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Relationships between vegetation condition and kangaroo density in lowland grassy ecosystems of the northern Australian Capital Territory

Analysis of data 2009, 2012 and 2013

FINAL REPORT

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Report for ACT Environment and Sustainable Development Directorate

ACT Government

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Copyright and disclaimer

Important disclaimer

Contents

Figures

Tables

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Vegetation surveys were conducted by:

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Glossary

ACT	Australian Capital Territory
ANCOVA	Analysis of covariance
asl	above sea level
EPBC Act	Environmental Protection and Biodiversity Conservation Act
GAM	Generalised Additive Model
ha	Hectare
IDH	Intermediate Disturbance Hypothesis
KMU	Kangaroo Management Unit
LiSM	Line-intersect Structure Method
NMDS	Non-metric multidimensional scaling
NR	Nature Reserve
NTG	Natural Temperate Grassland
YBRGGW	Yellow Box – Red Gum Grassy Woodland

Executive summary

1. The aim of this report was to determine whether relationships exist between kangaroo density and vegetation condition in Canberra's lowland grasslands and grassy woodlands. The report analyses field data collected in 2009, 2012 and 2013 from survey plots located in 20 sites across the northern ACT and Googong Foreshores.
2. The report does not address relationships between vegetation structure and composition and other grassland fauna.
3. Testable predictions were made relating kangaroo density to plant species richness, diversity (measured as the Floristic Value Score), indicator species abundance, inter-tussock space, native grass cover and vegetation height based on the Intermediate Disturbance Hypothesis.
4. A positive relationship existed between kangaroo density and native species richness and Floristic Value Score at lower kangaroo densities (0 to ca. 2 per ha), but only in some years. This relationship was strongly influenced by two small, isolated, natural temperate grassland sites that had few or no kangaroos. No relationship was evident at densities above 2 kangaroos per ha.

Figure 1: Eastern Grey Kangaroos in lowland woodlands of the Australian Capital Territory

5. There was evidence of a positive relationship between kangaroo density and inter-tussock space, and a negative relationship between kangaroo density and native grass cover, but only in some years (particularly the dry year 2009). Data from 2013 showed that kangaroo density was associated with an increase in the percentage cover of short vegetation (in natural temperate grassland sites), and a decrease in the percentage cover of tall vegetation (but only between kangaroo densities of 0 and ca. 2 per ha).
6. This study could not identify any upper limit of kangaroo density beyond which vegetation richness, diversity and overall condition declines. However few sites had kangaroo densities that exceeded 3 per ha.
7. This study could not identify an optimal kangaroo density that maximises richness, diversity and condition. Richness and diversity tended to be highest when at least some kangaroos were present, while cover of taller vegetation tended to be highest at lower kangaroo densities.
8. At the site level, changes in vegetation structure and composition varied more between years, which may be associated with different prevailing climatic conditions, than with kangaroo densities.
9. Most statistically significant relationships between kangaroo density and vegetation condition had low goodness-of-fit, wide confidence intervals, and varied across years and plant communities. Specific site-level predictions based on these relationships have a high level of uncertainty, particularly at higher kangaroo densities.
10. The correlative nature of this study and other limitations associated with the data make it difficult to isolate the effect of kangaroo grazing from the influence of a range of other site-level factors such as

land use history, site productivity and grazing by other animals (e.g. domestic stock, rabbits). These factors were not addressed in this study.

11. Suggestions are provided for future research. A manipulative field experiment that included multiple replicates of paired exclosure and non-exclosure plots would likely to be a more effectively design to quantify the effects of kangaroo grazing on grassland condition. Future designs would benefit from discussion with biostatisticians.

1 Introduction

1.1 Report outline

The report is structured as follows:

Chapter 1 provides a brief introduction to the lowland grassy ecosystems of the northern ACT and the issue of kangaroo management, referencing key reports that provide in-depth literature reviews on these topics. This chapter also states the aims, research questions and hypotheses to be addressed in the report, including a description of the Intermediate Disturbance Hypothesis.

Chapter 2 describes the sites and survey plots, including the method of selection and location.

Chapter 3 describes the methods for the vegetation and kangaroo density surveys, the measurements that were recorded, the selection of response and predictor variables, and the data analyses undertaken.

Chapter 4 presents the results of the data analysis, structured according to the research questions outlined in Chapter 1. Predictions relating to the IDH are explicitly tested in this chapter.

Chapter 5 discusses the results of the data analysis in relation to prediction and associated caveats, comments on the experimental design, and suggestions for future research.

Appendices: The appendices include the layout of the survey plots, GPS co-ordinates for survey plot locations, survey plot photographs, and copies of data sheets.

1.2 Lowland grassy ecosystems in the Australian Capital Territory

Canberra is Australia's "Bush Capital"; a city interspersed with extensive parkland, nature reserves, lakes, creeks and rivers. The city and its suburbs are located in the north of the Australian Capital Territory (ACT) (see Figure 5, pg. 9), a region that is also home to two endangered ecological communities: lowland Natural Temperate Grassland (NTG) (Figure 2) and Yellow Box-Red Gum Grassy Woodland (YBRGGW). Both of these communities are listed under the *Nature Conservation Act 1980* (Table 1).

Figure 2: Lowland Natural Temperate Grassland at Kama Nature Reserve in Belconnen, in the north of the Australian Capital Territory (see Figure 5 for location).

The conservation of these two communities is discussed in their respective Action Plans: *Woodlands for Wildlife: ACT Lowland Woodland Conservation Strategy, Action Plan No. 27* (ACT Government 2004) and *A Vision Splendid of the Grassy Plains Extended: ACT Lowland Native Grassland Conservation Strategy, Action Plan No. 28* (ACT Government 2005).

NTG is also listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act), as part of the ecological community Natural Temperate Grassland of the Southern Tablelands of NSW and the Australian Capital Territory (Table 2). This listing includes the lowland areas of NTG that are part of this study, as well as higher elevation grasslands that can occur at elevations of up to 1200 m above sea level (asl) in the ACT (Environment ACT 2005; pg. 5).

In addition, over half of the extent of YBRGGW in the ACT has been found to meet the criteria for listing under the Commonwealth EPBC Act 1999 as critically endangered White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland (Maguire & Mulvaney 2011)(Table 2).

Table 1: Definitions of Yellow Box-Red Gum Grassy Woodland and lowland Natural Temperate Grassland described by the *Nature Conservation Act 1980*.

Yellow Box-Red Gum Grassy Woodland	Lowland Natural Temperate Grassland
"Yellow Box-Red Gum Grassy Woodland is an open woodland community in which either or both of Yellow Box *Eucalyptus melliodora* and Blakely's Red Gum *E. blakelyi* are usually present and commonly dominant or co-dominant. Apple Box *E. bridgesiana* is a frequent associate. The trees form an open canopy above a species-rich understorey of native tussock grasses, herbs and scattered shrubs. The combination results in a variegated mosaic of vegetation patches with features that are transitional between forest and grassland, and the community is frequently interspersed with these other vegetation types. Yellow Box-Red Gum Grassy Woodlands are utilised by a large number of animal species. The name of this ecological community (Yellow Box-Red Gum Grassy Woodland) is intended to encompass the dominant trees of the upper stratum, the characteristic plants of the understorey and the characteristic animals that interact with the vegetation complex."(ACT Government 2004; pg. 29)	"Natural temperate grassland is a native ecological community that is dominated by native species of perennial tussock grasses. The dominant grasses are *Themeda triandra*, *Austrodanthonia* species, *Austrostipa* species, *Bothriochloa macra* and *Poa* species. The upper canopy stratum generally varies in height from mid high (0.25–0.5 m) to tall (0.5–1.0 m). There is also a diversity of native herbaceous plants (forbs), which may comprise up to 70% of species present. The community is naturally treeless or has less than 10% projective foliage cover of trees, shrubs and sedges in its tallest stratum. In the ACT it occurs where tree growth is limited by cold air drainage, generally below 625 m asl." (ACT Government 2005; pg. 13)

In the ACT, lowland NTG occurs in lower elevation valleys of less than 625 m asl where factors such as low temperatures, soil type or low rainfall restrict tree growth (ACT Government 2005). On lower and middle slopes between 600-900 m asl, NTG begins to intergrade with YBRGGW (ACT Government 1999). Secondary grasslands, which are lowland grassy woodlands that have been cleared, also occur in the area.

Table 2: Definitions of Natural Temperate Grassland and White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland under the Commonwealth *Environmental Protection and Biodiversity Conservation ACT 1999*.

White Box - Yellow Box – Blakely's Red Gum Grassy Woodland and Derived Native Grassland	Natural Temperate Grassland
"The ecological community must be, or have previously been, dominated or co-dominated by one or more of the following overstorey species (or hybrids of these species with any other *Eucalyptus* species): White Box (*Eucalyptus albens*), Yellow Box (*E. melliodora*) or Blakely's Red Gum (*E. blakelyi*) [or Western Grey Box (*E. microcarpa*) or Coastal Grey Box (*E. moluccana*) in the Nandewar bioregion]. It must have a predominately native understorey (i.e. more than 50% of the perennial vegetative groundlayer must comprise native species). The area covered by the ecological community (i.e. the patch size) must be greater that 0.1 hectares (ha) and contain 12 or more native understorey species (excluding grasses), including one or more important species (as listed in Appendix 1). If the groundlayer does not meet this last criterion (i.e. does not contain 12 or more native forb species and one or more important species) then the patch size must be 2 ha or greater in area and have an average of 20 or more mature trees per ha, or natural regeneration of the identified dominant overstorey eucalypts." (Department of Environment, Climate Change and Water NSW 2010; pg. 6)	"Natural Temperate Grassland is a native ecological community that is dominated by native species of perennial tussock grasses. The dominant grasses are *Themeda triandra*, *Austrodanthonia* species, *Austrostipa* species, *Bothriochloa macra* and *Poa* species. The upper canopy stratum generally varies in height from mid-high (0.25-0.5 m) to tall (0.5-1.0 m). There is also a diversity of native herbaceous plants (forbs), which may comprise up to 70% of species present. The community is naturally treeless or has less than 10% projective foliage cover of trees or shrubs in its tallest stratum. The ecological community that makes up NTG–ST is defined by the vegetation structure thought to have been present at the time of European settlement." (Environment ACT 2005; pg. 5)

These lowland communities provide habitat for a diverse range of flora and fauna, including several species that are also declared endangered under the *Nature Conservation Act 1980*.

1.3 Eastern grey kangaroos in Canberra's urban areas

A significant feature of the 'Bush Capital' are the highly visible populations of eastern grey kangaroos (*Macropus giganteus*) that occur in lowland grassy ecosystems throughout Canberra's urban area (Figure 3). Although the eastern grey kangaroo (hereafter referred to as kangaroo) is an integral part of these lowland grassy ecosystems, including NTG and YBRGGW, densities have substantially increased in the ACT since the 1960s (TaMS 2010).

Figure 3: Eastern grey kangaroos at Oakey Hill Nature Reserve, Lyons; Black Mountain Tower in background.

This increase has raised concerns about the impact of high kangaroo densities on lowland grassy ecosystems in the ACT, particularly in conservation reserves. A kangaroo management plan was released in 2010, which includes a review of the biology and ecology of kangaroos in the context of their population increase in the ACT, and their potential impacts on native ecosystems (TaMS 2010).

Effective management of these lowland grassy ecosystems requires an understanding of how changes in kangaroo densities may affect vegetation. To meet this need, a monitoring program commenced in 2009 to investigate the relationship between kangaroo densities and vegetation condition in lowland grassy ecosystems of the ACT and the nearby Googong Foreshores. Vegetation survey plots were established in sixteen sites in Canberra's urban area, including nature reserves and other conservation sites, as well as at Googong Foreshores, located to the east of the ACT. Corresponding surveys were conducted to estimate kangaroo densities at each site. Surveys were first conducted in spring 2009, followed by a second round of surveys in spring 2012. An interim report on the 2009 and 2012 surveys was recently released (Armstrong 2013).

1.4 Aim, research questions, and hypotheses

In spring 2013, a third year of surveys of vegetation condition and kangaroo densities was conducted, with an additional five sites incorporated into the study. This report presents the results of analyses of the data collected in all three years.

Report Aim

The aim of this report is to determine whether relationships exist between kangaroo density and vegetation condition in Canberra's lowland grasslands and grassy woodlands, using data collected in 2009, 2012 and 2013.

Research Questions

(1) How have kangaroo densities changed spatially and temporally between 2009 and 2013?
(2) How has vegetation condition changed spatially and temporally?
(3) What relationships exist between kangaroo density and vegetation condition?

1.4.1 INTERMEDIATE DISTURBANCE HYPOTHESIS

Disturbances play an important role in the ecology of grassy ecosystems of south-eastern Australia, particularly fire and grazing regimes (Tremont & McIntyre 1994; Prober, Thiele & Lunt 2007).

At very low levels of disturbance, plant species diversity in grassy ecosystems can decline, such as in areas where fire and grazing have been excluded. If disturbances are largely absent, grasses can increase in biomass and become dominant, monopolising resources and competitively excluding native forbs, many of which require inter-tussock space for recruitment, establishment, growth and flowering (Lunt 1994; Morgan 1997, 1998). Consequently, this can result in an overall decline in native plant species diversity. Low disturbance levels can also lead to a decline in the health of the grasses themselves: studies in wet *Themeda triandra* grasslands showed that in the absence of disturbance dead leaves will accumulate, potentially resulting in the collapse of the grass canopy (Morgan & Lunt 1999).

However, at the other end of the disturbance spectrum, very high disturbance levels in grassy ecosystems can also reduce plant species diversity. For example, high levels of grazing can cause the reduction, or even local extinction, of disturbance-intolerant species, resulting in lower overall species diversity. In particular, many native grassland forbs, including several rare species, are considered to be intolerant of very frequent disturbance, particularly grazing (McIntyre & Lavorel 1994; Rehwinkel 2007).

Accordingly, it is hypothesised that species diversity is maximised at intermediate levels of disturbance, with the lowest diversity at the extreme ends of the disturbance gradient (Figure 4). This 'intermediate disturbance hypothesis' (IDH) was originally postulated by Connell (1978) to describe patterns of diversity in coral reefs and tropical rainforests. Since then, the IDH has been tested in a range of ecosystem types worldwide – including in grassy ecosystems of south-eastern Australia, particularly those dominated by *Themeda triandra* – with mixed support (Lunt *et al.* 2012; Kershaw & Mallik 2013). The nature of the underlying mechanisms driving disturbance-diversity relationships and the extent to which the IDH is universally applicable is still debated (Fox 2013; Sheil & Burslem 2013). In particular, there are a range of factors that may affect the dynamics of this 'hump-shaped' diversity-disturbance relationship.

