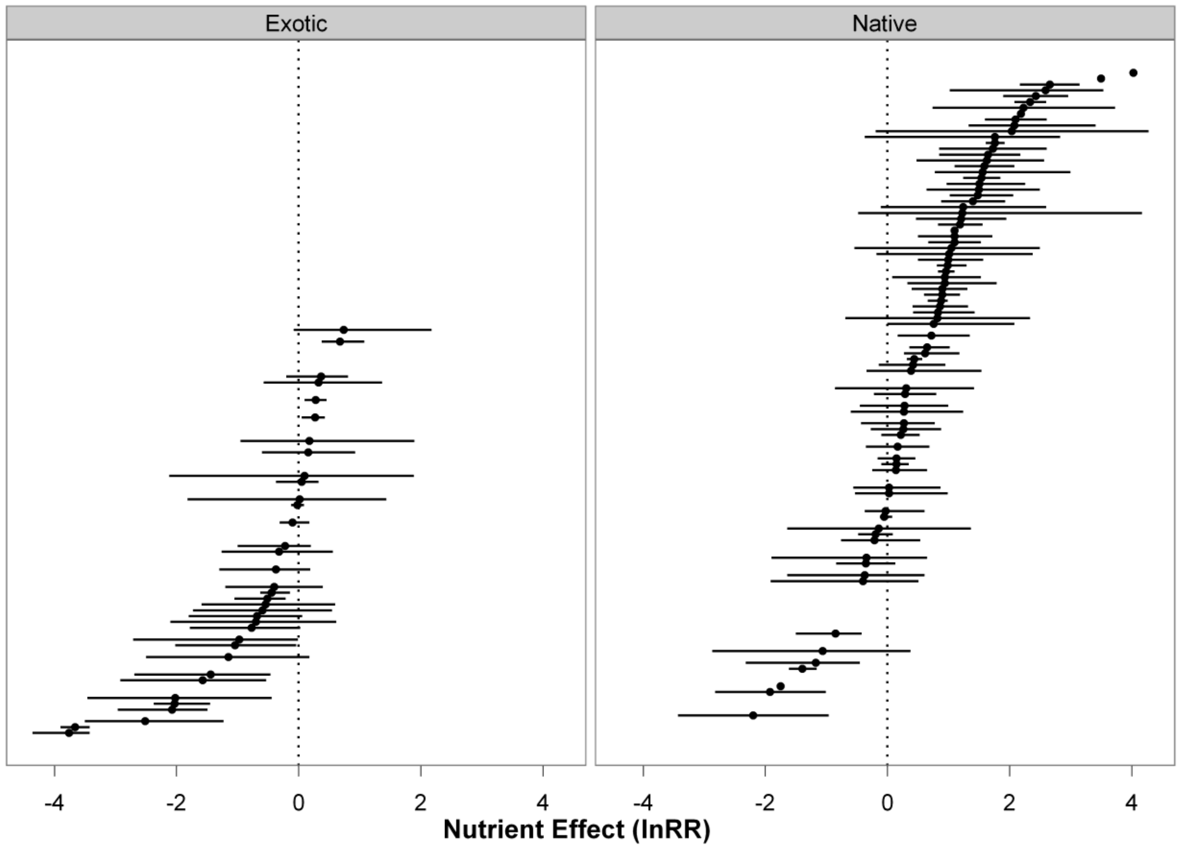

Fig. 11 Individual exotic and native species mean (+/-95% bias corrected CI) ln(RR) across nutrient enrichment contrasts.
Note positive effect sizes indicate greater abundance in low fertility, non-enriched land use states. These predictions average across both native pasture to fertilised and exclosed to enriched land use contrasts.

All native perennial growth forms tend to be most abundant in non-enriched pastures, shrubs in particular have large effect sizes suggesting they are most sensitive to enrichment (Fig. 12). With the exception of exotic perennial forbs, exotic plant growth forms tend to have mean negative effects.

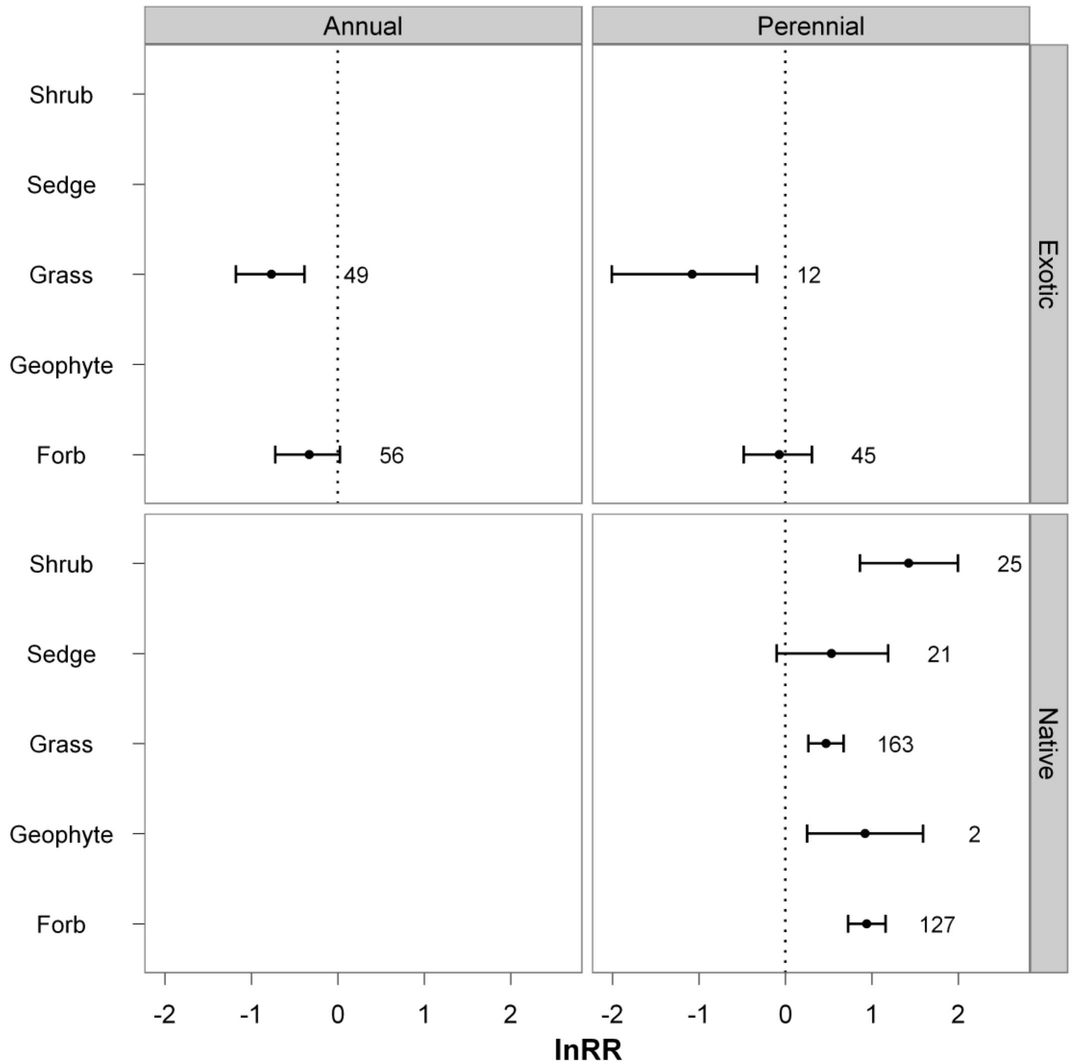

Fig. 12 Mean (+/-95% CI) ln(RR) of different plant growth forms for contrasts between enriched and non-enriched land use states. Positive values for lnRR indicate the plnt growth form tends to be more abundant in non-enriched habitats.

6. Discussion

There can be no doubt that livestock grazing and fertilisation have had great influence on the composition of grassy ecosystems within temperate Australia. Both livestock and fertilisation have contributed to dramatic changes in the composition of vegetation throughout south-eastern Australia and this study demonstrated that native plant species on average are more negatively affected by grazing and nutrient enrichment than exotic species. Much research in Australia has emphasized the role of livestock grazing in modifying vegetation composition and converting perennial native grasslands to exotic annual dominated pastures. While this pattern is supported in some regions (eg. the Mediteranean grasslands and grassy woodlands of South Australia, western Victoria and south-west Western Australia), the magnitude of effects is by no means consistent across the sub-humid grassy ecosystems of southern Australia. However, the effects of nutrient enrichment, often together with increased grazing pressure, do appear to be largely consistent, and this study provides evidence that nutrient enrichment has played a greater role in transformation of vegetation than livestock grazing.

Our estimates of the long term effects of livestock grazing on plant abundances was based on contrasts between areas that have been grazed by livestock since European settlement and those that have been protected from livestock grazing for typically 100 or more years. Some significant changes in vegetation may have occurred prior to gazetting and fencing of cemeteries, crown reserves, rail reserves and other Reference grasslands. However, these changes in vegetation have not been systematically documented and while the data compiled here provide the best possible estimates of long-term effects of livestock, they may underestimate the changes that have occurred.

The meta-analysis suggests that a species' response to long-term livestock grazing is a poor predictor of response to livestock exclusion. Livestock exclusion should not always be expected to lead to increases in the abundance of native species relative to exotics, let alone reverse the vegetation changes that have occurred owing to long-term livestock grazing. While livestock exclosure can have positive outcomes for some native species, the data are highly variable and outcomes hard to predict. Basing current decision making (whether or not to exclude livestock) on plant species abundances in Reference grasslands, could lead to unexpected outcomes. While the decision framework of Lunt et al. (2007) has considerable value, the results presented here suggest that positive outcomes of livestock exclosure may occur less frequently than assumed.

Theory and empirical work have emphasized that responses to livestock grazing are contingent on primary productivity. Most models are based around how livestock grazing modify species diversity. These models predict that at small scales and at high levels of primary productivity the effects of excluding herbivores will be negative, while at low productivity livestock exclusion can result in positive outcomes for species diversity (Olff & Ritchie 1998). One problem with these models in terms of their applicability to restoration of vegetation communities is that they do not take into account whether the changes in diversity are driven by native or exotic plant species (Lunt et al. 2007). Furthermore they focus only on species richness, number of species per unit area, without regard to changes in the abundance of individual species. The analyses I present here have focused on how individual plant species respond to livestock exclusion, and have explicitly taken into account whether or not each species is native or exotic.

When considering changes in the abundance of native and exotic species I found that livestock exclusion is predicted to favour native plant species abundance most in those grasslands with higher long-term annual rainfall (ie high primary productivity), not because exclusion benefits native plant abundance but rather because of increasingly negative effects of exclusion on the abundance of exotics at high annual rainfall. The mechanisms that underpin this are unclear but may be driven by declines in the abundance of short-lived and short-statured species, many of which are exotic, following livestock exclosure.

Lunt et al. (2007) in their decision framework importantly also separate sites according to their level of degradation, indicated by the degree of exotic plant dominance prior to exclosure. In our analyses of short-term exclusion I did not test whether native species responses varied according to the degree of site degradation. However, our results do provide some guidance on this issue. While many exotic species decline following livestock removal, a number of individual species respond in an opposing fashion and knowledge of those species that potentially will increase will be important in assessing the potential for positive outcomes of livestock removal. For example, several studies reported large increases in robust exotic annual grasses such as *Avena barbata* and *Lolium rigidum* following stock removal (Williams 1969; Schultz, Morgan, & Lunt 2011), similar to observations following abandonment of cropping lands in south-west Australia (Standish, Cramer, & Hobbs 2008) and California (Huenneke & Vitousek 1990; Stromberg & Griffin 1996). *Avena barbata* in particular has been found to form persistent stands upon abandonment, is highly competitive at both low and high soil nutrient levels and can limit re-invasion by native plant species (Standish, Cramer, & Hobbs 2008). Also not all native species respond positively to exclosure and not all sites dominated by native species (ie. with low levels of degradation based on native vs exotic dominance) should be expected to improve in native plant diversity and abundance following removal of livestock.

As responses to exclosure are species specific and the decision to exclude livestock might be better guided by species composition rather than environmental conditions at a site. Positive outcomes of removing livestock should not be assumed, even when site productivity is low. Improving our understanding of those native species that have differing responses to exclosure and long-term absence of livestock will be important for informed decisions and the meta-analyses provide some guidance on this.

Our data is largely restricted to the frequent plant species observed in any particular study. Possibly, rare and infrequent species may differ in their responses to either livestock or enrichment. In cases where knowledge is required about specific rare species the meta-analyses described here may be less useful and additional data collection would be warranted to guide management and decision making.

While the effects of long-term livestock grazing and livestock exclosure are often weak and vary among agroclimatic zones, the effects of nutrient enrichment, often in conjunction with livestock grazing, appear to be relatively large and consistent. Very few native species have been favoured by nutrient enrichment while exotics tend to be least abundant on non-enriched soils. Australian soils are recognized as being inherently low in available nutrients, and as a result many pastures in southern Australia have been fertilised with phosphate fertilisers and broadcast with annual legumes to counter both phosphorus and nitrogen limitations, although other nutrients, notably sulphur, have been found to be limiting, particularly on basalt derived soils (McLachlan 1952; Spencer 1966). The role of nitrogen and phosphorus enrichment in loss of native plant diversity and invasion by exotic species has been documented globally (Janssens et al. 1998; Bobbink et al. 2010) and results from southern Australia are consistent with this (Prober, Thiele, & Lunt 2002; Dorrough et al. 2006).

The difference in the size of effects between livestock and nutrient enrichment contrasts may however be due in part to confounding factors. Fertilised pastures are likely to have been subjected to more intensive grazing than native pastures. One of the key reasons that graziers add fertilisers is to enable them to increase livestock densities. Also I intentionally avoided classifying pastures with uncertain enrichment history as native (unfertilised) pastures. Because enrichment was often not reported in moderately and heavily grazed pastures, and were hence excluded from the review, this could have biased our native pasture sample towards those with a lighter or more infrequent grazing history. This would affect both (a) the estimates of the size of effect related to imposing livestock on Reference grasslands (i.e. potentially lower than the true effect size) and (b) the comparative effects of nutrient enrichment and grazing. In a small number of cases I did include some pastures which potentially had a range of enrichment histories in the fertilised pasture land use state, although excluding these observations did not modify our conclusions. Even so, it is important to recognize that the effect sizes obtained for the native pasture to fertilised pasture contrast, potentially represent effects of both increased livestock densities and nutrient enrichment.

Nutrient enrichment is also thought to create a significant barrier to restoration of native grassland communities (Prober, Thiele, & Lunt 2002; Spooner & Allcock 2006). Unfortunately I was unable to find any studies that described the changes in vegetation that arise from a gradual decline in soil nutrient availability after fertiliser applications cease. There were nine land use state observations for pastures that were classified as past-fertilised but none of these provided contrasting plant abundances for fertilised pastures. There were few frequently observed species in this pasture type (*Microleaena stipoides* was the most frequently observed species with 4 observations), and more data would be required to describe this land use state with any degree of confidence. I did however compile data from four observations that described the use of carbon additions to reduce nitrate availability. These active interventions did suggest that elimination of nutrient enrichment could allow the vegetation to cross an important transition threshold, potentially reversing the effects of nutrient addition on native and exotic plant abundances. There is continuing international interest in the role of soil fertility in the restoration success of temperate and Mediterranean ecosystems (Gilbert, Gowing, & Wallace 2009; Geurts et al. 2011) and further research in this area could have global implications.

The current understanding of how livestock grazing and fertilisation affects groundlayer plant composition is primarily derived from studies that rely on contrasts among sites with differing land use history. Most of our current knowledge therefore reflects the long-term, historical effects of these management practices. In this context the vegetation changes owing to livestock grazing of Reference grassland or fertilisation of native pasture are relatively well described. In contrast there are very few studies that explicitly examine exclosure of fertilised grasslands or the run-down of available nutrients in previously fertilised pastures (also see above). Information about the vegetation of these land-use states and respective transitions is required to assist managers in allocating limited conservation resources. A greater emphasis on experimental studies, supported by appropriately designed natural experiments, is needed to address our understanding of these land use states and respective land-use transitions.

Some previous syntheses of livestock grazing impacts in grassy ecosystems have not separated the effects of long-term livestock grazing from livestock exclosure (Milchunas & Lauenroth 1993; Vesk & Westoby 2001; Diaz et al. 2007). The available evidence suggests that studies examining the imposition of grazing, and possibly fertiliser, would generate different estimates than those studies based on relief from these practices. Likewise the results clearly suggest that failure to account for fertiliser history will bias estimates of the effects of livestock grazing – inspection of the primary data used in two recent quantitative reviews (Vesk & Westoby 2001; Diaz et al. 2007) indicates that confounding owing to nutrient enrichment may be a possible issue. Distinguishing between land use states in future studies is important for improving both our scientific knowledge of these ecosystems but also for informing management. Many studies, particularly of grazed pastures and exclosed pastures were not included in this review owing to inadequate information on land-use history. Publication of data must include site history in relation to grazing and fertilisation. Design of research projects should base site selection on the availability of such information.