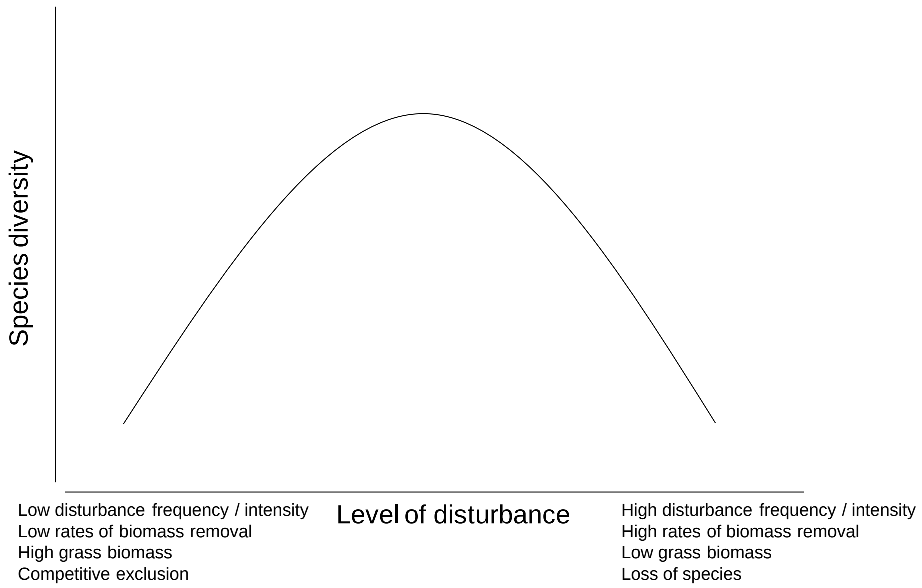


Figure 4: Simplified diagram of the Intermediate Disturbance Hypothesis.

Importantly, the relationship can be dependent on site productivity, and is predicted to more evident in productive ecosystems, such as those in higher rainfall climates (Schultz, Morgan & Lunt 2011). For example, periodic drought in drier regions may counteract competitive exclusion by dominant grasses by reducing grass biomass and increasing grass mortality (Prober *et al.* 2007; Schultz *et al.* 2011). Additionally, plants may recover more slowly after disturbance at unproductive sites, resulting in a slower rate of competitive exclusion (Lunt *et al.* 2007).

Plant species diversity may also be affected by the presence of tree canopies in grassy ecosystems, such as in grassy woodlands, which can suppress the germination, growth and dominance of some grass species, and alter nutrient dynamics through processes such as litter fall, accumulation of animal droppings, and water use (Prober, Lunt & Thiele 2002; Schultz *et al.* 2011). Thus, in lowland grassy ecosystems, it might be expected that diversity-disturbance relationships differ between grassland and grassy woodland habitats.

The impacts of different disturbance types can also influence disturbance-diversity relationships. For example, where disturbances such fire and mowing are largely indiscriminate in their removal of biomass, grazers can be selective in terms of which species they consume. If the dominant grass species is unpalatable to the grazers present, then there may be little impact of the grazers on promoting species diversity (Lunt *et al.* 2007).

1.4.2 PREDICTIONS FROM THE INTERMEDIATE DISTURBANCE HYPOTHESIS

This report will use the IDH as a basis to examine the relationship between vegetation condition and kangaroo density in the lowland grassy ecosystems of the ACT, with kangaroo density assumed to be a surrogate for grazing (disturbance) intensity.

A range of variables will be examined in relation to vegetation condition. As the IDH relates specifically to species diversity, this report will focus on the relationships between kangaroo density and plant species richness and diversity, assessed as both native and exotic species richness, and as diversity by using the Floristic Value Score (which will be described in Section 3.6.1).

However, the overall condition of grassy ecosystems in south-eastern Australia can be also be described by a range of additional variables, such as understorey structure, inter-tussock space, tussock height, grass cover and grass biomass. Many of these additional variables can be extremely important for fauna that reside in grassy ecosystems, and are therefore also important to consider, alongside floristic patterns.

Indeed, there are several underlying mechanisms predicted by the IDH that relate to other ecological factors such as these (Figure 4).

Hence, using the IDH, several predictions can be made pertaining to the relationships between kangaroo density, species richness/diversity, and vegetation condition in lowland grassy ecosystems of the ACT:

Prediction 1: A relationship will exist between kangaroo density and species richness/diversity. The IDH specifically predicts that the relationship will be humped-shaped, with the highest species richness/diversity evident under intermediate levels of kangaroo grazing pressure.

Prediction 2: Kangaroo density will be positively related to inter-tussock space.

Prediction 3: Kangaroo density will be negatively related to native grass cover and understorey vegetation height.

These predictions will be explicitly examined as part of addressing the third research question.

An important outcome of this project is to identify whether there are upper and lower kangaroo densities that result in a decline in species richness/diversity and overall vegetation condition, and whether there is an optimal kangaroo density that results in the maximum species diversity and vegetation condition.

2 Site and survey plot selection

2.1 Site selection and overview

At the commencement of the project in 2009, 17 sites across the northern ACT region were selected for inclusion, including at Googong Foreshores (Armstrong 2013). These sites consisted of a range of land use types, managed by difference agencies, including nature reserves, Department of Defence land and National Capital Authority land. One of these sites (Majura Training Area) was dropped from the project in 2012 due to access issues (Armstrong 2013), and will not be reported on further. The sites that were initially included in the study in 2009 were selected to encompass a range of kangaroo densities in areas that possessed relatively high grassland or woodland values. The selection was limited by the kangaroo density data available at the time.

In 2012, an additional site, Campbell Park, was added to the project to replace the loss of Majura Training Area (Armstrong 2013). In 2013, a further four sites were added to the project: Gungaderra Nature Reserve, Majura Nature Reserve, Mt Painter Nature Reserve and the Pinnacle Nature Reserve, giving 20 sites in total (Table 3; Figure 5).

Sites ranged in size from 1.5 ha (St Mark's Cathedral, in Barton) to 1,443 ha (Googong Foreshores). The size of several sites was calculated as the broader kangaroo management unit (KMU), an area which includes any adjacent open space areas that kangaroos may also occupy, typically bounded by features that may restrict kangaroo movement such as high speed roads (Environment ACT 2014). No size was calculated for Campbell Park because it is unclear how far kangaroos roam in this area.

Both woodland-dominated and grassland-dominated sites were included in the project (Table 3). The percentage of grassland for each reserve was determined as the percent of grassland patches present greater than 3 ha in size.

2.2 Survey plot selection and overview

Between one and five square survey plots were established at each site (Figure 5) and permanently marked with a star picket in one corner and three yellow corner pegs in the remaining three corners. Each survey plot consisted of a 20 x 20 m quadrat, with an additional 50 metre step point transect extending out from one of the corners. The layout and design of the survey plots, along with the grid co-ordinates and any location details, are provided in Appendix A .

The number of individual survey plots within each of the twenty sites was determined by the overall site size and heterogeneity (e.g. sites with NTG and YBRGGW have more survey plots than similar sized sites with only one vegetation type), the number of high quality remnant patches within the site and the survey resources available at the time (see Figure 8, pg. 18 for stylised example).

The survey plots were purposely located within each site to target high quality vegetation patches. As a consequence, any outcomes and conclusions that are drawn from this project should be applicable only to high quality vegetation patches.

One survey plot at Mulangarri Nature Reserve (NR) was removed in 2013 due a new fence being constructed through the plot, and is not included in the analysis.

After taking into account the addition and removal of sites and survey plots across the three years, the total number of survey plots included in this report is as follows: 46 in 2009, 49 in 2012 and 62 in 2013 (Table 3; Figure 5).

2.3 Kangaroo exclosures

Two large kangaroo exclosures were constructed at Jerrabomberra East Nature Reserve and Jerrabomberra West NR at the end of 2009. At Jerrabomberra East NR, an area of 15.17 ha was fenced in late August 2009, with one of the two survey plots present contained within the exclosure. At Jerrabomberra West NR, an area of 42.25 ha was fenced in late October 2009, with two out of the five survey plots contained within the exclosure. Since the fences were constructed, at any one time a small number of kangaroos have been able to gain access inside the exclosures, albeit at very low densities, with up to 12 animals recorded during the 2012 and 2013 kangaroo density surveys (see Table 4).

Table 3: Sites and plots surveyed in 2009, 2012 and 2013, including the number of survey plots, site size, and the percentage of grassland vegetation present.

	NUMBER OF SURVEY PLOTS ESTABLISHED				
SITE	2009	2012	2013	SITE SIZE (HA)	GRASSLAND (%)
Belconnen Naval Transmission Station	5	5	5	111	89
Broadcast Australia**	2	2	2	20	98
Callum Brae Nature Reserve	3	3	3	143	0
Campbell Park #	-	3	3	-	-
Crace Nature Reserve	2	2	2	163	89
Dunlop Nature Reserve	4	4	4	105	77
Googong Foreshores (KMU)	5	5	5	1,443	27
Goorooyaroo Nature Reserve	5	5	5	576	1
Gungaderra Nature Reserve (KMU)	-	-	4	342	74
Jerrabomberra East Nature Reserve	2	1	1	97	100
Kangaroo exclosure	-	1	1	15	100
Jerrabomberra West Nature Reserve	5	3	3	225	63
Kangaroo exclosure	-	2	2	15	100
Kama Nature Reserve	4	4	4	155	24
Majura Nature Reserve	-	-	4	509	0
Mt Painter Nature Reserve (KMU)	-	-	2	210	46
Mulangarri Nature Reserve (KMU)	3	3	2*	183	63
North Mitchell Nature Reserve	1	1	1	26	86
Pinnacle Nature Reserve (KMU)	-	-	2	366	7
St Mark's Cathedral	1	1	1	1.5	100
Wanniassa Hills Nature Reserve	2	2	4	268	0
Yarramundi Reach	2	2	2	102	59
Total	***46***	***49***	***62***		

* One survey plot at Mulangarri Nature Reserve was discarded due to a new fence running through it. ** Previously known as National Transmission Authority. KMU = kangaroo management area; size and % grassland are provided for the KMU. # There is no area calculated for Campbell Park as it is unknown how far kangaroos roam in the area.

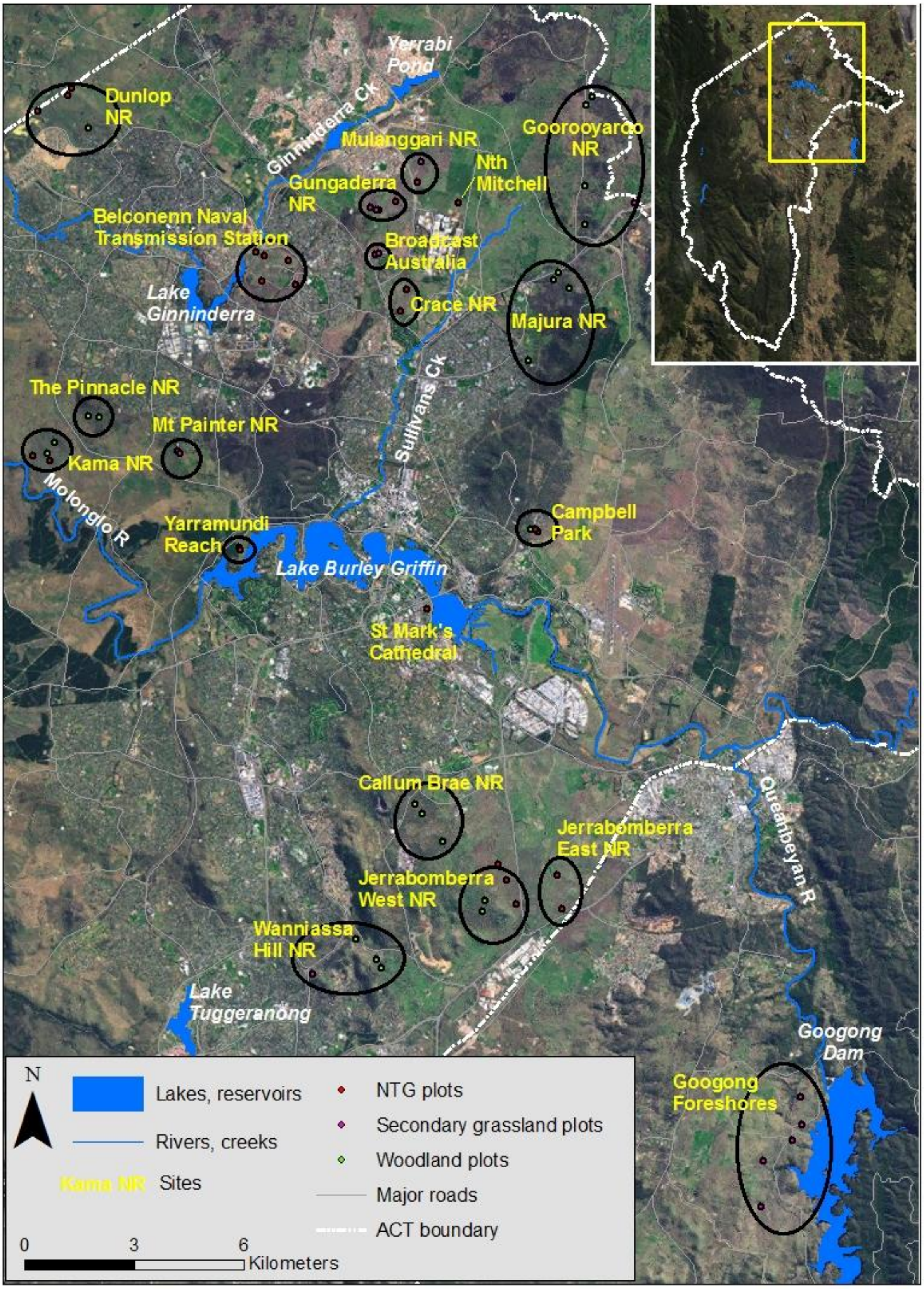


Figure 5: Map showing the location of the twenty sites and 62 survey plots. Inset in top right hand corner shows the location of the larger map in the context of the ACT boundary (indicated by the yellow square). NTG = natural temperate grassland.

3 Survey methods and data analysis

3.1 Survey timing and weather conditions

Vegetation surveys commenced in spring of 2009, with the survey plots re-surveyed in spring 2012 and 2013. The first surveys in 2009 occurred during the latter part of a long-term meteorological drought in south-eastern Australia, which was alleviated by the development of a moderate to strong La Nina event in 2010 (National Climate Centre 2010). Rainfall in the region was above-average for most months in 2010 (Figure 6). Record-breaking rainfall occurred in early 2012, prior to the second survey period (Bureau of Meteorology 2012). Long-term average annual rainfall at Canberra Airport is 616 mm per annum.