7. Directions for future research

1. **Better documentation and reporting of research is required.** It is essential that studies report fertiliser history or measures of available soil nutrients, overstorey tree cover and some estimate of primary productivity. Dry sheep equivalents is a standard measure of livestock grazing in most agronomic studies but was infrequently available in ecological studies. Even so, it is not an exact measure of actual grazing pressure when comparing sites varying in primary productivity and vegetation composition. Measurements of sward height would provide a consistent indicator of stock pressure, albeit confounded with primary productivity, but less than 10% of studies provide such data. The ideal data to enable cross study comparisons would be off-take as a proportion of dry matter production.

   The minority of studies reported actual fertiliser histories in terms of total superphosphate applications and surprisingly only 1/3 of fertilised pasture observations provided such data. Very few studies reported results of soil nutrient analyses (eg. available phosphorus, available nitrogen or total nitrogen) and methods of extraction vary. In unfertilised Reference grasslands and native pastures landscape position, lithology, mean annual temperature and precipitation can be used as surrogates for site productivity – this information is available for most observations.

2. **Data is particularly required on exclosure of fertilised pastures.** There were only two land use transition/contrast studies and five land use state observations that I was able to classify as describing the removal of livestock from previously grazed and fertilised sites. Such areas are often fenced in incentive programs, however the literature contains very little data on their

ground layer composition. Do these areas remain dominated by exotic species or does the abundance of native species gradually increase after exclosure? How does tree planting modify this response?

3. **There is a need to collect data on the outcomes of ceasing fertiliser inputs.** Soil phosphorus is gradually "tied up", particularly in soils high in iron and clay. Only nine land use state observations and no contrasts from fertilised to native pasture, were found for inclusion in the review. Given the widespread decline in phosphorus use, owing to land use change and rising fertiliser costs, it will be important to know whether gradually declining available soil P levels across large proportions of the landscape will result in improved conservation and ecological outcomes. Over what time frame do nutrient levels decline and how does this vary? How and at what rate does the vegetation respond to this and how does this vary depending on climate, site and local species composition, soil type and grazing management?
4. **Other response data could also be considered.** A considerable number of studies reported changes in native and/or exotic plant growth form richness and cover, without actually reporting individual species abundance. These were not compiled owing to time constraints but these studies could provide useful additional information about overall outcomes of exclosure and soil nutrient run-down. Policy and management is often focused on changes in the cover and diversity of native species or exotic species as a whole and these data would be useful in this regard.
5. **Are alternative grazing strategies better than exclosure or status quo?** There is an increasing number of studies examining alternative grazing stratgies (e.g. strategic rest, planned rotational grazing, season deferment). Contrasting responses of plants to these alternative strategies with total exclusion and continuous grazing may be valuable. There is also, however, evidence to suggest that stock densities, not regime, are of paramount importance and this should also be considered. Difference between species of grazing animal (eg. sheep vs cattle) may also influence the vegetation, but there has been no systematic compilation of such data.
6. **Do rare native species respond differently?** Conservation management is often most concerned about the responses of specific rare or threatened taxa. While some information on individual species was generated through the meta-analysis, this is confined to frequent species. Does a species abundance locally or regionally affect response to livestock exclusion or declines in soil nutrient availability? Do rare native species differ in their responses to livestock exclusion compared to similar but widespread and abundant taxa?

8. Implications for management and policy

1. **The outcomes of excluding livestock from long-grazed areas is difficult to predict.** There appears to be few clear patterns to help guide when and when not to exclude livestock. Although in some cases native species will be favoured and exotics decline following livestock removal, such a pattern is not always certain. Even in E1 Mediterranean landscapes, where the long-term positive effects of livestock on exotic species abundance was so clear, exclosure did in some instances lead to increasing abundance of exotics (Souter & Milne 2009). Determination

of whether livestock should be removed may be better based on the species present at a locality. Sites lacking exotic species potentially favoured by exclosure and containing native geophytes and other key native species known to have increased following exclosure are those likely to provide better conservation outcomes. While there was some suggestion that exotic plant abundance is most likely to decline following exclosure in areas with high rainfall, when trees are present and soil fertility is low, care needs to be taken in developing general rules as individual species variation still strongly influences confidence around predictions.

2. **The data obtained confirm that grazed, but not fertilised, pastures frequently support a diversity of native perennial species and so play an important role in the conservation of native plants in grassy woodlands.** The dominant native species of Native pastures do however differ from Reference grasslands and many native plant species decline in abundance as a result of livestock grazing. However, few fertilised pastures are dominated by native plants, and apart from a few widespread species most native plant species decline in abundance following fertilisation. While fertilised pastures may provide other environmental values, they cannot be assumed to contribute to native plant conservation.
3. **Removal of high levels of available nutrients seems important but currently may not be practical.** While the experimental reduction in available nitrate through carbon (sugar) additions seems a valuable tool for restoring native pastures, it is costly, short-term and probably not practical at large scales. In addition it does not address high soil phosphate levels, which in turn can promote growth of nitrogen fixing legumes, which could facilitate rapid return to pre-treatment nitrate levels. While there has also been considerable success through physical removal of nutrient enriched topsoil, this is unlikely to be practical in most areas. At this stage priorities should be directed towards preventing enrichment rather than restoring enriched sites.
4. **Weed control needs to be a very high priority in areas from which livestock have been removed.** In cases where exclosure seems to be a good option (for example in Mediterranean woodland remnants and some cool wet (D5) woodlands), adequate resources for exotic plant weed control must be available. Invasion and increasing dominance by species such as *Avena barbata* seem to be likely in many cases – strategies to manage these species should be in place prior to exclosure. In almost all cases some form of biomass reduction will be necessary and planning should aim for a transition from grazing to an alternative method (eg. fire, hay cutting).
5. **Managing to prevent nutrient enrichment should be a very high priority.** Livestock are one of the key sources of nutrient inputs into remnant vegetation. The benefit of excluding livestock may be more to prevent nutrient inputs than herbivory. Nutrient run-on from adjacent sites can also be important, but is less commonly documented. Strategies should be put in place to limit the potential for nutrient transfers into remnant woodlands. In cases where this can only be achieved through complete livestock exclusion, alternative methods to manage biomass and weeds must be in place (see 3. above).
6. **Exclosed sites are likely to become woodier.** Livestock exclosure had negative effects on the average abundance of native herbaceous species (grasses and forbs), although shrubs tend to increase. At a landscape scale woody encroachment of open grassy ecosystems has been widely

documented in southern Australia eg. Lunt et al. (2010). Woody plant invasion is likely to influence ground layer species composition as well as ecosystems processes such as water and nutrient cycling. In the absence of livestock there will be many grassy woodlands where specific goals and strategies will need to be developed for managing shrub and tree densities.

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9. Appendices.

Appendix 1. Studies Accepted Into the Final Review

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Appendix 2. Accepted studies and the type of data they provided for the review.

Studies are categorized by whether or not they supplied data for land use state descriptions (l), livestock grazing and exclosure contrasts (g) and/or the fertiliser and nutrient run-down contrasts (f).

Author	Date	Data Type
Allcock & Hik	2004	g
Austin, Williams and Belbin	1981	g,l
Barnes, et al	2009	f,l
Bean and Whalley	2002	l
Benson and Howell	2002	g,l
Benson, Ashby, Porteners	1997	l
Biddiscombe	1953	g,l
Bowman,et al	2009	g
Chalmers	1996	f,l
Chilcott et al.	1997	l
Clarke, PJ	2003	f*,g,l
Conway	2000	g,l
Davies, Scott, Fraser	1934	f,l
Doing	1972	l
Donald and Williams	1954	f,l
Dorrough	2001	f,g,l
Dorrough & Ash	2004	g
Dorrough, Ash and McIntyre	2004	f*,g,l
Dorrough, Scroggie & McIntyre	2011	f,g
Dowling, Robinson, Murison	1987	l
Earl	1998	l
Fensham	1989	l
Fensham & Kirkpatrick	1989	g
Frood	1992	l
Garden et al.	2003	f,l
Garden et al.	2000	l
Gilfedder, L. & Kirkpatrick, J. B.	1994	g,l
Grant & MacGregor	2001	g,l
Hacker, et al	2011	f
Hamilton	2001	f,g,l
Hill & French	2004	g,l
Hill et al	2004	f,l
Hill, Tung, Leishman	2005	g,l
Hyde	1994	l
King, Dowling, Michalk et al	2006	l
Kirkpatrick et al	2005	g
Leonard & Kirkpartrick	2004	l
Lodge	1981	f,l

Author	Date	Data Type
Lodge	1982	l
Lunt	1997	g,l
Lunt & Morgan	1999a	g,l
Lunt & Morgan	1999b	l
Lunt, et al	2007	g,l
Macgale-Macandog	1991	l
McIntyre	2008	f,g,l
McIntyre & Lavorel	1994	l
Moore	1953	l
Morgan	1997	l
Morgan & Rollason	1995	l
Morris, De Barse	2012	f,l
Pettit & Froend	2001	g
Pettit, Ladd & Froend	1998	g,l
Price and Morgan	2007	f
Price, Wong, Morgan	2010	g,l
Prober	1996	g,l
Prober & Theile	1995	g,l
Prober & Thiele	2004	g,l
Prober et al	2011	g,l
Prober et al.	2002	l
Prober, et al	2005	f,l
Reseigh	2004	f,g
Robertson	1985	l
Robinson & Dowling	1976	f,l
Robinson & Lazenby	1976	l
Roe	1947	l
Schultz	2012	g,l
Schultz, Morgan, Lunt	2011	g,l
Sharp, S	1997	g,l
Souter and Milne	2009	g,l
Stuwe & Parsons	1977	g,l
Tiver	1947	f,l
Tremont	1994	g,l
Trumble and Fraser	1932	f,l
Verrier & Kirkpatrick	2005	l
Whalley et al.	1978	f,l
Williams	1969	g
Williams	1955	l
Williams	1956	l
Zimmer et al	2010	g

Appendix 3. All species ranked as dominant (rank 1-5) in at least one observation.

The number of observations each species was dominant, within each land use state and across all studies is shown. The total number of observations within each land use state is in brackets. Species dominant in 10% or more observations for each land use state are highlighted, except enriched and past fertilised states. In these later cases all species with two or more observations as dominat are highlighted.

Species	Origin	Enriched (5)	Exclosed (37)	Fertilised (36)	Native Pasture (90)	Past Fertilised (9)	Reference (44)	Total (216)
Acacia acuminata	N	0	1	0	1	0	1	3
Acacia genistifolia	N	0	0	1	1	0	0	2
Acacia pycnantha	N	0	0	1	1	0	1	3
Acaena novae-zelandiae	N	0	0	0	1	0	0	1
Acetosella vulgaris	E	0	0	0	0	2	0	2
Agrostis avenacea	N	0	0	0	1	0	0	1
Aira caryophyllea	E	0	1	0	3	0	0	4
Aira cupaniana	E	0	0	1	0	0	0	1
Aira elegantissima	E	0	0	0	1	0	0	1
Aira spp.	E	0	1	0	0	0	1	2
Alternanthera denticulata	N	0	0	1	0	0	0	1
Ammobium alatum	N	0	0	0	1	0	0	1
Amphibromus archeri	N	0	0	0	0	0	1	1
Amphibromus neesii	N	0	0	0	1	0	0	1
Anthoxanthum odoratum	E	0	2	0	0	0	0	2
Aphanes arvensis	E	0	0	0	0	1	0	1
Arctotheca calendula	E	0	1	2	3	1	0	7
Aristida behriana	N	0	1	0	0	0	0	1
Aristida ramosa	N	0	2	3	12	0	6	23
Aristida vagans	N	1	1	0	1	0	1	4
Aristida warburgii	N	0	0	1	1	0	0	2
Arthropodium minus	N	0	1	0	0	0	0	1
Arthropodium strictum	N	0	0	0	0	0	1	1
Asperula conferta	N	0	0	1	1	0	2	4
Atriplex semibaccata	N	0	1	0	0	0	0	1
Austrodanthonia auriculata	N	0	0	0	0	0	1	1
Austrodanthonia bipartita	N	0	0	0	1	3	0	4
Austrodanthonia caespitosa	N	0	5	2	6	0	4	17

Species	Origin	Enriched (5)	Exclosed (37)	Fertilised (36)	Native Pasture (90)	Past Fertilised (9)	Reference (44)	Total (216)
Austrodanthonia carphoides	N	0	0	0	5	0	3	8
Austrodanthonia duttoniana	N	0	0	0	1	1	0	2
Austrodanthonia eriantha	N	0	0	1	2	0	0	3
Austrodanthonia geniculata	N	0	1	0	2	0	0	3
Austrodanthonia penicillata	N	0	1	0	2	0	0	3
Austrodanthonia pilosa	N	0	0	0	5	0	1	6
Austrodanthonia racemosa	N	0	0	2	3	0	0	5
Austrodanthonia setacea	N	0	2	0	2	0	0	4
Austrodanthonia spp.	N	0	3	8	16	3	0	30
Austrostipa aristiglumis	N	0	0	0	3	0	0	3
Austrostipa densiflora	N	0	0	1	2	0	0	3
Austrostipa gibbosa	N	0	1	0	1	0	0	2
Austrostipa nitida	N	0	0	0	1	0	0	1
Austrostipa nodosa	N	0	1	0	3	0	0	4
Austrostipa scabra	N	0	4	4	10	0	3	21
Austrostipa semibarbata	N	0	0	0	0	0	1	1
Austrostipa setacea	N	0	0	0	4	0	0	4
Austrostipa spp.	N	0	3	0	3	0	0	6
Austrostipa stuposa	N	0	0	0	0	0	5	5
Austrostipa tenuifolia	N	0	1	0	0	0	0	1
Austrostipa verticillata	N	0	0	0	1	0	0	1
Avena barbata	E	3	6	0	2	0	1	12
Avena spp.	E	0	0	1	1	0	1	3
Axonopus affinis	E	1	1	0	0	0	0	2
Borya sphaerocephala	N	0	0	0	0	0	1	1
Bossiaea ornata	N	0	0	0	1	0	0	1
Bothriochloa decipiens	N	0	0	0	1	0	0	1
Bothriochloa macra	N	1	1	12	12	1	0	27
Brachypodium distachyon	E	0	0	1	1	0	0	2
Briza maxima	E	0	2	0	1	0	0	3
Briza minor	E	0	3	1	2	1	3	10
Briza spp.	E	0	0	0	1	0	0	1
Briza subaristata	E	1	1	0	0	0	0	2

Species	Origin	Enriched (5)	Exclosed (37)	Fertilised (36)	Native Pasture (90)	Past Fertilised (9)	Reference (44)	Total (216)
Bromus brevis	E	0	0	1	0	0	0	1
Bromus catharticus	E	2	1	0	0	0	0	3
Bromus diandrus	E	1	2	2	5	0	0	10
Bromus hordeaceus	E	0	0	2	3	0	0	5
Bromus molliformis	E	0	0	2	2	1	0	5
Bromus racemosus	E	0	0	2	1	0	0	3
Bromus rubens	E	0	0	0	1	0	0	1
Bromus spp.	E	0	3	1	1	0	0	5
Bromus tectorum	E	0	0	0	1	0	0	1
Brunoniella australis	N	0	1	0	2	0	1	4
Bulbine bulbosa	N	0	0	0	0	0	2	2
Bursaria spinosa	N	0	0	0	1	0	0	1
Calotis scabiosifolia	N	0	1	0	0	0	0	1
Carex breviculmis	N	0	0	0	1	0	0	1
Carex inversa	N	0	2	0	0	0	0	2
Carex spp.	N	0	0	0	0	1	0	1
Carex tereticaulis	N	0	1	0	0	0	0	1
Cassinia arcuata	N	0	0	0	0	0	1	1
Centaurium spp.	E	0	0	0	1	0	0	1
Cerastium glomeratum	E	0	0	0	0	1	0	1
Cheilanthes sieberi	N	0	0	0	0	0	1	1
Chloris truncata	N	0	1	3	8	1	0	13
Chrysocephalum apiculatum	N	0	1	0	1	0	5	7
Cirsium vulgare	E	0	0	3	0	1	0	4
Conyza albida	E	2	0	0	0	0	0	2
Crassula macrantha	N	0	0	0	4	0	0	4
Crassula sieberiana	N	0	0	0	1	0	0	1
Cymbopogon refractus	N	0	0	0	0	0	2	2
Cynodon dactylon	N/E	1	1	2	0	1	0	5
Cynosurus echinatus	E	0	0	0	1	0	0	1
Dactylis glomerata	E	0	2	1	0	0	0	3
Daucus glochidiatus	N	0	0	0	1	0	0	1
Daviesia ulicifolia	N	0	0	1	1	0	1	3