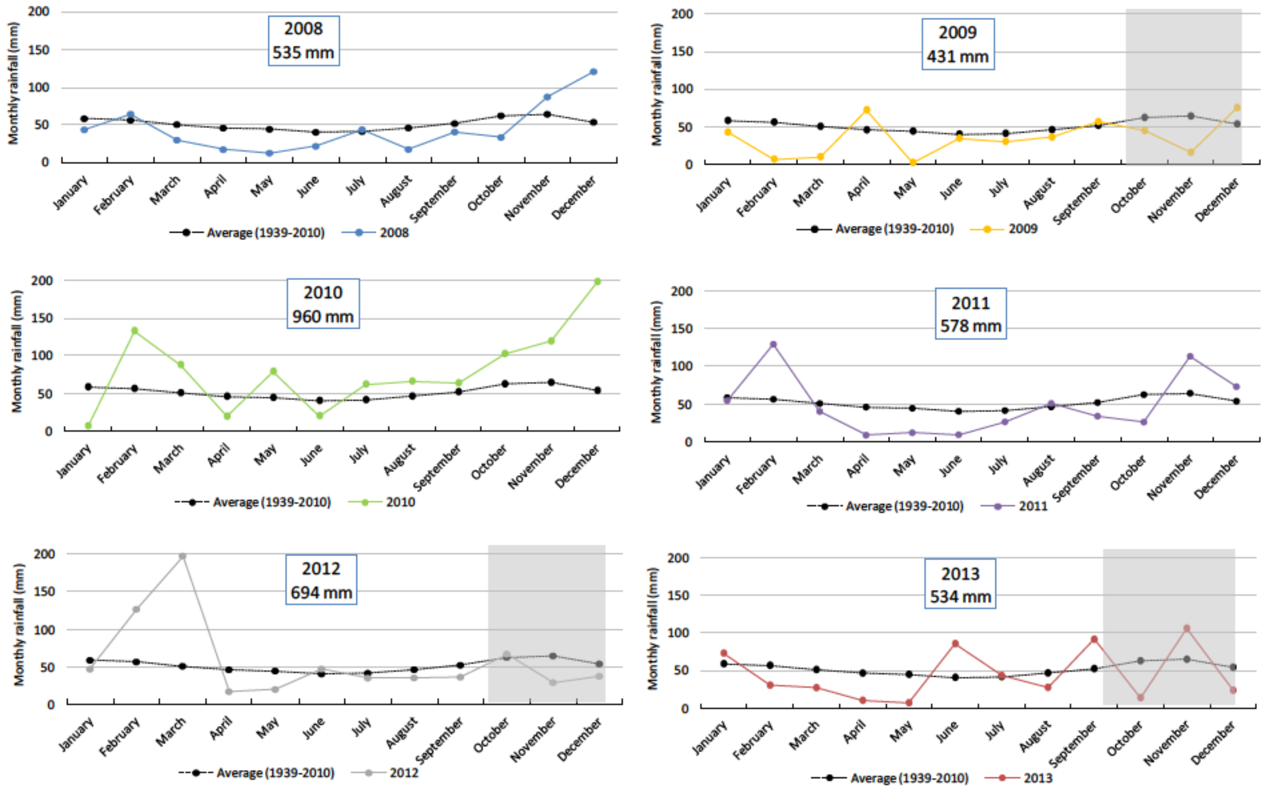


Figure 6: Monthly rainfall at Canberra Airport between 2008 and 2013. Grey shaded areas show the timing of vegetation surveys (spring/early summer in 2009, 2012 and 2013).

3.2 Kangaroo density estimates

The kangaroo density surveys varied in timing and method between years and sites (Armstrong 2013) (Table 4). Where possible, if there was a choice between using density data from a survey conducted in the winter prior to the spring vegetation surveys, or the following summer, then the data from the following summer was used. This is because a winter survey may underestimate kangaroo density in spring due to pouch young not yet being emergent. No kangaroos are known to occur at St Mark's Cathedral or Yarramundi Reach. No population estimates were available for Googong Foreshores in 2012 due to unseasonal conditions interfering with data collection.

Table 4: Kangaroo density estimates for each site for the years 2009, 2012 and 2013. Descriptions of the different methods for estimating densities can be read in the Kangaroo Management Plan (TaMS 2010).

	2009			2012			2013		
RESERVE	**DENSITY**	**TIMING**	**METHOD**	**DENSITY**	**TIMING**	**METHOD**	**DENSITY**	**TIMING**	**METHOD**
Belconnen Naval Transmission Station	1.42	May 2010	Direct count	2.74	Jan 2013	Direct count	1.3	Jan 2014	Direct count
Broadcast Australia	1.47	Oct 2009	Direct count	1.73	Jan 2013	Direct count	2.15	June 2013	Direct count
Callum Brae Nature Reserve	2.05	Aug 2009	Pellet count	2.01	Feb 2013	Walked line	2.01	Feb 2013	Walked line
Campbell Park	-	-	-	1.53	Dec 2012	Pellet count	2.54	Jan 2014	Pellet count
Crace Nature Reserve	0.85	Aug 2009	Direct count	0.88	March 2013	Direct count	1.01	Oct 2013	Direct count
Dunlop Nature Reserve	0.6	Dec 2008	Direct count	0.57	Jan 2013	Direct count	0.83	Dec 2013	Direct count
Googong Foreshores (KMU)	2.16	Sept 2009	Pellet count	Not available	-	Walked line	3.27	July 2013	Walked line
Goorooyarooo Nature Reserve	2.17	Sept 2009	Pellet count	2.08	Feb 2013	Walked line	1.18	July 2013	Walked line
Gungaderra Nature Reserve (KMU)	-	-	-	-	-	-	1.92	Sept 2013	Sweep count
Jerrabomberra East Nature Reserve	3.05	Oct 2009	Direct count	2.67	Dec 2012	Pellet count	4.54	July 2013	Pellet count
Kangaroo exclosure	same as reserve	-	-	0	Dec 2013	Direct count	0.8	July 2013	Direct count
Jerrabomberra West Nature Reserve	1.19	Aug 2009	Pellet count	1.74	Feb 2013	Walked line	2.47	Jan 2014	Pellet count
Kangaroo exclosure	same as reserve	-	-	0.33	Feb 2013	Direct count	0.33	Dec 2013	Direct count
Kama Nature Reserve	1.4	Sept 2009	Sweep count	1.29	March 2013	Sweep count	0.86	July 2013	Pellet count
Majura Nature Reserve	-	-	-	-	-	-	0.93	Oct 2013	Pellet count
Mt Painter Nature Reserve (KMU)	-	-	-	-	-	-	2.26	Aug 2013	Sweep count
Mulangarri Nature Reserve (KMU)	1.05	Oct 2009	Direct count	1.24	Jan 2013	Direct count	1.37	June 2013	Direct count
North Mitchell Nature Reserve	0	Oct 2009	Direct count	0.04	Oct 2012	Direct count	0.04	Oct 2013	Direct count
Pinnacle Nature Reserve (KMU)	-	-	-	-	-	-	1.77	Aug 2013	Sweep count
St Mark's Cathedral	0	-	-	0	-	-	0	-	-
Wanniassa Hills Nature Reserve (KMU)	1.27	Sept 2009	Pellet count	4.23	Feb 2013	Walked line	3.62	June 2013	Walked line
Yarramundi Reach	0	-	-	0	-	-	0	-	-

KMU = kangaroo management area

At Jerrabomberra East and West Nature Reserves, the 2009 vegetation surveys were conducted in late November and early December, one and three months respectively after the construction of the two exclosures (see Section 2.3). Given the short period of time following removal of kangaroo grazing pressure, these 2009 surveys are considered to be representative of the conditions prior to fence construction, with the same kangaroo densities as estimated for the surrounding reserve.

Descriptions of the different methods for estimating kangaroo densities can be read in the Kangaroo Management Plan (TaMS 2010).

3.3 Floristic and vegetation condition measurements

A range of detailed measurements relating to species diversity and vegetation condition were recorded at each of the 20 x 20 m survey plots. The data sheets for recording this information in the field are included in Appendix B .

- **Floristics**: All vascular plant species present within the survey plot were recorded to species level if identification in the field was possible, otherwise to genus level.
- **Cover**: Each taxa recorded - both native and exotic - was assigned a cover value based on a modified Braun-Blanquet scale (Table 5).

Table 5: Cover abundance values (based on a modified Braun-Blanquet scale) assigned to taxa recorded in the survey plots.

VALUE	ABUNDANCE/COVER
5	Any number, with cover >75 %
4	Any number, with cover 50 – 75 %
3	Any number, with cover 25 – 50 %
2	Any number, with cover 5 – 25 %
1	Numerous, with cover < 5 %, or scattered with cover up to 5 %
+	Few (approximately 4-15 plants), with cover <5%
r	Solitary (approximately 1-3 plants), with cover <5%

- **Indicator species**: Prior to the commencement of the first survey, twenty-five species were selected as 'Indicator Species' (distinct from the indicator species used in the FVS; see Section 3.6.1 below), considered to be indicators of high grassy ecosystem quality (Table 6). The number of individual plants of each species was recorded in two 1 metre wide belt transects located along two sides of the 20 x 20 survey plot (sides T1 and T3; see Appendix A for survey plot layout). Where the number of individuals of any one taxon exceeded 100, a value of $\geq$ 100 was recorded. These 25 species were considered to be sufficiently common enough to detect year to year and site to site changes, yet also not too numerous or common that it would be overly time consuming to count individual plants.
- **Step-point transects**: Broad composition and structural data was collected from a 100 metre step-point transect, running away from the survey plot from the star picket located between the plot sides T1 and T4 (see Appendix A for survey plot layout). The method was described in Armstrong (2013; pg. 5) as follows:

> *"This method involves recording the life form at intercept points along the linear transect such as the toe of a boot (when striding along a transect) or each metre mark. For this study, the toe-of-boot method was used to record composition at intercept points between the permanent star-picket marker of the survey plot and the permanent star-picket transect marker 50 m from the*

plot. To allow for over 100 samples in a transect, this is repeated for a further five steps (or metres) left or right of the transect marker, and returning back to the survey plot. A record of the relative composition of perennial native grass, other native, cryptogam (moss/lichen), bare earth, rocks, litter/dead vegetation, annual exotic grass, perennial exotic grass or exotic broadleaf is recorded at each intercept point, and tallied to surmise a percentage value of the site... the toe-of-boot method allows for a rapid appraisal across a larger area."

Table 6: List of indicator species selected for the study.

SPECIES	
Ajuga australis	*Leucochrysum albicans*
Arthropodium milleflorum	*Microseris lanceolata*
Dichopogon fimbriatus	*Microtis parvifolia/unifolia*
Austrostipa densofolia	*Pimelea curviflora*
Brachyscome heterodonta	*Ranunculus/Geranium spp.*
Bulbine bulbosa	*Scleranthus biflorus*
Burchardia umbellata	*Sorghum leiocladum*
Calocephalus citreus	*Stackhousia monogyna*
Craspedia variabilis	*Stylidium graminifolium*
Dichelachne spp.	*Swainsona spp.*
Eryngium ovinum	*Thysanotus tuberosus*
Goodenia pinnatifida	*Wurmbea dioica*

- **Understorey vegetation structure:** In 2009, the point-centred quarter method (Tongway & Hindley 2004) was used to collect data on understorey vegetation structure. However, this method was discarded for the 2012 survey because it was time consuming and was not providing the desired results (Armstrong 2013). A new method, called the 2D Line-intersect Structure Method (LiSM), was developed to rapidly capture data on grassland structure at each survey plot , described in Armstrong (2013; pg. 5) as follows:

  "Data was collected at intervals (or points of change ≥ 2cm in length) along a 5m measuring tape across a floristically and structurally representative transect within the survey plot. Variations of greater than 2cm in width were recorded, allowing for 250 samples within each 5m transect. Information was recorded at points along the measuring tape when there was a change in height category, and/or growth form (native grass, forb, sedge, rush, fern, shrub, bare earth, rock, cryptogam, leaf litter, woody debris, other). This detail was summarised to provide information on mean grassland height, mean width of height category per growth form, portion of native versus exotic cover and number and size of inter-tussock spaces (and whether they are bare or covered with cryptogams or litter)... Information was also collected on mean tussock shape for each height category for native grasses, information which may be useful for projects where tussock structure is of interest (e.g. Grassland Earless Dragon Tympanocryptis pinguicolla *habitat studies)."*

The LiSM was continued in 2013. The data was collected along two 5 metre long transects in each survey plot, with the location selected based on a floristically and structurally representative transect within the plot (Armstrong 2013). Transects were placed in different locations within each plot in the two years. Full methods are provided in Appendix C .

- **Rapid assessment of survey plot characteristics**: Basic information on the characteristics of each survey plot was collected in 2009 and 2012. This included data on the dominant species present in the survey plot and surrounding area within each vegetation stratum, the plot structural formation (e.g. grassland, secondary grassland, or woodland), and evidence of introduced or native grazers. This data remained relatively constant between years, and hence for the 2013 surveys this data was checked for each survey plot and not repeated if there were no differences from the 2012 surveys. However, the rapid assessment was completed for the new survey plots established in 2013.

3.4 Notes on plant species names

In this report, the following plant species names are adopted:

- *Themeda triandra* (syn. *Themeda australis*)
- *Rytidosperma* spp. (formerly *Austrodanthonia* spp.)
- *Xerochrysum viscosum* (formerly *Bracteantha viscosa*)

In the ACT, at least twenty species of *Rytidosperma* are listed as occurring (Lepschi, Mallinson & Cargill 2012), many of which require detailed examination of flowers to identify. During most surveys, it was too difficult to determine the number different *Rytidosperma* species and their identity due to lack of flowering; hence, in most cases these are identified to the genus level only. It should be noted that by lumping these commonly-occurring native grasses, actual native species richness is likely to be underestimated. However, consistency in lumping across years and surveys should result in a relatively uniform under-estimation.

Other species that were almost always identified to genus level only include: *Wahlenbergia*, *Aira*, *Bromus*, *Avena* and *Juncus*.

3.5 Issues with the 2D Line-intersect Structure Method

Exploratory data analysis revealed several issues with the quality and consistency of the data collected using the LiSM, particularly in 2012. For these reasons, only the 2013 data will be used in the analysis. These issues are discussed further in Section 5.5.3.

3.6 Data analysis

3.6.1 RESPONSE VARIABLES

A range of response variables were calculated for each survey plot that relate to species richness, diversity and vegetation condition (Table 7).

Calculation of the Floristic Value Score (FVS)

Numerous indices have been developed to quantify species diversity, many of which take into account both species richness or number as well as the relative abundance of species (Krebs 1994). In this study, diversity was estimated with a locally-developed metric called the Floristic Value Score (FVS).

Each survey plot was assigned a floristic value score (FVS), a relative quantitative value developed by Rehwinkle (2007) for grasslands and the ground layer of grassy woodlands in the region to indicate a site's conservation value. This value incorporates not only a site's species richness, but also the presence and abundance of significant species occurring in the Southern Tablelands region of New South Wales and the Australian Capital Territory. A site scores a higher value when there is the presence of rare 'indicator' species, which are mostly rare grazing-intolerant, or declining species (Rehwinkel 2007). A full list of these species is provided in the appendices of Rehwinkle (2007). According to Rehwinkle (2007; pg. 3):

> *"This method relies on three groupings of species, referred to as:*
>
> *1. Common or increaser species, which do not add much to the value of a site; these have a significance score of 1;*
>
> *2. "Indicator species, level 1", which indicate that the site has value; and*

3. "Indicator species, level 2", which are the highly significant species; these are the rarest of the grassy ecosystems species and have the highest significance scores.

The indicator species are also sometimes referred to as "grazing-intolerant" or "declining" species. It is thought that these species are rare for two reasons:

1. Some species have always been rare, particularly some species which are restricted in distribution; and

2. Many species are thought to have undergone serious declines since European settlement, from disturbances such as over-grazing and application of fertilisers. This is based upon analysis of the data and observations of where such species still occur; the sites with the greatest concentrations of significant species today include cemeteries, road and rail reserves and sites such as travelling stock reserves and private land sites where grazing has been either non-existent or light."

A site that is given a score of 4 or more is considered to have moderate to high conservation values, and if the site is a natural grassland then it has values consistent with those defined for NTG (Rehwinkel 2007).

Table 7: Response variables relating to floristics and vegetation condition, and the method of calculation.

VARIABLE	CALCULATION
Native species richness	Number of native species recorded in survey plot.
Native forb richness	Number of native forbs recorded in survey plot; the 'grass-like' genera *Dianella* and *Lomandra* were excluded from this category.
Exotic species richness	Number of exotic species recorded in survey plot.
Floristic value score (FVS)	A value combining species richness and presence of significant grassland species; described above.
% inter-tussock space	Sum of the percentage cover of non-perennial grass categories recorded along the 100 m step-point transect; i.e. the 'space' available for plant growth between perennial grass tussocks. These categories are: bare ground, cryptogams, litter, annual exotic grass, exotic broadleaf, and other natives.
% native grass cover	The percentage of native grass cover recorded along the 100 m step-point transect.
% cover of tall vegetation (2013 only)	The mean percentage of vegetation in height classes 5 and 6 (>30 cm) across the two LiSM transects, excluding shrubs.
% cover of short vegetation (2013 only)	The mean percentage of vegetation in height classes 5 and 6 (<10 cm) across the two LiSM transects, excluding shrubs.
Number of individuals of indicator species	
- in total (including all species)	The total number of individual plants recorded out of the list of 25 indicator species along two 1 m wide and 20 m long belt transects.
- for each species individually	The number of individual plants recorded per indicator species along two 1 m wide and 20 m long belt transects.

3.6.2 PREDICTOR VARIABLES

The main predictor variables to be examined are given in Table 8. Survey plots within a site receive the same kangaroo density, as this was measured at the site level.

Table 8: Predictor variables calculated at the site level and survey plot level.

VARIABLE	LEVEL	VARIABLE TYPE	CATEGORIES
Kangaroo density	Site	Continuous	N/A
Vegetation structure	Plot	Categorical	NTG Secondary grassland Woodland

Vegetation structure: NTG, secondary grassland and woodland

Structure at the plot level was determined *a priori* as either NTG, secondary grassland or woodland. Whether a plot was secondary grassland or NTG was determined based on knowledge of the area's history, and any evidence of clearing. For example, presence of tree stumps suggests that a plot is likely to be secondary grassland (cleared grassy woodland), rather than NTG.

An ordination of all plots across all years, based on species presence/absence, showed that the plots largely clustered together based on their pre-determined structure type (non-metric multidimensional scaling [NMDS], stress = 0.29; first two axes shown in Figure 7). Despite secondary grassland plots being largely devoid of trees, these plots remained more similar to woodland plots in terms of their species composition, compared to NTG plots (Figure 7), indicating strong support for the *a priori* assessment of structure.

However, the NMDS does indicate some degree of overlap between structure types, with many sites falling along a fuzzy boundary between NTG and the woodland/secondary grassland group. This is likely an indication of the continuous nature of the gradient between grasslands and woodlands, with these different vegetation structures often intergrading, particularly on slopes. Some sites also appeared to be outliers, which could suggest that either their *a priori* classification may need to be reconsidered, or that these plots fall at the extremes of either grassland or woodland vegetation, based on species composition. For example, plot 04 at Dunlop NR in 2009 (classified as woodland), and plot 01 at Broadcast Australia in 2009 (classified as secondary grassland), both clustered with NTG sites. In contrast, plot 04 at Kama NR (classified as NTG) clustered with the woodland/secondary grassland group for each of the three years it was surveyed (Figure 7).

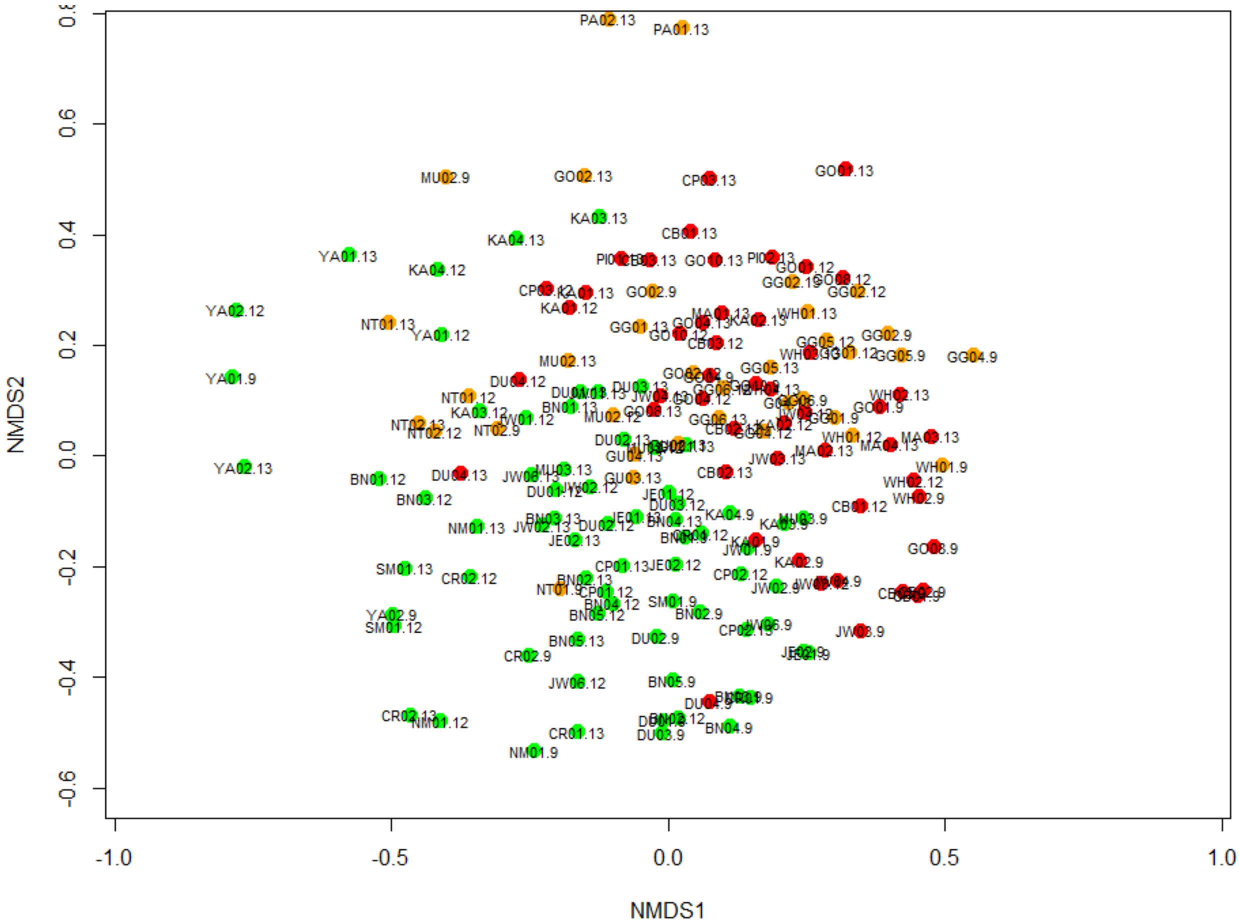


Figure 7: NMDS showing distribution of sites across all years based on species presence/absence. Sites are coloured by pre-determined vegetation structure type. Green = natural temperate grassland, red = woodland, and orange = secondary grassland. Site codes: BN = Belconnen Naval Transmission Station; CB = Callum Brae Nature Reserve; CP = Campbell Park; CR = Crace Nature Reserve; DU = Dunlop Nature Reserve; GG = Googong Foreshores; GO = Goorooyaroo Nature Reserve; GU = Gungaderra Nature Reserve; JE = Jerrabomberra East Nature Reserve; JW = Jerrabomberra West Nature Reserve; KA = Kama Nature Reserve; MA = Majura Nature Reserve; MU = Mulangarri Nature Reserve; NM = North Mitchell; NT = Broadcast Australia; PA = Mt Painter Nature Reserve; PI = The Pinnacle Nature Reserve; SM = St Mark's Cathedral; WH = Wanniassa Hills NR; YA = Yarramundi Reach. The figures after the site codes are the survey plot number, followed by the year of survey (09, 12 or 13).

3.6.3 DATA EXPLORATION AND ANALYSIS

This study examines correlations between field measurements recorded at survey plots located within sites with different kangaroo densities. Due to the non-experimental nature of the study design, several considerations need to be taken into account for statistical analyses.

Firstly, measurements of the same survey plot in different years need to be considered as 'repeated measures', rather than as independent observations (Gurevitch & Chester 1986). In particular, measurements taken at the same plot in different years are likely to be more similar to one another than to measurements taken at a different plot. Furthermore, measurements taken at closer time intervals (e.g. 2012 compared to 2013) may be more highly correlated than those taken at more distance time intervals (e.g. 2009 compared to 2013).

To address this issue, patterns between kangaroo density and vegetation response variables were examined within each year separately. In addition, as an alternative approach to examining year to year differences, the relationship between kangaroo density and vegetation response variables were also investigated as the changes within a single time period, i.e. between 2009 and 2012, and between 2012 and 2013.

Secondly, plots measured within the same site are also likely to be more correlated with one another compared to plots within a different site (Figure 8). The main predictor variable, or the 'treatment' variable, (i.e. kangaroo density) is also applied at the site level, rather than at the plot level (Figure 8). Thus plots located within a site are spatially closer to one another that to plots located at different sites (e.g. see Figure 5), as well as experiencing the same kangaroo density level. This means that the level of replication of the response variables (e.g. species richness) should also be calculated at the site level.

Measurements recorded from multiple plots within a site were therefore averaged, and statistical analyses performed on the average site-level value. However, differences between vegetation structure (i.e. NTG, secondary grassland and woodland) are also of interest in this study; particularly woodland versus grassland ecosystems (see Section 1.4.1). Therefore, if a site contained more than one vegetation structure type (e.g. Figure 8b), average site-level measurements were separated for NTG, secondary grassland and woodland plots. As such, all data points (i.e. observations) are the mean values of survey plots within a vegetation structure type, within a site (Figure 8).

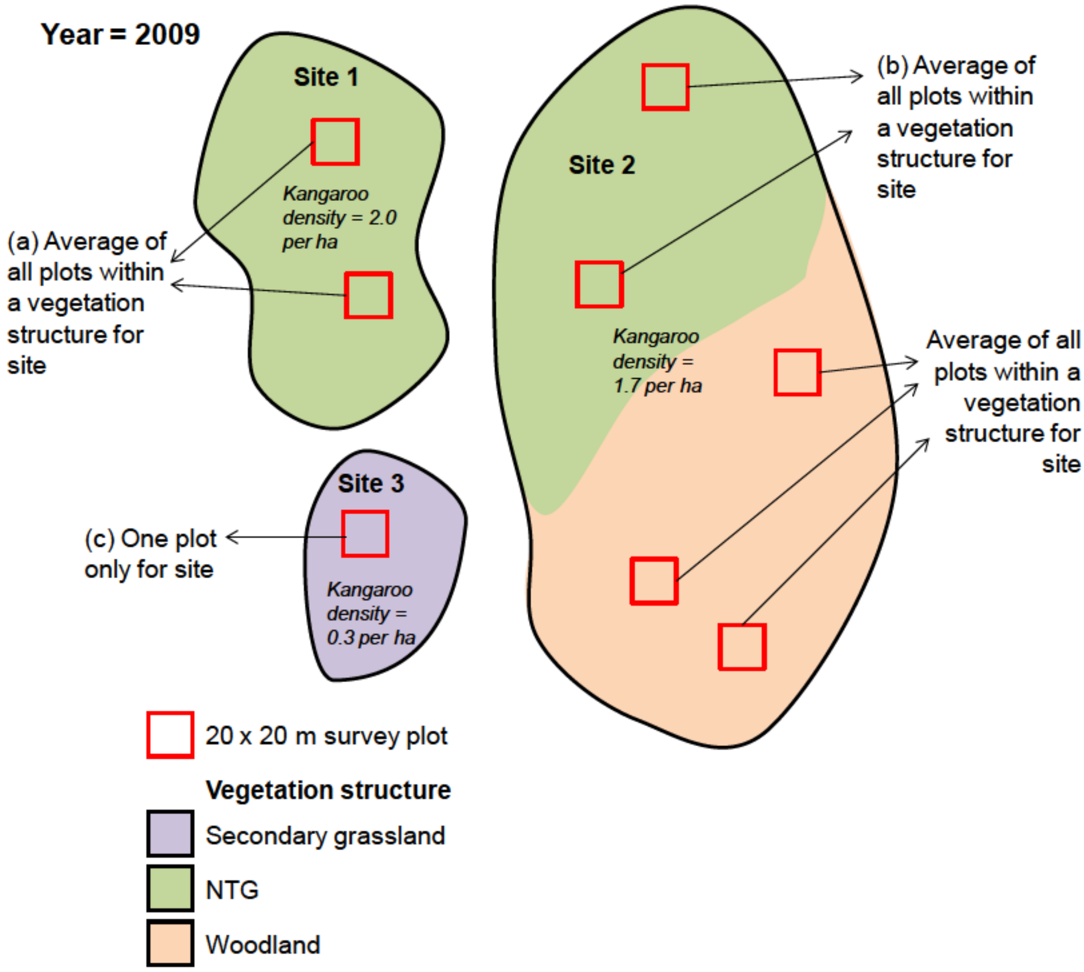


Figure 8: Stylised diagram of sites and survey plots, indicating the calculation of average plot values (e.g. native species richness) within each vegetation structure type for a site. Measurements of the same plot/site in different years are repeated measurements, rather than independent observations. Site 2 will have two data points, one for each vegetation type, and these two data points will have the same kangaroo density value.

The first two research questions were addressed through exploratory techniques including summary statistics, scatter plots, bar charts, and box-and-whisker plots. Box-and-whisker plots are particularly useful for graphical presentation of variables as they are robust to being skewed by non-normally distributed data, and clearly display the distribution of data points, including the median value and the 25% quartiles, as well as identifying outliers (Quinn & Keough 2002).

To address the third research question, several analyses were performed to examine the effects of:

1. Kangaroo density (the main predictor variable of interest);

2. Potential differences in the relationship between kangaroo density and vegetation condition across vegetation structure types (NTG, secondary grassland, and woodland), given their different floristic composition (Figure 7) and overstorey structure (i.e. tree canopy) (e.g. Section 1.4.1);

3. Potential differences between years.

Firstly, comparisons of changes within two time intervals were undertaken separately: (a) 2009-12 and (b) 2012-13. This approach avoids the temporal correlation between measurements taken at the same survey plot in different years. For each time period, the percentage change in each of the main vegetation response variables was calculated (i.e. native species richness, FVS, exotic species richness, native forb richness, inter-tussock space and native grass cover). Scatter plots were then used to examine the relationship between the percentage change in vegetation response and the corresponding change in kangaroo density, considered as both a percentage change and as the raw numbers. Any evidence of a relationship was examined further with linear regression models.

This data is also presented in separate tables for each site to enable a more thorough understanding of changes at individual sites.