Species	Origin	Enriched (5)	Exclosed (37)	Fertilised (36)	Native Pasture (90)	Past Fertilised (9)	Reference (44)	Total (216)
Desmodium varians	N	0	0	0	4	0	3	7
Dianella revoluta	N	0	0	0	0	0	1	1
Dichanthium sericeum	N	0	0	2	1	0	0	3
Dichelachne micrantha	N	0	0	0	2	0	1	3
Dichondra repens	N	0	1	2	0	0	5	8
Dichondra spp.	N	0	0	0	0	0	2	2
Digitaria coenicola	N	0	0	0	1	0	0	1
Dillwynia cinerascens	N	0	0	0	0	0	1	1
Echium plantagineum	E	1	0	1	3	2	0	7
Echium vulgare	E	2	0	0	0	0	0	2
Eleusine tristachya	E	0	0	1	0	0	0	1
Elymus scaber	N	0	2	0	6	1	2	11
Enneapogon nigricans	N	0	0	0	0	0	1	1
Enteropogon acicularis	N	0	3	0	5	0	2	10
Enteropogon spp.	N	0	0	0	1	0	0	1
Epilobium billardieranum	N	0	0	0	0	2	0	2
Eragrostis brownii	N	1	0	1	0	3	0	5
Eragrostis leptostachya	N	0	0	2	0	0	1	3
Eragrostis spp.	N/E	0	0	1	1	0	0	2
Eragrostis trachycarpa	N	0	0	0	1	0	0	1
Erodium botrys	E	1	2	2	1	0	0	6
Erodium cicutarium	E	0	0	1	1	0	0	2
Erodium cygnorum	N	0	0	0	1	0	0	1
Erodium spp.	N/E	0	0	1	0	0	0	1
Euchiton collinus	N	0	0	0	1	0	0	1
Euchiton gymnocephalus	N	0	0	0	2	0	0	2
Euchiton involucratus	N	0	0	0	1	0	0	1
Fimbristylis dichotoma	N	0	0	0	3	0	0	3
Fimbristylis spp.	N	0	0	1	1	0	0	2
Gahnia sp	N	0	0	0	2	0	0	2
Galium aparine	E	0	0	0	0	1	0	1
Geranium solanderi	N	0	0	0	2	0	4	6
Geranium spp.	N	0	0	0	1	0	0	1

Species	Origin	Enriched (5)	Exclosed (37)	Fertilised (36)	Native Pasture (90)	Past Fertilised (9)	Reference (44)	Total (216)
Glycine clandestina	N	0	1	0	2	0	5	8
Glycine spp.	N	0	1	0	2	0	0	3
Glycine tabacina	N	0	1	1	0	0	1	3
Gnaphalium spp.	N/E	0	0	0	1	1	0	2
Goodenia hederacea	N	0	0	0	1	0	1	2
Goodenia pusilliflora	N	0	1	0	1	0	0	2
Haloragis heterophylla	N	0	0	0	1	0	1	2
Hirschfeldia incana	E	2	0	0	0	0	0	2
Holcus lanatus	E	0	2	2	1	2	2	9
Hordeum leporinum	E	0	0	4	2	1	0	7
Hordeum marinum	E	0	0	1	0	0	0	1
Hypochaeris glabra	E	1	1	1	3	0	0	6
Hypochaeris radicata	E	0	7	7	11	2	12	39
Hypochaeris spp.	N	0	1	1	5	0	1	8
Hypoxis glabrella	N	0	0	0	1	0	0	1
Joycea pallida	N	0	1	2	2	0	3	8
Juncus bufonius	N	0	0	0	0	2	0	2
Juncus spp.	N/E	0	1	0	0	1	0	2
Juncus usitatus	N	0	0	0	0	0	1	1
Lachnagrostis aemula	N	0	1	0	0	0	0	1
Lachnagrostis filiformis	N	0	1	0	0	0	0	1
Lagenophora gracilis	N	0	0	0	0	0	1	1
Lagenophora huegelii	N	0	0	0	1	0	0	1
Lagenophora spp	N	0	0	0	1	0	0	1
Lagenophora stipitata	N	0	0	0	1	0	0	1
Leontodon taraxacoides	E	0	0	3	4	0	0	7
Lepidosperma gracile	N	0	0	0	1	0	0	1
Lepidosperma laterale	N	0	0	0	0	0	2	2
Leptorhynchos squamatus	N	0	1	0	2	0	0	3
Leucanthemum vulgare	E	0	0	0	1	0	0	1
Lissanthe strigosa	N	0	0	0	1	0	0	1
Lolium perenne	E	0	2	2	1	1	0	6
Lolium rigidum	E	0	1	4	2	1	0	8

Species	Origin	Enriched (5)	Exclosed (37)	Fertilised (36)	Native Pasture (90)	Past Fertilised (9)	Reference (44)	Total (216)
Lolium spp.	E	0	0	1	5	0	1	7
Lomandra confertifolia	N	0	0	0	1	0	0	1
Lomandra effusa	N	0	1	0	0	0	0	1
Lomandra filiformis	N	0	1	0	4	0	0	5
Maireana aphylla	N	0	1	0	0	0	0	1
Maireana ciliata	N	0	2	0	0	0	0	2
Maireana excavata	N	0	1	0	1	0	0	2
Maireana pentagona	N	0	0	0	2	0	0	2
Malva parviflora	E	0	0	1	0	0	0	1
Marrubium vulgare	E	0	0	2	0	0	0	2
Marsilea drummondii	N	0	0	0	1	0	0	1
Medicago minima	E	0	0	0	1	0	1	2
Medicago polymorpha	E	0	0	0	1	0	0	1
Medicago spp.	E	0	0	1	6	1	1	9
Medicago truncata	E	0	0	0	1	0	0	1
Microlaena stipoides	N	0	3	9	14	4	19	49
Microseris lanceolata	N	0	0	0	0	0	1	1
Moenchia erecta	E	0	0	0	0	1	0	1
Moraea setifolia	E	0	0	0	0	0	1	1
Neurachne alopecuroidea	N	0	1	0	0	0	1	2
Notodanthonia semiannularis	N	0	0	1	4	0	1	6
Onopordum acanthium	E	0	0	2	0	0	0	2
Opercularia diphylla	N	0	0	0	0	0	1	1
Oxalis corniculata	E	0	0	0	0	2	0	2
Oxalis perennans	N	0	0	1	1	0	5	7
Panicum effusum	N	0	0	1	3	4	0	8
Panicum spp.	N	0	0	1	0	0	0	1
Parapholis incurva	E	0	0	0	1	0	0	1
Paronychia brasiliana	E	0	0	4	0	0	0	4
Paspalidium distans	N	0	0	0	1	0	0	1
Paspalidium gracile	N	0	0	0	0	0	1	1
Paspalum dilatatum	E	1	0	0	0	1	0	2
Pentameris airoides	E	0	0	0	1	0	0	1

Species	Origin	Enriched (5)	Exclosed (37)	Fertilised (36)	Native Pasture (90)	Past Fertilised (9)	Reference (44)	Total (216)
Petrorhagia nanteuilii	E	0	0	0	1	0	0	1
Phalaris aquatica	E	2	2	1	0	0	0	5
Pimelea humilis	N	0	0	0	1	0	3	4
Pimelea linifolia	N	0	0	1	0	0	0	1
Plantago gaudichaudii	N	0	1	0	0	0	1	2
Plantago lanceolata	E	0	3	0	4	0	3	10
Plantago varia	N	0	0	0	2	0	3	5
Poa annua	E	0	0	0	1	1	0	2
Poa labillardierei	N	0	0	0	0	0	6	6
Poa morrisii	N	0	0	1	1	0	1	3
Poa pratensis	E	0	0	1	0	1	0	2
Poa rodwayi	N	0	1	0	1	0	8	10
Poa sieb/lab	N	0	3	0	8	0	5	16
Poa sieberiana	N	0	0	3	12	0	22	37
Polygonum aviculare	E	0	0	0	0	2	0	2
Ptilotus macrocephalus	N	0	1	0	1	0	0	2
Pycnosorus globosus	N	0	0	0	1	0	0	1
Rhodanthe corymbiflora	N	0	0	0	2	0	0	2
Romulea minutiflora	E	0	1	0	1	0	0	2
Romulea rosea	E	0	3	1	5	1	2	12
Rubus parvifolius	E	0	1	0	0	0	0	1
Rubus ulmifolius hybrids	E	0	1	0	0	0	0	1
Rumex brownii	N	0	0	4	0	0	0	4
Sarga leiocladum	N	0	0	2	1	0	1	4
Schoenus absconditus	N	0	0	0	1	0	0	1
Schoenus apogon	N	0	2	0	2	0	5	9
Scleranthus biflorus	N	0	0	0	1	0	0	1
Sclerolaena muricata	N	0	1	0	0	0	0	1
Senecio madagascariensis	E	0	0	0	0	0	2	2
Setaria gracilis	E	1	0	0	0	0	0	1
Sida corrugata	N	0	1	0	3	0	0	4
Sida rhombifolia	E	0	1	0	0	0	0	1
Sida spp.	N/E	0	1	0	0	0	0	1