Secondly, Analyses of Covariance (ANCOVA) and Generalised Additive Models (GAMs) were used to examine the relationship between each of the main vegetation response variables and the two main predictor variables: kangaroo density and vegetation structure type, with separate analyses conducted for the three years of the study (2009, 2012 and 2013). ANCOVAs were performed to test for any significant interaction between kangaroo density (the *covariate*) and vegetation structure type (the *factor*, with three levels: NTG, woodland and secondary grassland). A significant interaction between these two predictor variables indicates that the relationship between kangaroo density and the vegetation response variable depends on whether vegetation type is NTG, woodland or secondary grassland.

If a significant interaction was found, then the relationships between response variables and kangaroo densities were examined for each vegetation type separately. However, if no significant interaction was identified, then all observations were pooled across all vegetation structure types.

ANCOVAs test for linear relationships between the variables. However, the relationships between kangaroo density and vegetation response variables may not necessarily be linear; for example, the IDH predicts a humped-shape relationship between diversity and disturbance. As such, fitting a linear model may not necessarily be an appropriate description of the relationship (Quinn & Keough 2002). After testing for any interaction between kangaroo density and vegetation structure, two analyses were therefore performed: a standard linear regression followed by a GAM. GAMs allow the fitting of smooth curves to the data without the *a priori* assumption of a particular response curve shape (Zuur *et al.* 2009). For some response variables, the linear regression was a better fit to the data, as assessed by model goodness of fit (R^2). The degree of smoothing for each GAM fit was determined by the gam function's default method, except for several response variables where the degree of smoothing was explicitly specified to eliminate a tendency for the model to overfit the data.

The *P* level for statistical significance was set at 0.05, with values between 0.05 and 0.08 being described in the results as 'marginally significant'. In the latter cases there is a higher probability of a false rejection of the null hypothesis (i.e. that there is *no relationship between the variables*), also known as a Type I error. It is also important to note that statistical significance does not necessarily imply biological significance, and even when a statistical relationship is present, predictive power may be very low. Consequently, 95% confidence intervals for relationships are provided graphically where possible. The issue of using the statistical models for prediction is more thoroughly explored in the Discussion.

All analyses were conducted using R, the free software environment for statistical computing and graphics (R Development Core Team 2009). Packages used included lattice (Sarkar 2008), vegan (Oksanen *et al.* 2009), mgcv (Wood 2011) and ggplot2 (Wickham 2009).

4 Results

4.1 Question 1: How have kangaroo densities changed spatially and temporally?

Kangaroo densities at a site ranged between zero and 4.54 kangaroos per hectare (Figure 9). Two sites had no kangaroos recorded in any year: Yarramundi Reach and St Mark's Cathedral. North Mitchell had no kangaroos present in 2009 and just one kangaroo (a male) at a density of 0.04 per hectare in 2012 and 2013.

At most sites in most years less than three kangaroos per ha were recorded. There were only five occasions where more than three kangaroos per ha were recorded (Figure 9):

- Wanniassa Hills NR in 2012 and 2013;
- Googong Foreshores in 2013;
- Jerrabomberra East NR in 2009, and
- Jerrabomberra East NR outside of the exclosure in 2013, which was the highest density recorded in any survey (4.54 kangaroos per ha).

Some sites have active kangaroo management to either maintain or reduce kangaroo densities from year to year.

There was no consistent change in kangaroo density between years in sites that were surveyed in multiple years (Table 9). For example, at Callum Brae NR there was very little change in density between 2009-12 and 2012-13. At some sites density increased across both time periods (e.g. Jerrabomberra West NR, Broadcast Australia, Crace NR and Mulangarri NR), whereas in other sites it declined (e.g. Kama NR and Goorooyaroo NR). At other sites, density declined across one time period but increased across the other (e.g. Wanniassa Hills NR, Jerrabomberra East NR, Belconnen Naval Transmission Station and Dunlop NR).

Several sites experienced relatively large year-to-year fluctuations in kangaroo density, shown here as outliers that fall outside 1.5 times the range of the spread between the 25% and 75% quartiles (Figure 10). At Wanniassa Hills NR density increased by 3 kangaroos per ha – a greater than 200% increase – between 2009 and 2013 (Figure 10a,c), while at Belconnen Naval Transmission Station density increased by 1.3 kangaroos per ha – an almost 100% increase – between 2009 and 2012 (Figure 10a,c). Changes at most other sites were less than ca. 0.5 kangaroos per ha (Table 9; Figure 10). The two kangaroo exclosures at Jerrabomberra East NR and Jerrabomberra West NR experienced the largest declines of any site in kangaroo densities between 2009 and 2012 (Figure 10a,c).

Between 2012 and 2013, Jerrabomberra East NR (outside of the exclosure) experienced a relatively large increase in raw kangaroo density (Figure 10b), although in terms of the percentage change in density it was not an outlier (Figure 10d). Similarly, Goorooyaroo NR and Belconnen Naval Transmission Station both experienced a relatively large decline in kangaroo density between 2012 and 2013 (Figure 10b), although not in percentage terms (Figure 10d).

It could be hypothesised that those sites that experienced relatively large changes in kangaroo density may also undergo relatively large changes in vegetation condition and plant species diversity, relative to sites where kangaroo numbers changed little.

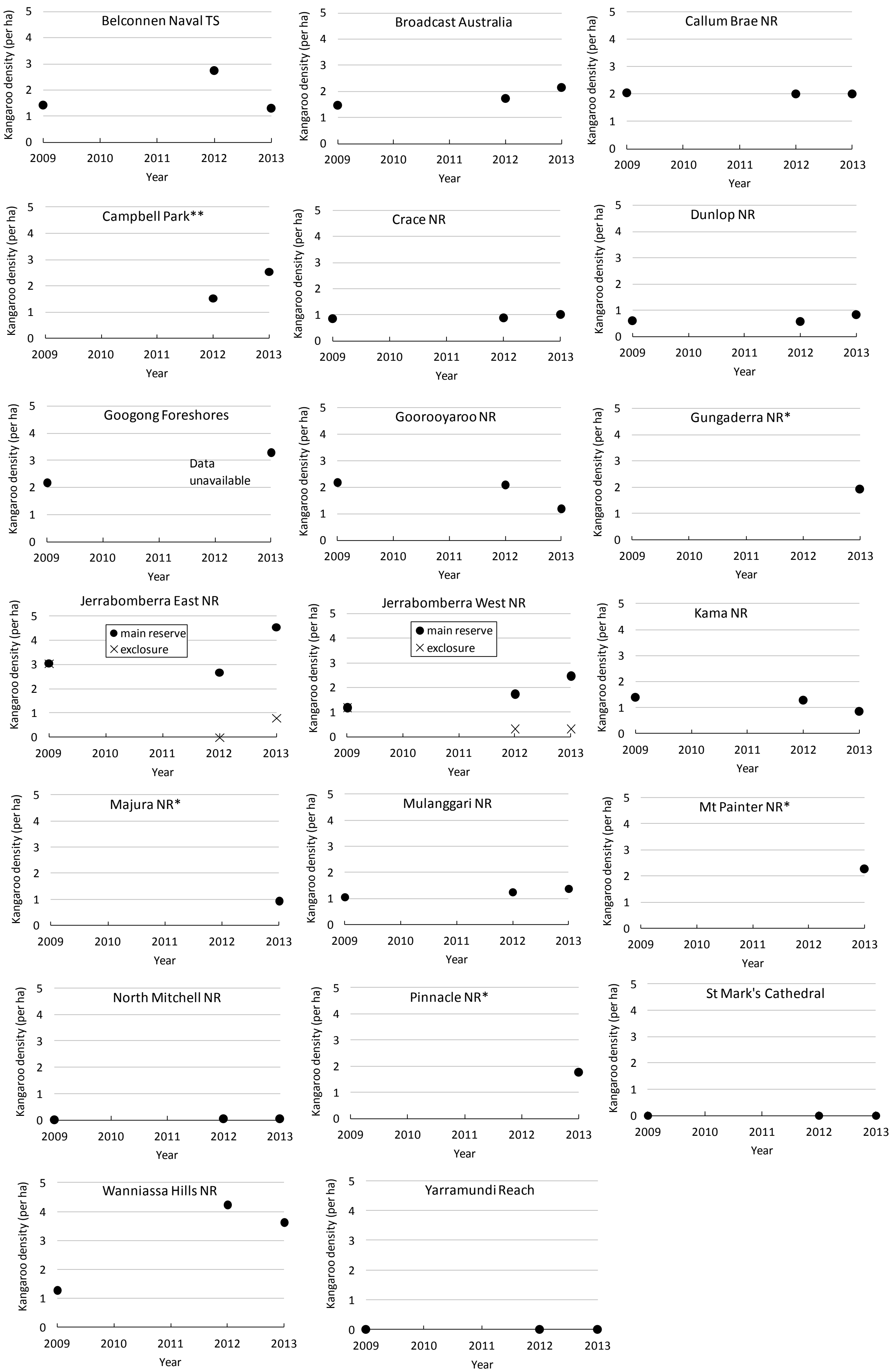

Belconnen Naval TS
Broadcast Australia
Callum Brae NR
Campbell Park**
Crace NR
Dunlop NR
Googong Foreshores
Data unavailable
Goorooyaroo NR
Gungaderra NR*
Jerrabomberra East NR
main reserve
exclosure
Jerrabomberra West NR
main reserve
exclosure
Kama NR
Majura NR*
Mulanggari NR
Mt Painter NR*
North Mitchell NR
Pinnacle NR*
St Mark's Cathedral
Wanniassa Hills NR
Yarramundi Reach
Kangaroo density (per ha)
Year
2009
2010
2011
2012
2013
0
1
2
3
4
5

Figure 9: (previous page) Comparison of kangaroo densities between surveys conducted in 2009, 2013 and 2013.* sites surveyed only in 2013. ** site surveyed only in 2012 and 2013. Densities are presented with the same x-axis for ease of comparison.

Table 9: Year to year changes in kangaroo densities at sites surveyed in multiple years. Sites are listed in descending order of average percentage change across the two time periods. Actual densities can be seen in the previous figure (Figure 9) and also in Table 4 on page 11.

	Year to year change in kangaroo densities		Year to year percentage change in kangaroo densities	
SITE	2009-12	2012-13	2009-12	2012-13
Wanniassa Hills NR	2.96	-0.61	233.1	-14.4
Campbell Park *(surveyed in 2012 and 2013 only)*	NA	1.01	NA	66.0
Jerrabomberra West NR (main reserve)	0.55	0.73	46.2	42.0
Jerrabomberra East NR (main reserve)	-0.38	1.87	-12.5	70.0
Broadcast Australia	0.26	0.42	17.7	24.3
Dunlop NR	-0.03	0.26	-5.0	45.6
Belconnen Naval Transmission Station	1.32	-1.44	93.0	-52.6
Mulangarri NR	0.19	0.13	18.1	10.5
Crace NR	0.03	0.13	3.5	14.8
North Mitchell	0.04	0	ca. 0.0	0.0
St Mark's Cathedral	0	0	0.0	0.0
Yarramundi Reach	0	0	0.0	0.0
Callum Brae NR	-0.04	0	-2.0	0.0
Kama NR	-0.11	-0.43	-7.9	-33.3
Goorooyaroo NR	-0.09	-0.9	-4.1	-43.3
Jerrabomberra West NR (exclosure)	-0.86	0	-72.3	0.0
Jerrabomberra East NR (exclosure)	-3.05	0.8	-100.0	-

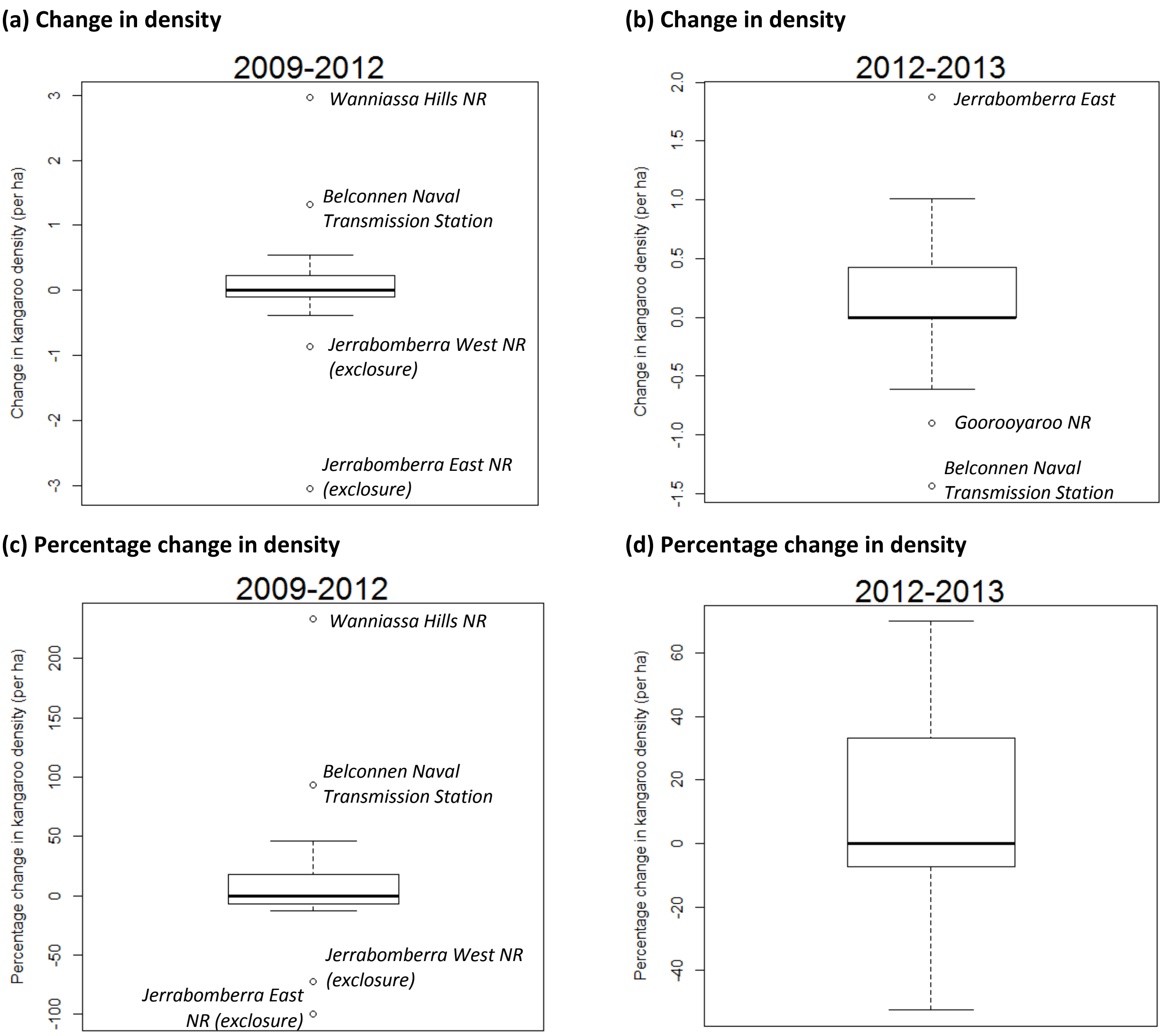


Figure 10: Box-and-whisker plots illustrating the distribution of site-level kangaroo density changes between 2009-2012 and 2012-13, showing the median (indicated by the thick black line), the spread between the 25% and 75% quartiles (indicated by the ends of the boxes), values that fall within 1.5 times the spread (indicated by the length of the whiskers), and outliers (data points that are greater than 1.5 times the spread). (a) Change in density between 2009 and 2012; (b) Change in density between 2012 and 2013; (c) Percentage change in density between 2009 and 2012; (d) Percentage change in density between 2012 and 2013. Outliers are labelled.

4.2 Question 2: How has vegetation condition changed spatially and temporally?

4.2.1 COMPARISON OF VEGETATION STRUCTURE TYPES AND YEARS

Patterns in native species richness, FVS, native forb richness and exotic species richness between years and between vegetation structure type (NTG, woodland and secondary grasslands) are presented as box-and-whisker plots in Figure 11.

In 2009, native species richness was similar among vegetation types, with median values ranging between 21 (in NTG) and 27 (in secondary grasslands). Variability was greatest among NTG plots (Figure 11a). In

2012 and 2013, native species richness tended to be higher in secondary grasslands and woodlands than in NTG (Figure 11b-c). Yarramundi Reach was an outlier in 2012 and 2013, with native species richness relatively low compared to other NTG sites.

FVS was similar across vegetation types, although again median differences tended to be more pronounced in 2012 and 2013 (Figure 11d-f). Variability in FVS can be high; for example, in 2009 FVS ranged between 7 and 47 in NTG alone (Figure 11d). The NTG plot at Mulangarri NR was an outlier with high native species richness and FVS in 2012 (Figure 11b,e).

Native forb richness followed a similar pattern to native species richness, with a tendency to be higher in secondary grasslands and woodlands compared to NTG in 2012 and 2013 (Figure 11g-i). There were a number of outliers in all three years; Yarramundi Reach was again an outlier with low native forb richness in NTG plots in 2012 and 2013.

Exotic species richness tended to be similar across vegetation types in 2009, with median values ranging between 11.9 and 13.8. Variation across sites was low except in NTG; Kama NR contained 18 exotic species (Figure 11j). Exotic species richness tended to rise in 2012 and 2013, particularly in woodlands in 2012, with a median value of 19 species (Figure 11k).

Patterns in inter-tussock space and native grass cover richness between years and between NTG, woodland and secondary grasslands are presented as box-and-whisker plots in Figure 12. These are measurements recorded along the step point transect.

Inter-tussock space tended to be high in 2009, with median values of 49% (in NTG and secondary grasslands) and 58% (in woodlands) (Figure 12a). In comparison, median values in 2012 were lower, especially in NTG (26%), but also in secondary grasslands (42%) and woodlands (46%). A similar pattern was observed in 2013 although data for secondary grasslands were more variable. There were a number of outliers – in particular the NTG and woodlands plots at Dunlop NR, which had a relatively high percentage of inter-tussock space in 2013 (Figure 12c). This was driven by high percentages of exotic annual grass recorded at this site during 2013.

Native grass cover did not differ consistently across vegetation types, apart from a weak tendency for cover to be lower in woodlands than in NTG (Fig. 12d-f), but generally increased between 2009 and 2012-2013. In 2013 North Mitchell, the Pinnacle NR and Dunlop NR had low native grass cover compared to other sites (Figure 12f).

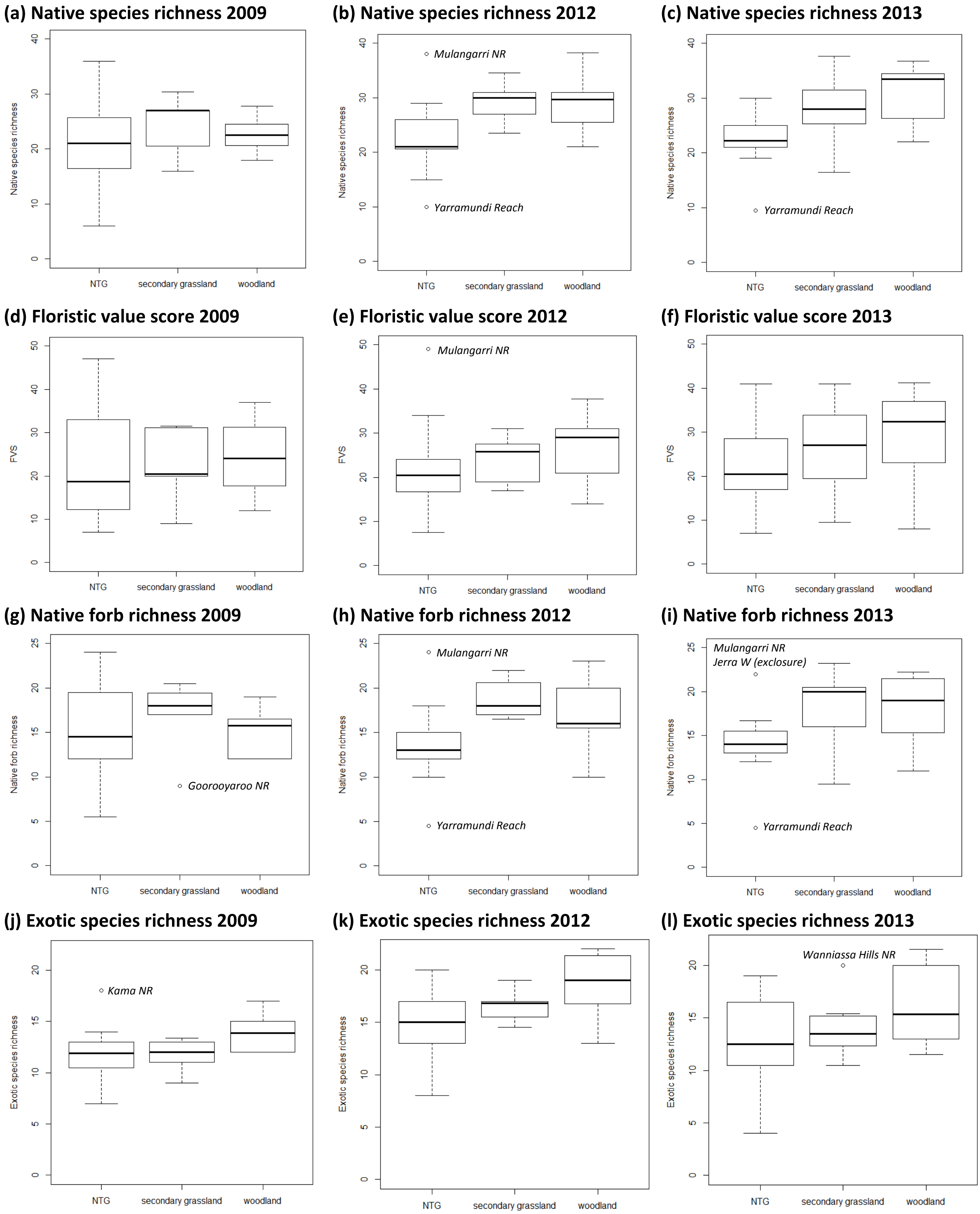


Figure 11: Box-and-whisker plots of (a-c) native species richness, (df) Floristic Value Score, (g-i) native forb richness and (j-l) exotic species richness, between years and vegetation structure, illustrating the median (indicated by the thick black line), the spread between the 25% and 75% quartiles (indicated by the ends of the boxes), values that fall within 1.5 times the spread (indicated by the length of the whiskers), and outliers (data points that are greater than 1.5 times the spread). Outliers are labelled.

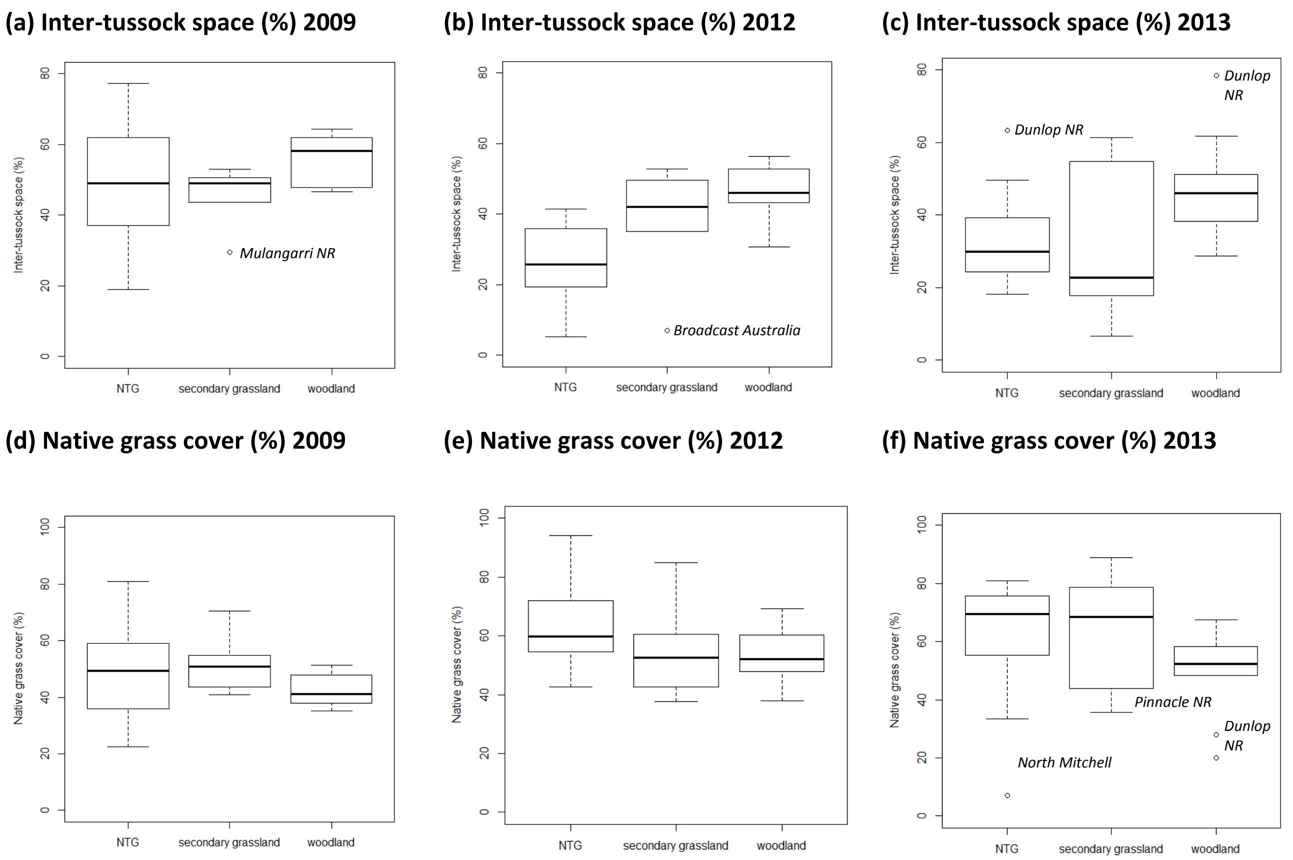


Figure 12: Box-and-whisker plots of (a-c) inter-tussock space and (d-f) native grass cover, between years and vegetation structure, illustrating the median (indicated by the thick black line), the spread between the 25% and 75% quartiles (indicated by the ends of the boxes), values that fall within 1.5 times the spread (indicated by the length of the whiskers), and outliers (data points that are greater than 1.5 times the spread). Outliers are labelled.

4.2.2 OVERVIEW OF INDICATOR SPECIES

Twenty-three indicator species were recorded over the three survey years (Table 10). Several genera (*Arthropodium, Ranunculus, Microtis, Geranium* and *Pterostylis*) contained more than one species or had individual plants identified only to genus; for each of these individuals were summed to produce total counts. The most frequently recorded species (i.e. identified to species level) were *Goodenia pinnatifida, Bulbine bulbosa, Eryngium ovinum* and *Wurmbea dioica* (Figure 13). These species will be the focus of further exploration.

Table 10: Total counts of indicator species, listed in order of most frequently recorded.

Species	2009	2012	2013	Total
Goodenia pinnatifida	1170	411	1068	2649
Bulbine bulbosa	567	307	1114	1988
Arthropodium sp.	67	283	1527	1877
Eryngium ovinum	606	137	345	1088
Wurmbea dioica	275	198	603	1076
Microtis sp.	474	77	0	551
Leucochrysum albicans	0	0	412	412
Stackhousia monogyna	117	18	268	403
Austrostipa densiflora	39	126	220	385
Ranunculus sp.	205	58	92	355
Calocephalus citreus	187	9	101	297
Geranium sp.	13	41	72	126
Microseris lanceolata	64	9	2	75
Rutidosis leptorrynchoides	0	0	39	39
Pimelea curviflora	0	0	39	39
Dichelachne sp.	23	1	11	35
Pterostylis sp.	0	0	12	12
Thelymitra sp	0	0	11	11
Trichoryne eliator	0	0	7	7
Craspedia variabilis	6	0	1	7
Dichopogon fimbriatus	3	0	0	3
Velleia paradoxa	0	0	1	1
Scleranthus biflorus	0	0	1	1
Total	3816	1675	5946	11437

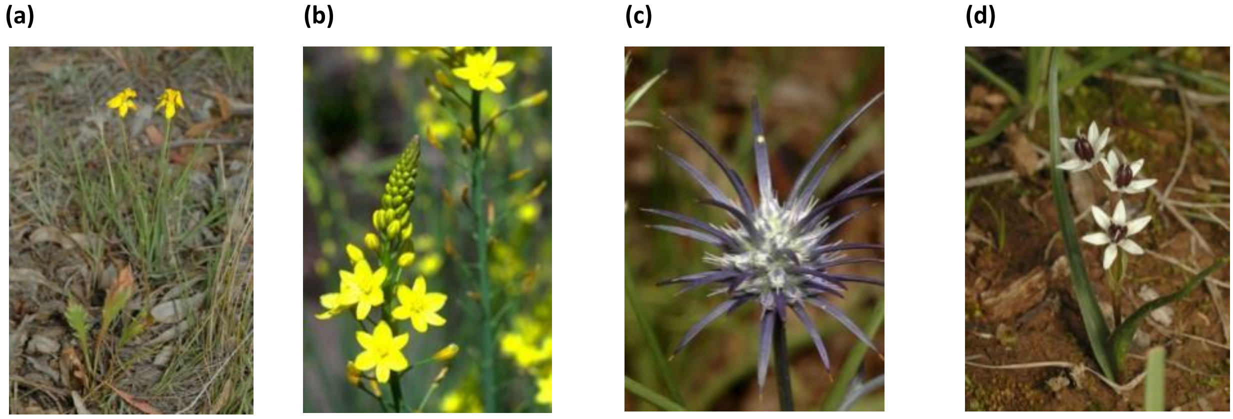


Figure 13: Four most common indicator species: (a) *Goodenia pinnatifida*; (b) *Bulbine bulbosa; (c) Eryngium ovinum* and (d) *Wurmbea dioica.* All images courtesy of the Australian National Botanic Gardens photographic collection (photographs by Murray Fagg).