Species	Origin	Enriched (5)	Exclosed (37)	Fertilised (36)	Native Pasture (90)	Past Fertilised (9)	Reference (44)	Total (216)
Silybum marianum	E	0	0	2	0	0	0	2
Sporobolus caroli	N	0	0	0	3	0	0	3
Sporobolus creber	N	0	0	7	1	0	2	10
Sporobolus elongatus	N	0	0	3	2	3	0	8
Stellaria media	E	0	0	0	0	1	0	1
Swainsona procumbens	N	0	0	0	1	0	0	1
Themeda triandra	N	1	16	1	28	1	30	77
Tricoryne elatior	N	0	0	0	2	0	3	5
Trifolium arvense	E	0	1	2	2	1	3	9
Trifolium campestre	E	0	1	2	2	0	2	7
Trifolium dubium	E	0	1	2	0	0	0	3
Trifolium glomeratum	E	0	0	2	4	0	0	6
Trifolium repens	E	0	0	7	1	0	0	8
Trifolium resupinatum	E	0	0	1	0	0	0	1
Trifolium spp.	E	0	1	5	3	0	0	9
Trifolium striatum	E	0	0	0	1	0	0	1
Trifolium subterraneum	E	1	2	5	6	3	0	17
Trifolium tomentosum	E	0	0	1	0	0	0	1
Tripogon loliiformis	N	0	0	0	1	0	0	1
Triptilodiscus pygmaeus	N	0	0	0	5	0	0	5
Ursinia anthemoides	E	0	0	0	0	0	1	1
Verbena bonariensis	E	0	0	0	1	0	0	1
Vulpia bromoides	E	0	2	0	5	1	2	10
Vulpia myuros	E	0	0	2	3	0	0	5
Vulpia spp.	E	0	3	5	11	2	2	23
Wahlenbergia luteola	N	0	0	0	0	0	2	2
Wahlenbergia queenslandica	N	0	0	0	0	0	2	2
Wahlenbergia stricta	N	0	1	0	1	0	0	2
Waitzia acuminata	N	0	0	0	0	0	1	1
Walwhalleya poluta	N	0	1	1	0	0	0	2
Xerochrysum bracteatum	N	0	0	0	0	0	2	2

Appendix 4 Individual species mean lnRR and bias corrected 95% CI for short-term (Native pasture to Exclosed grassland) and long-term exclosure (Native pasture to Reference grassland).

Species with fewer than 2 observations were excluded from estimates.

		Native Pasture to Exclosed			Native Pasture to Reference		
Species	**Origin**	**Lower**	**Mean**	**Upper**	**Lower**	**Mean**	**Upper**
Acaena agnipila	Native				-0.2898	-0.1793	-0.0566
Acaena echinata	Native	-0.9574	-0.0722	0.4896	-0.4231	0.2647	0.8883
Acaena ovina	Native				0.1014	0.48	0.7221
Acetosella vulgaris	Exotic				-1.793	-0.7107	-0.1482
Aira caryophyllea	Exotic	-1.1635	-0.3878	0			
Aira cupaniana	Exotic	-4.0775	-2.0896	-0.1018			
Aira elegantissima	Exotic				-0.2927	0.3305	1.3669
Aira spp.	Exotic	-0.824	-0.2686	0.0181	-0.1737	-0.0791	0.0155
Anagallis arvensis	Exotic	-0.2174	0.243	0.7879	-0.5516	-0.0258	0.3943
Anthoxanthum odoratum	Exotic	0.1431	0.9362	1.7292			
Aphelia pumilio	Native	0	0.26	0.5199			
Arctotheca calendula	Exotic	-0.9163	-0.5924	-0.05	-2.2613	-1.26	-0.5816
Aristida behriana	Native				-2.0369	-0.8915	0.2539
Aristida ramosa	Native	0.7732	1.3225	1.8718	-1.995	-1.1451	-0.3747
Arthropodium fimbriatum	Native	0.6931	1.7329	2.7726	-0.323	0.0767	0.5229
Arthropodium minus	Native				-2.2888	-1.601	-1.0173
Arthropodium strictum	Native	3.0445	3.0445	3.0445			
Asperula conferta	Native	-1.0095	-0.4738	0.065	-0.3018	0.1774	0.5229
Astroloma humifusum	Native	-0.0771	1.5955	2.9178			
Austrodanthonia auriculata	Native				-1.2704	-0.4686	0.8534
Austrodanthonia bipartita	Native				-0.4756	0.5532	1.582
Austrodanthonia caespitosa	Native	-0.5714	0.5793	2.1187	-0.816	-0.2196	0.3521
Austrodanthonia eriantha	Native				0.0572	0.1724	0.2877
Austrodanthonia geniculata	Native	-2.4423	-1.2211	0			
Austrodanthonia pilosa	Native				0.5845	1.8885	2.8005
Austrodanthonia racemosa	Native	-1.0186	-0.7283	-0.3254	-0.8914	-0.4328	0.107
Austrodanthonia setacea	Native	-1.1317	-0.5551	0.1671	-1.4565	-0.6379	-0.1174
Austrodanthonia spp.	Native	-1.4966	-0.8374	-0.2142			
Austrostipa bigeniculata	Native				-2.7213	-1.011	0.6993
Austrostipa mollis	Native				0.1464	0.3791	0.6119
Austrostipa scabra	Native	-0.8977	0.6225	2.1221	-0.3383	0.2489	1.05
Austrostipa setacea	Native				-1.3633	-0.272	0.452
Austrostipa spp.	Native	-0.8627	-0.3377	0.0574			
Avena barbata	Exotic	0.3818	1.4171	2.8402			
Avena spp.	Exotic				-1.1471	-0.3819	0.4953

		Native Pasture to Exclosed			Native Pasture to Reference		
Species	**Origin**	**Lower**	**Mean**	**Upper**	**Lower**	**Mean**	**Upper**
Bothriochloa macra	Native	-3.964	-2.4499	-0.7309	-1.4045	-0.7835	0.0518
Briza maxima	Exotic	0.0941	0.308	0.5314	-1.9031	-0.493	0.66
Briza minor	Exotic	-2.1341	-0.561	0.094	-1.1806	-0.5114	0.0891
Bromus diandrus	Exotic				-1.2167	-0.5323	0.25
Bromus hordeaceus	Exotic	-0.8422	-0.4249	-0.0652	-1.8541	-0.8353	-0.2854
Bromus molliformis	Exotic				-0.4704	-0.0602	0.4923
Bromus racemosus	Exotic	-0.9163	-0.0281	0.8602			
Bromus rubens	Exotic	-3.0194	-1.7216	-0.4237	-1.0145	-0.5402	0.0869
Bromus spp.	Exotic	-0.5755	1.0487	3.0285			
Brunoniella australis	Native				0.1008	0.3865	0.6721
Bulbine bulbosa	Native	1.3863	2.2897	2.9178	0.3097	0.7791	1.4667
Burchardia umbellata	Native	0.8473	1.05	1.2528			
Caesia calliantha	Native	2.1401	2.3125	2.4849			
Calandrinia eremaea	Native				-0.2272	0.0177	0.2626
Calotis lappulacea	Native				-0.8286	-0.6284	-0.4281
Capsella bursa-pastoris	Exotic				-2.3543	-1.1011	0.1521
Carex gaudichaudiana	Native				-0.8536	-0.0214	0.8109
Carex inversa	Native	-0.3238	0.2785	1.4469	-1.3357	-0.9269	-0.565
Carthamus lanatus	Exotic				-2.2032	-1.4311	-1.0084
Centaurium erythraea	Exotic	-0.452	0.292	1.0361	-2.1025	-1.1213	0.1032
Centaurium tenuiflorum	Exotic	-3.7013	-2.1117	-0.5222			
Centrolepis aristata	Native	0.0174	0.1906	0.3637			
Centrolepis strigosa	Native	0.4353	0.844	1.2528			
Cerastium glomeratum	Exotic				-1.75	-1.2172	-0.4217
Chamaescilla corymbosa	Native	0.2683	0.3619	0.4555			
Chamaesyce drummondii	Native	-0.6078	-0.3715	0			
Cheilanthes distans	Native				0.1405	0.5761	1.0116
Cheilanthes sieberi	Native				-0.0168	0.425	0.7442
Chloris truncata	Native	-3.2525	-1.2426	-0.0562	-2.3746	-1.1179	0.6894
Chrysocephalum apiculatum	Native				0.6547	1.425	2.3523
Cicendia quadrangularis	Exotic	-1.6139	-0.4271	0.3878			
Cirsium vulgare	Exotic	-0.3365	1.8717	3.0432	-2.1061	-1.0484	-0.1549
Convolvulus erubescens	Native	-0.11	0.1994	0.5327	0.2112	0.6214	1.0878
Conyza bonariensis	Exotic				-0.9749	-0.3732	0.458
Crassula sieberiana	Native	-4.3175	-2.454	-1.0986	-0.8811	-0.443	-0.0048
Cymbonotus lawsonianus	Native				-0.4086	-0.0717	0.4132
Cymbopogon refractus	Native				0.6699	1.6419	2.614
Cynoglossum suaveolens	Native				-0.024	0.331	0.686
Cynosurus echinatus	Exotic				-2.5419	-1.6188	-0.0114
Daucus glochidiatus	Native	-1.2654	-0.6746	0	-1.1136	-0.8412	-0.5103