Sites ranged from having zero to five different indicator species recorded in any one survey (Figure 14). The only site with zero indicator species was Callum Brae in 2009.

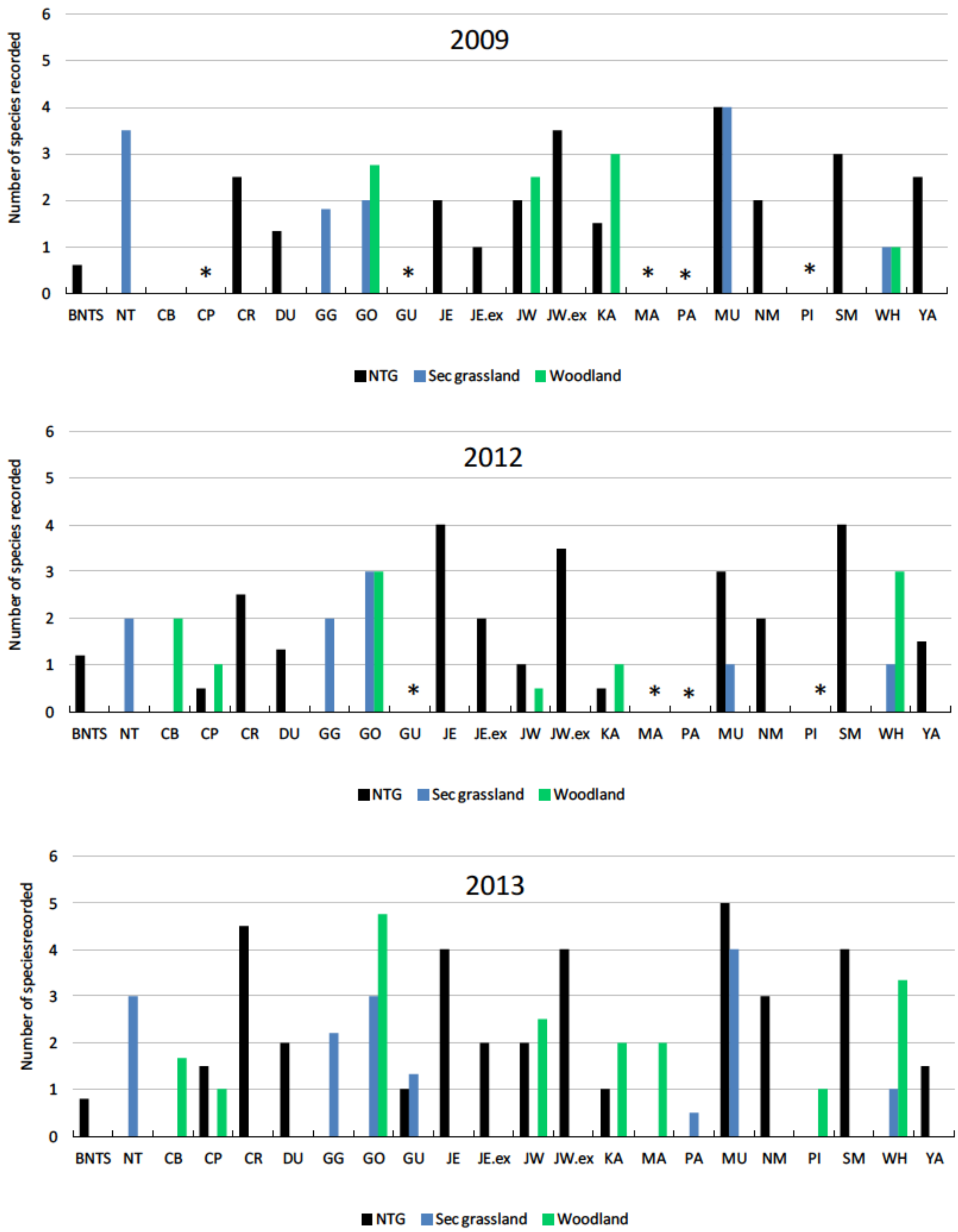


Figure 14: Comparison of the number of indicator species recorded at different sites; data are average number across survey plots within a vegetation structure type. Site codes: BNTS = Belconnen Naval Transmission Station; CB = Callum Brae Nature Reserve; CP = Campbell Park; CR = Crace Nature Reserve; DU = Dunlop Nature Reserve; GG = Googong Foreshores; GO = Goorooyaroo Nature Reserve; GU = Gungaderra Nature Reserve; JE = Jerrabomberra East Nature Reserve; JW = Jerrabomberra West Nature Reserve; KA = Kama Nature Reserve; MA = Majura Nature Reserve; MU = Mulangarri Nature Reserve; NM = North Mitchell; NT = Broadcast Australia; PA = Mt Painter Nature Reserve; PI = The Pinnacle Nature Reserve; SM = St Mark's Cathedral; WH = Wanniassa Hills NR; YA = Yarramundi Reach. ".ex" denotes the kangaroo enclosures. * = sites not surveyed.

The number of individuals recorded fluctuated from year to year (Figure 15). For example, very high numbers (in the 100s) were recorded at Mulangarri NR in 2009, with lower numbers in 2012 and 2013. This appeared to be largely driven by very high counts of *Microtis unifolia*, a common native terrestrial orchid, at two plots at Mulangarri NR in 2009. Consistently higher numbers were recorded across all sites in 2013, particularly compared to 2012.

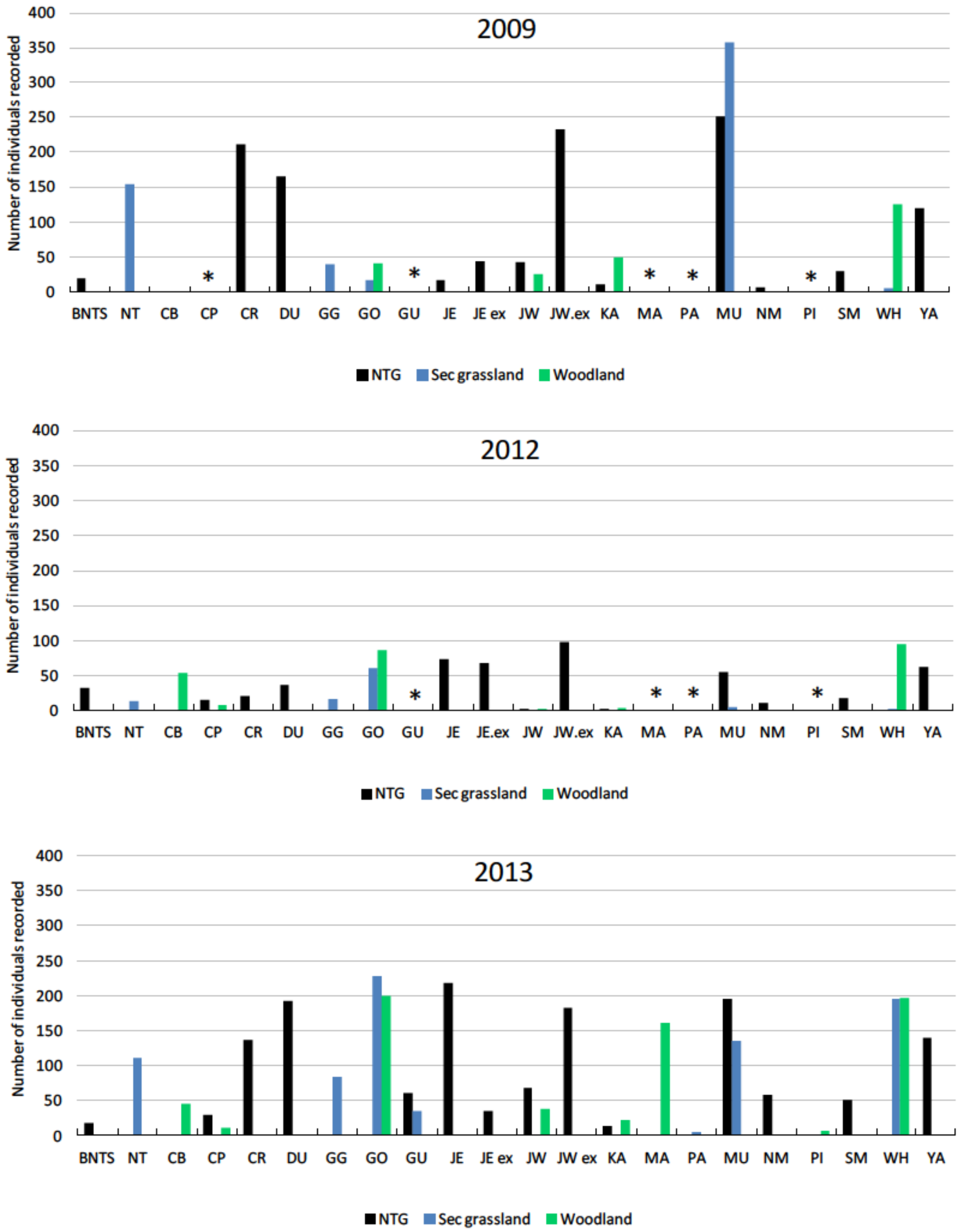


Figure 15: Comparison of number of individuals of indicator species recorded at different sites; data are average number across survey plots within a vegetation structure type. Site codes: BNTS = Belconnen Naval Transmission Station; CB = Callum Brae Nature Reserve; CP = Campbell Park; CR = Crace Nature Reserve; DU = Dunlop Nature Reserve; GG = Googong Foreshores; GO = Goorooyaroo Nature Reserve; GU = Gungaderra Nature Reserve; JE = Jerrabomberra East Nature Reserve; JW = Jerrabomberra West Nature Reserve; KA = Kama Nature Reserve; MA = Majura Nature Reserve; MU = Mulangarri Nature Reserve; NM = North Mitchell; NT = Broadcast Australia; PA = Mt Painter Nature Reserve; PI = The Pinnacle Nature Reserve; SM = St Mark's Cathedral; WH = Wanniassa Hills NR; YA = Yarramundi Reach. ".ex" denotes the kangaroo enclosures. * = sites not surveyed.

While *B. bulbosa* was recorded reasonably consistently across all vegetation types (NTG, secondary grasslands and woodlands), the other three most commonly-recorded species tended to be associated with a particular vegetation type(Figure 16). Specifically, *E. ovinum* and *G. pinnatifida* were recorded in higher numbers in NTG, while *W. dioica* was mostly associated with woodlands and secondary grasslands. However, during 2009 *W. dioica* was more evenly distributed across vegetation types (Figure 16).

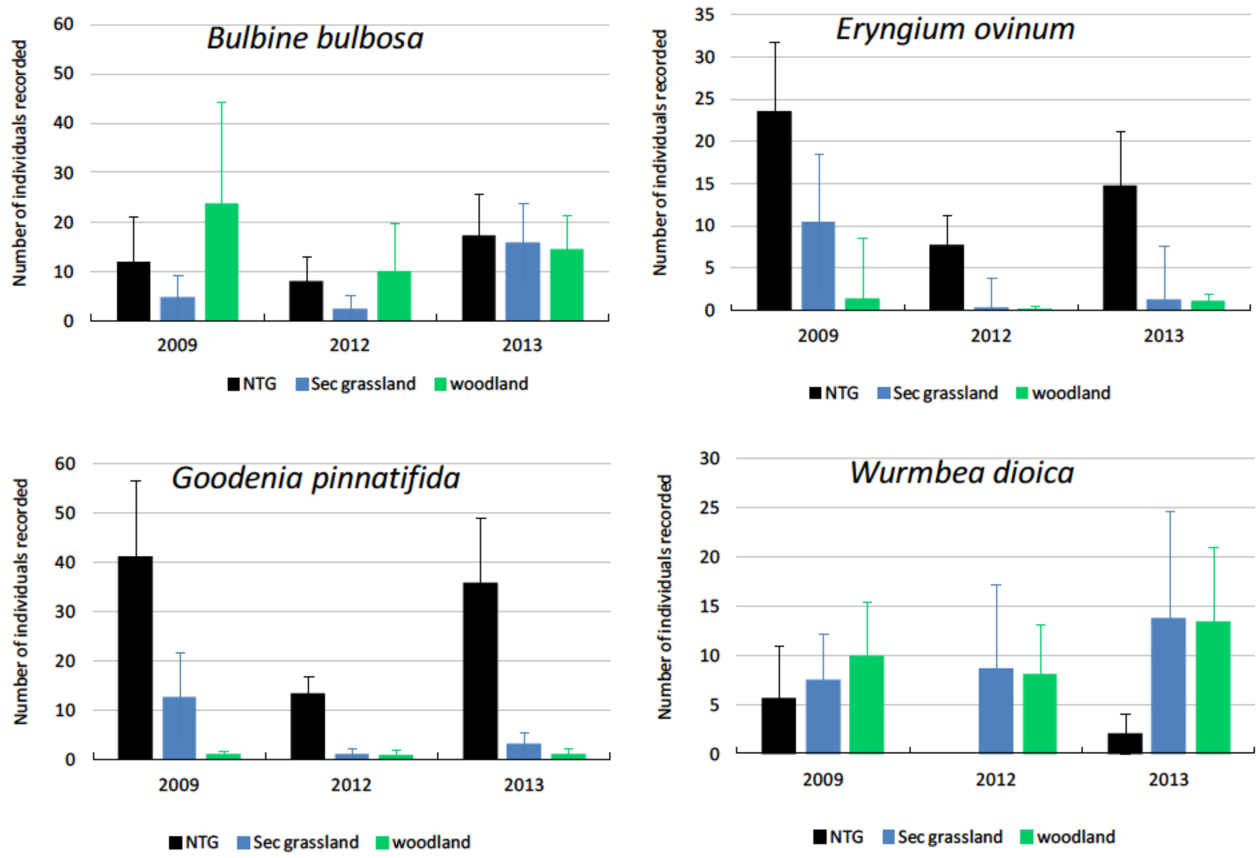


Figure 16: The four most common indicator species and their occurrence in different vegetation structures.

The four most common indicator species did not tend to be evenly distributed across the study region (Table 11), in many cases being recorded in less than half of all sites included in the survey.

Table 11: Percentage of sites that the four most common indicator species were recorded in.

SPECIES	% SITES RECORDED IN 2009	% SITES RECORDED IN 2012	% SITES RECORDED IN 2013
Bulbine bulbosa	47	50	55
Eryngium ovinum	65	61	50
Goodenia pinnatifida	71	61	55
Wurmbea dioica	35	22	41

Overall, the patchy distribution and limited occurrence of many of the indicator species makes it difficult to examine their relationships with kangaroo density. Even the four most commonly recorded species (*G. pinnatifida*, *B. bulbosa, W. dioica, and E. ovinum*) were either largely restricted to a particular vegetation type (e.g. *E. ovinum* and *G. pinnatifida* in NTG), or were recorded in less than half of the sites in any one survey year. In contrast, the total number of individuals – including all indicator species – was well distributed across sites, vegetation structure and years (although there was a considerably lower total count in 2012). As such, the following analyses examining the relationship between vegetation condition and kangaroo density will focus on total counts of all indicator species together.