Species	Origin	Native Pasture to Exclosed Lower	Mean	Upper	Native Pasture to Reference Lower	Mean	Upper
Desmodium varians	Native				-0.5815	-0.1639	0.2592
Dianella longifolia	Native				0.8279	1.1732	1.5204
Dianella revoluta	Native				0.5793	0.9404	1.4486
Dichanthium sericeum	Native				-1.6094	-0.4704	0.6685
Dichelachne crinita	Native	-0.2877	0.0416	0.3254	-0.3219	0.2433	0.5969
Dichelachne micrantha	Native				-0.0355	0.579	1.2287
Dichondra repens	Native	-1.6094	-0.4044	0.8005	-1.2086	-0.3146	0.3307
Digitaria coenicola	Native				-0.8602	1.0808	2.3979
Drosera peltata	Native	-2.7652	-1.4151	-0.065	-0.5017	0.1216	1.1588
Dysphania multifida	Exotic				-0.3336	-0.2224	0
Echinopogon caespitosus	Native				0.0553	0.7208	1.3863
Echium plantagineum	Exotic				-1.4644	-1.0258	-0.2245
Einadia hastata	Native				-2.1017	-1.5066	-0.9114
Einadia nutans	Native				0.0366	0.2313	0.426
Elymus scaber	Native	-1.2332	-0.1322	0.7119	-0.1351	0.1634	0.4679
Enneapogon nigricans	Native				2.6856	3.1869	3.5531
Enteropogon acicularis	Native	0.3466	1.2482	2.2702	-0.135	0.7347	2.1181
Epilobium billardieranum	Native				-1.1044	-0.0237	1.057
Eragrostis cilianensis	Exotic				-4.5053	-4.0304	-3.5695
Eragrostis leptostachya	Native				0.0919	0.27	0.448
Erodium botrys	Exotic	-0.0662	0.044	0.1542	-2.0687	-1.1177	-0.1667
Erodium cicutarium	Exotic				-1.2809	-0.8182	-0.4163
Erodium cygnorum	Native				-1.8975	-1.1794	-0.2039
Eryngium rostratum	Native	-0.9163	0.1596	1.395	0.3201	0.8711	1.4222
Euchiton gymnocephalus	Native	-4.9127	-1.7474	0.5372			
Euchiton involucratus	Native				-1.9577	-1.4513	-0.8612
Euchiton spp.	Native	-2.8342	-1.0905	-0.1956			
Fimbristylis dichotoma	Native				-1.7091	-1.3607	-1.0124
Galium divericatum	Exotic	-2.0971	-1.8276	-1.5581			
Galium gaudichaudii	Native				-0.8596	-0.201	1.0626
Gamochaeta coarctata	Exotic				-0.7916	-0.619	-0.4463
Geranium retrorsum	Native				0.7642	0.9344	1.1046
Geranium solanderi	Native				-0.6903	0.1734	0.7978
Geranium spp.	Native	-0.8928	-0.1586	0.2719			
Glycine clandestina	Native				0.4264	0.8353	1.1569
Glycine tabacina	Native				-0.4974	0.2796	0.9797
Gonocarpus tetragynus	Native	0.9163	1.1407	1.3652	-0.3877	0.7214	1.8697
Goodenia geniculata	Native	1.6094	2.5964	3.5835			
Goodenia pinnatifida	Native				-0.2745	-0.1454	0.0059
Goodenia pusilliflora	Native	-1.901	-1.0032	-0.1054			

		Native Pasture to Exclosed			Native Pasture to Reference		
Species	**Origin**	**Lower**	**Mean**	**Upper**	**Lower**	**Mean**	**Upper**
Haloragis heterophylla	Native	-1.6938	-0.8078	-0.3131	-1.6422	-0.7293	1.0283
Hardenbergia violacea	Native				-0.0614	0.2995	0.6605
Hibbertia obtusifolia	Native				0.0963	1.1628	3.1781
Holcus lanatus	Exotic	-1.653	0.3665	2.0978	-0.0386	0.2788	0.8751
Hordeum leporinum	Exotic	-1.7441	-0.9571	0	-3.3934	-2.2156	-1.2929
Hordeum murinum	Exotic				-1.8718	-1.0255	-0.1793
Hydrocotyle foveolata	Native	-0.1823	-0.0261	0.1301			
Hydrocotyle laxiflora	Native	0.1011	1.3913	3.8286	-0.8171	-0.1138	0.3736
Hypericum gramineum	Native	-2.5626	-0.5397	0.572	-0.5676	-0.1485	0.0566
Hypericum perforatum	Exotic				-2.3588	-1.7797	-1.2007
Hypochaeris glabra	Exotic	-2.9066	-1.2656	-0.089	-1.0124	-0.6013	-0.1644
Hypochaeris radicata	Exotic	-1.3706	-0.5126	0.1967	-0.4283	-0.1075	0.0694
Hypoxis glabrella	Native	-0.1872	1.3791	2.9454			
Hypoxis vaginata	Native	2.7726	3.0613	3.3499			
Isolepis cernua	Native	-0.0953	0.0548	0.2048			
Isolepis spp.	Native	-0.8105	-0.2971	0.5596			
Juncus bufonius	Native	-1.7925	-0.8659	0.0606	-2.175	-1.1908	-0.2066
Juncus capitatus	Exotic	-0.9895	-0.3945	0.0911	-1.4783	-0.7257	0.027
Juncus flavidus	Native	-0.9558	-0.6217	-0.2877			
Juncus subsecundus	Native	0.069	1.7828	3.4965			
Lagenophora stipitata	Native	-0.9457	-0.0608	0.9808			
Leontodon taraxacoides	Exotic	-1.8328	-0.6366	0.5596			
Leptorhynchos squamatus	Native	-2.6247	-1.3136	-0.2325	0.2345	1.0253	1.8249
Lespedeza juncea	Native				-1.1044	-0.9191	-0.7338
Levenhookia dubia	Native	-0.2787	0.0308	0.3403			
Linum marginale	Native				0.6777	1.2146	1.7321
Lissanthe strigosa	Native				-0.5195	-0.0377	0.811
Lolium perenne	Exotic	-0.1828	0.0525	0.2877	-2.307	-1.8358	-1.3647
Lolium rigidum	Exotic	0.3318	1.6571	3.0445			
Lolium spp.	Exotic				-1.6784	-0.8363	-0.2915
Lomandra confertifolia	Native				-0.1417	0.4258	0.9933
Lomandra filiformis	Native	1.481	2.1103	2.4577	-1.191	-0.3897	0.1704
Lomandra longifolia	Native				-0.4869	0.0858	0.8995
Lomandra multiflora	Native				0.5221	1.1764	1.9069
Lomandra nana	Native	-0.4475	-0.1784	0.1759			
Luzula meridionalis	Native	-0.2126	-0.1063	0			
Maireana excavata	Native	-0.7494	-0.322	0.1054			
Marrubium vulgare	Exotic				-3.1355	-1.9733	-0.5382
Medicago lupulina	Exotic				-2.4789	-0.6016	3.0445
Medicago minima	Exotic				0.2657	0.5873	0.9089

Species	Origin	Native Pasture to Exclosed Lower	Mean	Upper	Native Pasture to Reference Lower	Mean	Upper
Medicago polymorpha	Exotic				-5.0782	-3.6623	-2.2463
Medicago spp.	Exotic				-0.5114	-0.1505	0.4099
Melichrus urceolatus	Native				0.0991	0.4796	0.8602
Mentha satureioides	Native				-2.4092	-1.1631	0.0829
Microlaena stipoides	Native	-2.7308	-1.0888	-0.0729	-0.7322	-0.2557	0.2037
Microseris lanceolata	Native	1.665	1.704	1.743	0.5461	1.269	2.1641
Microtis unifolia	Native	-0.3185	0.1196	0.3637	-0.3314	0.4763	1.284
Moenchia erecta	Exotic				-3.0207	-1.6202	-0.0182
Neurachne spp.	Native	1.7918	2.2822	2.7726			
Orobanche minor	Exotic				-1.4039	-0.6907	0.0224
Oxalis perennans	Native	-0.9221	-0.4311	0.0226	-0.5446	0.0029	0.64
Panicum effusum	Native	-4.2341	-2.6128	-0.9916	-2.2336	-0.6259	0.9817
Parentucellia latifolia	Exotic				-2.389	-2.1684	-1.9478
Paronychia brasiliana	Exotic				-2.4007	-0.9149	1.6221
Paspalidium gracile	Native				1.6618	2.6732	3.439
Pentapogon quadrifidus	Native	0.1092	0.2509	0.3926	-0.7345	0.3259	1.3863
Petrorhagia nanteuilii	Exotic				-0.6469	-0.1678	0.6464
Phalaris aquatica	Exotic				-0.1282	1.0816	2.2913
Phyllangium divergens	Native	-0.5306	0.187	0.9045			
Pimelea curviflora	Native				-0.3244	1.1416	2.4725
Pimelea humilis	Native	-0.991	0.0233	1.2098			
Pimelea linifolia	Native				-0.5596	-0.3005	0.0637
Plantago coronopus	Exotic	-0.5108	1.2707	3.0171			
Plantago debilis	Native				-0.2494	-0.2164	-0.1744
Plantago gaudichaudii	Native	-0.3483	0.4022	1.1527	-0.5982	0.9288	2.4557
Plantago lanceolata	Exotic	-0.3517	0.8322	1.7917	-1.333	-0.5784	0.0558
Plantago varia	Native	-1.6232	-0.4236	0.7761	-0.3931	0.2355	1.2499
Poa bulbosa	Exotic				-3.0207	-1.5924	-0.1106
Poa labillardierei	Native	-2.1972	-1.6479	-1.0986			
Poa sieberiana	Native	0.4111	1.2453	2.0794	-0.3604	0.2846	0.7936
Poa spp.	Native	0	0.1593	0.3185			
Poranthera microphylla	Native	0.1092	0.2173	0.3254	-1.7789	-1.0567	-0.2322
Pterostylis spp.	Native	1.9459	2.043	2.1401			
Ptilotus spathulatus	Native				-0.6377	-0.4372	-0.2367
Ranunculus lappaceus	Native				-0.3174	0.4814	1.2803
Richardia stellaris	Exotic	-3.5553	-2.2257	-0.8961			
Romulea rosea	Exotic	-0.6553	-0.256	-0.0023	-1.2532	-0.3445	0.3626
Rosa rubiginosa	Exotic				-1.1473	-0.5505	-0.0689
Rumex brownii	Native				-0.9858	-0.182	0.9747
Salvia verbenaca	Exotic				-0.3434	-0.0063	0.6217

		Native Pasture to Exclosed			Native Pasture to Reference		
Species	**Origin**	**Lower**	**Mean**	**Upper**	**Lower**	**Mean**	**Upper**
Sarga leiocladum	Native				0.1753	1.4942	3.6783
Schoenus apogon	Native	-2.0416	-1.0177	-0.1774	0.0203	0.504	1.1729
Scleranthus biflorus	Native				-0.7568	-0.1074	0.711
Sebaea ovata	Native	-0.4937	-0.3393	-0.1849			
Selaginella gracillima	Native	-0.2513	-0.1257	0			
Senecio quadridentatus	Native	0.6931	2.2488	3.1355	0.7032	1.4651	2.7243
Senecio sp.	Native	1.6094	2.2385	2.6047			
Sherardia arvensis	Exotic				-3.2961	-3.0055	-2.6772
Sida corrugata	Native	-0.9531	-0.1658	0.5699	-0.3861	-0.2165	-0.0469
Silene sp.	Exotic	-0.8873	-0.3147	0.2578			
Siloxerus multiflorus	Native	2.0794	2.426	2.7726			
Solenogyne bellioides	Native				-0.4613	-0.2272	0.0068
Solenogyne dominii	Native	-3.2057	-1.8904	-0.5297	-0.935	-0.8448	-0.7546
Solenogyne gunnii	Native				-0.9493	-0.8377	-0.7262
Sonchus oleraceus	Exotic	1.1632	1.7222	2.2813	-0.5685	-0.1235	0.2086
Sporobolus creber	Native	-3.9512	-3.1745	-2.3979	-1.432	-0.873	-0.4469
Stackhousia monogyna	Native				0.7212	1.5617	2.8292
Templetonia stenophylla	Native				0.3854	1.2914	2.1974
Thelymitra sp.	Native	1.0788	1.1864	1.2939			
Themeda triandra	Native	-0.2122	0.263	1.0168	0.3488	0.8305	1.3295
Thyridolepis mitchelliana	Native				0.8865	1.6573	2.3026
Tribulus terrestris	Exotic				-0.579	-0.2744	0.2183
Tricoryne elatior	Native	-0.9609	0.0191	1.4986	0.3402	0.632	1.0714
Trifolium angustifolium	Exotic	-1.6513	-1.2067	-0.7621	-0.9237	0.2567	1.2709
Trifolium arvense	Exotic	-0.8789	-0.3279	0.2231	-1.2573	-0.3057	0.3744
Trifolium campestre	Exotic	-2.3271	-0.8477	0.1216	-2.4891	-1.048	0.0421
Trifolium dubium	Exotic	-1.0185	-0.5295	-0.0998			
Trifolium glomeratum	Exotic				-1.6459	-0.5074	0.143
Trifolium repens	Exotic				-1.4457	-0.6978	0.05
Trifolium spp.	Exotic	-3.1132	-1.1428	0.2082			
Trifolium striatum	Exotic				-0.9565	-0.3772	-0.0616
Trifolium subterraneum	Exotic	-0.9113	-0.1961	0.5233	-1.7528	-1.1992	-0.5541
Triptilodiscus pygmaeus	Native	-2.8076	-2.2659	-1.6556	-0.5882	-0.3994	-0.1442
Veronica calycina	Native				-0.6254	-0.3381	-0.0508
Veronica plebeia	Native				-3.2055	-1.1973	0.8109
Viola betonicifolia	Native				0.0829	0.1867	0.2905
Viola cleistogamoides	Native	0.5108	1.1153	1.7198			
Vittadinia muelleri	Native				-0.2472	0.9755	2.1982
Vittadinia sp._cuneata?	Native				-2.2172	-0.6094	1.7047
Vulpia bromoides	Exotic	-3.089	-1.5728	0.4055	-0.7573	-0.2173	0.0827

Species	Origin	Native Pasture to Exclosed Lower	Mean	Upper	Native Pasture to Reference Lower	Mean	Upper
Vulpia myuros	Exotic	-2.7726	-1.2988	-0.5182	-2.505	-1.1189	0.2671
Vulpia spp.	Exotic	-3.0108	-1.5463	-0.659	-0.3311	-0.001	0.3726
Wahlenbergia communis	Native				-1.1711	-0.4647	0.2417
Wahlenbergia gracilenta	Native	-1.5315	-0.3993	0.7329			
Wahlenbergia luteola	Native				0.5392	0.7405	0.9364
Wahlenbergia stricta	Native	0.7161	1.4137	1.8435			
Wurmbea dioica	Native	0.4855	0.4855	0.4855	-1.4939	-1.0596	-0.6254
Xerochrysum bracteatum	Native				0.3288	0.9269	1.525