4.3 Question 3: What relationships exist between vegetation condition and kangaroo density?

4.3.1 COMPARISON OF CHANGES WITHIN TIME INTERVALS

There was no clear relationship between the percentage change in vegetation response and change in kangaroo density in either of the two time intervals (i.e. between 2009 and 2012, nor between 2012 and 2013). This lack of relationship was evident when change in kangaroo density is considered in terms of both raw numbers and percentages (Figure 17-Figure 22).

In the previous section examining how kangaroo densities have changed spatially and temporally, it was hypothesised that "*those sites that experienced relatively large changes in kangaroo density may also undergo relatively large changes in vegetation condition and plant species diversity, relative to sites where kangaroo numbers changed little*" (pg. 20). The data presented below suggest otherwise. Instead, most sites experienced relatively small changes in kangaroo density, particularly in the first time interval (2009-12). However, the variation in corresponding vegetation response variables was often very large, varying from strongly negative to strongly positive. Those sites that did experience relatively large changes in kangaroo density did not consistently exhibit large changes in vegetation condition and plant species diversity.

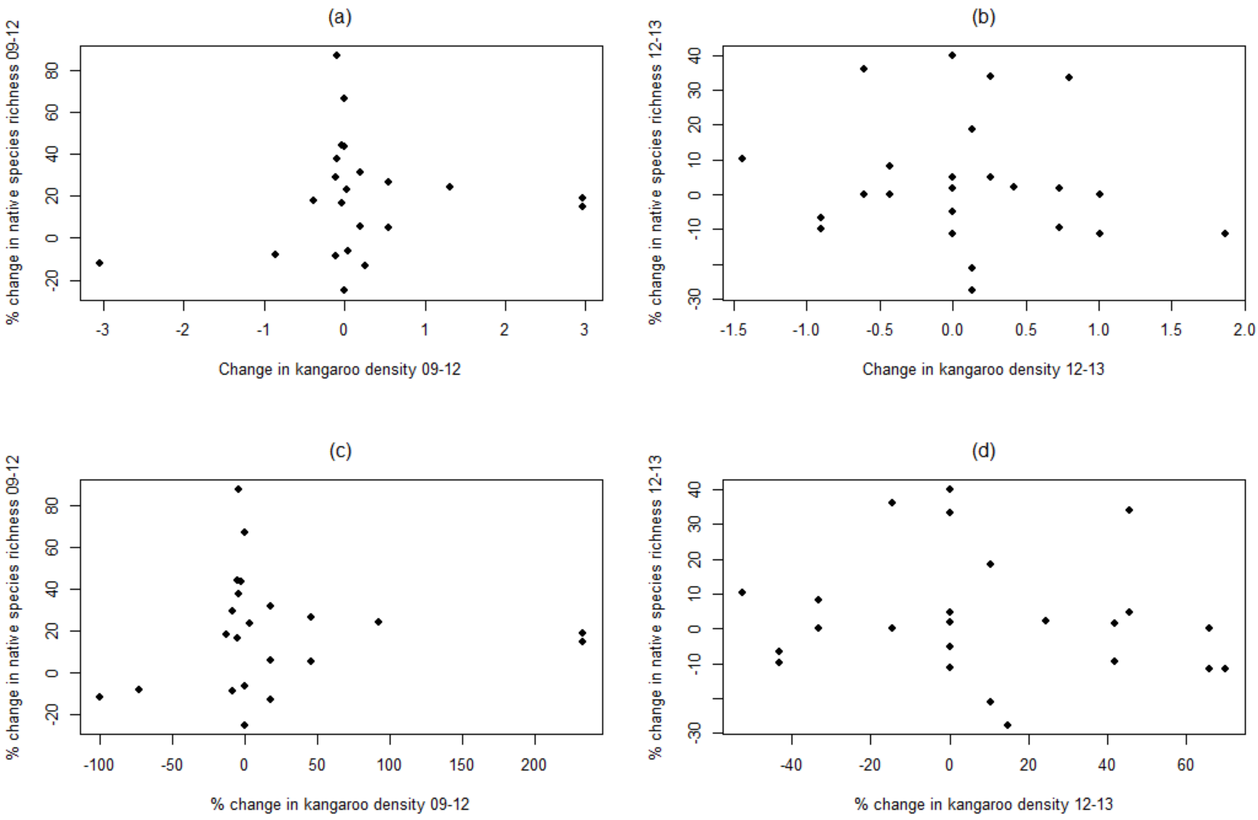


Figure 17: Comparison of the percentage change in native species richness with: (a) change in kangaroo density between 2009-2012; (b) change in kangaroo density between 2012-2013; (c) percentage change in kangaroo density between 2009-2012; and (d) percentage change in kangaroo density between 2012-2013.

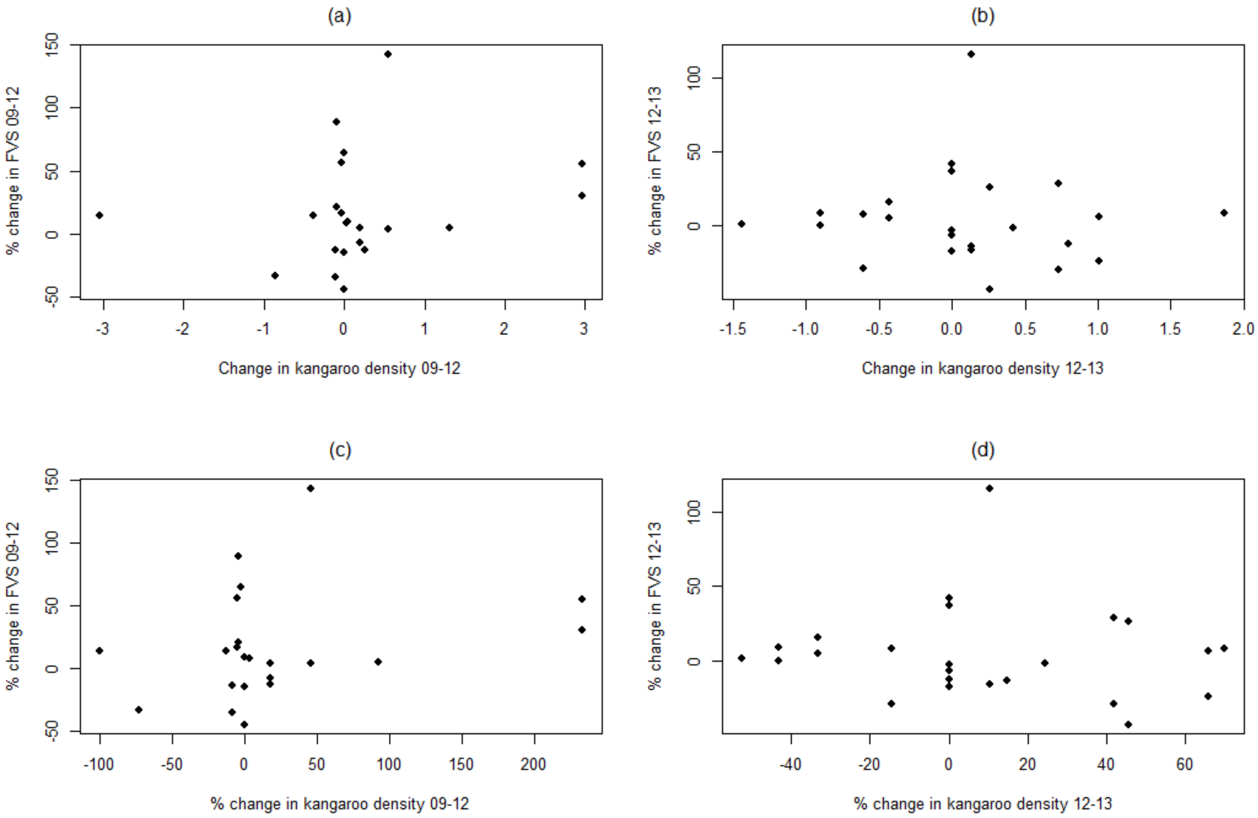


Figure 18: Comparison of the percentage change in floristic value score (FVS) with: (a) change in kangaroo density between 2009-2012; (b) change in kangaroo density between 2012-2013; (c) percentage change in kangaroo density between 2009-2012; and (d) percentage change in kangaroo density between 2012-2013.

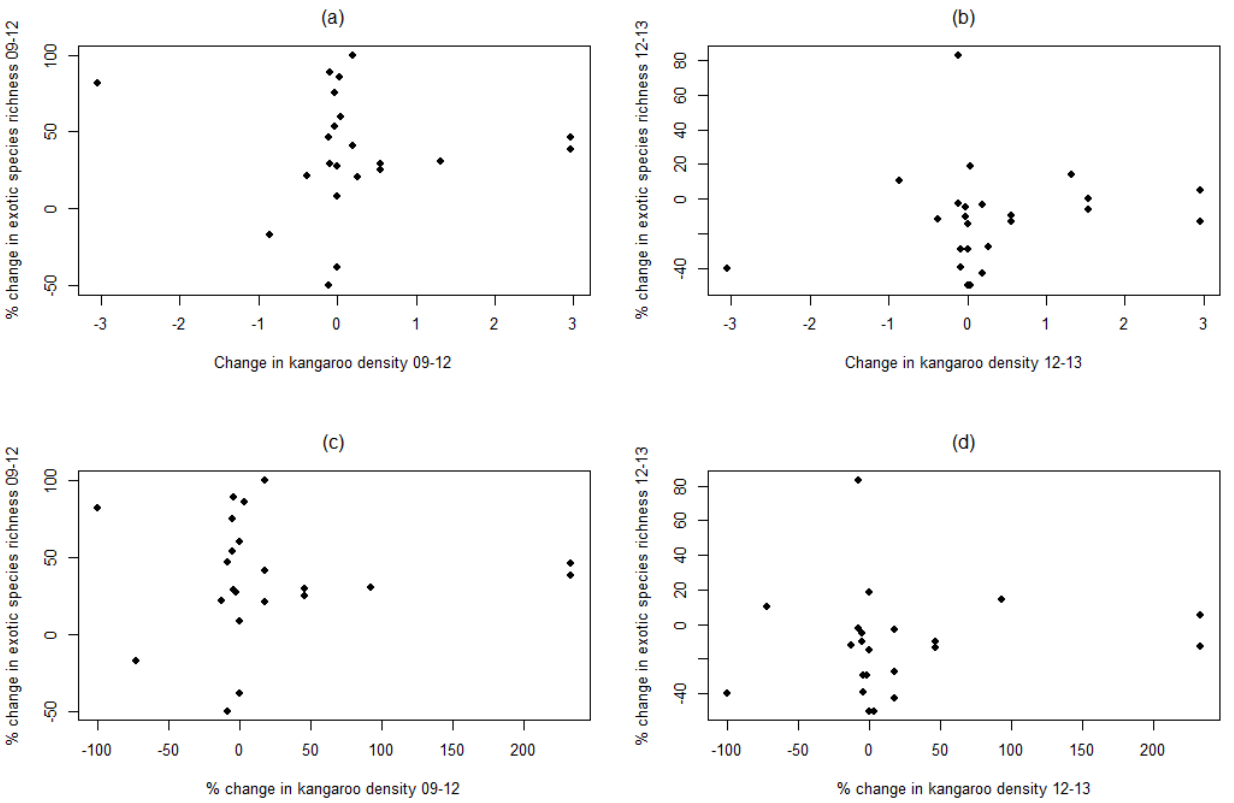


Figure 19: Comparison of the percentage change in exotic species richness with: (a) change in kangaroo density between 2009-2012; (b) change in kangaroo density between 2012-2013; (c) percentage change in kangaroo density between 2009-2012; and (d) percentage change in kangaroo density between 2012-2013.

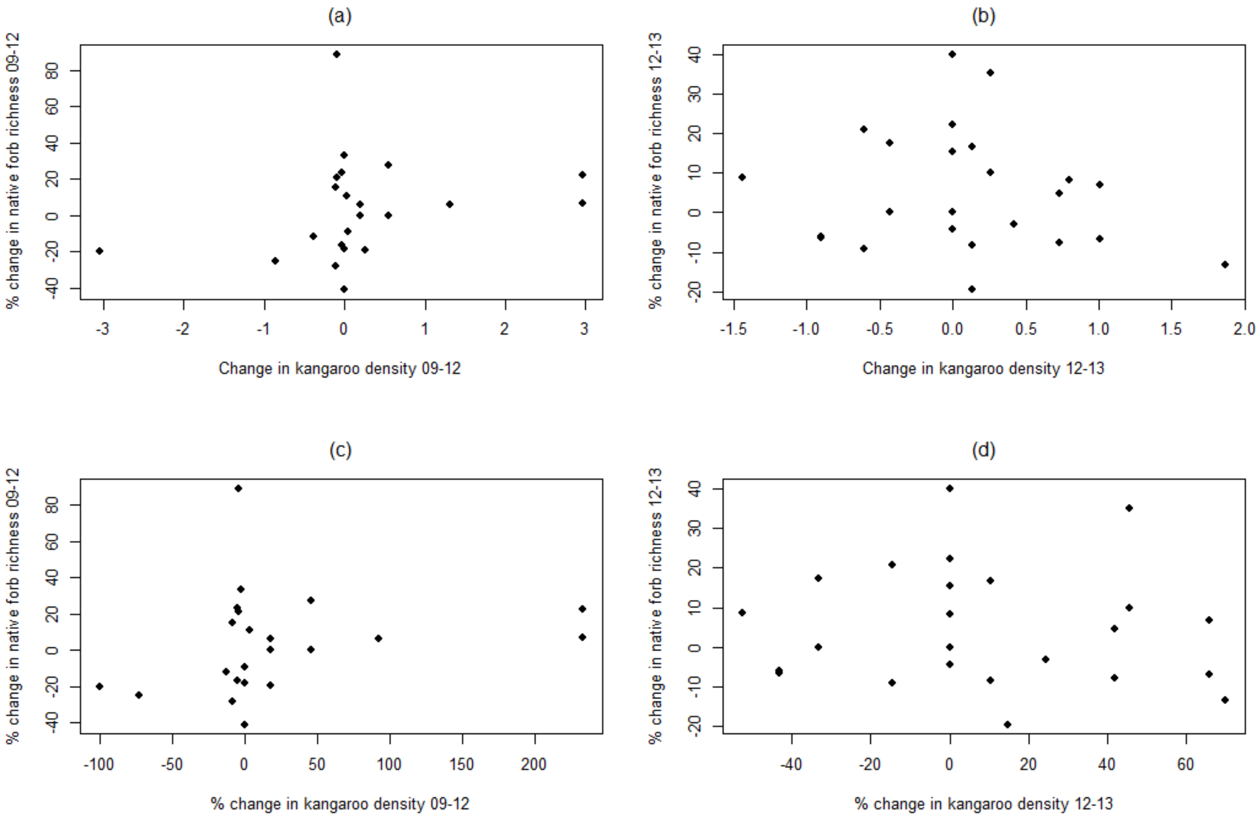


Figure 20: Comparison of the percentage change in native forb richness with: (a) change in kangaroo density between 2009-2012; (b) change in kangaroo density between 2012-2013; (c) percentage change in kangaroo density between 2009-2012; and (d) percentage change in kangaroo density between 2012-2013.

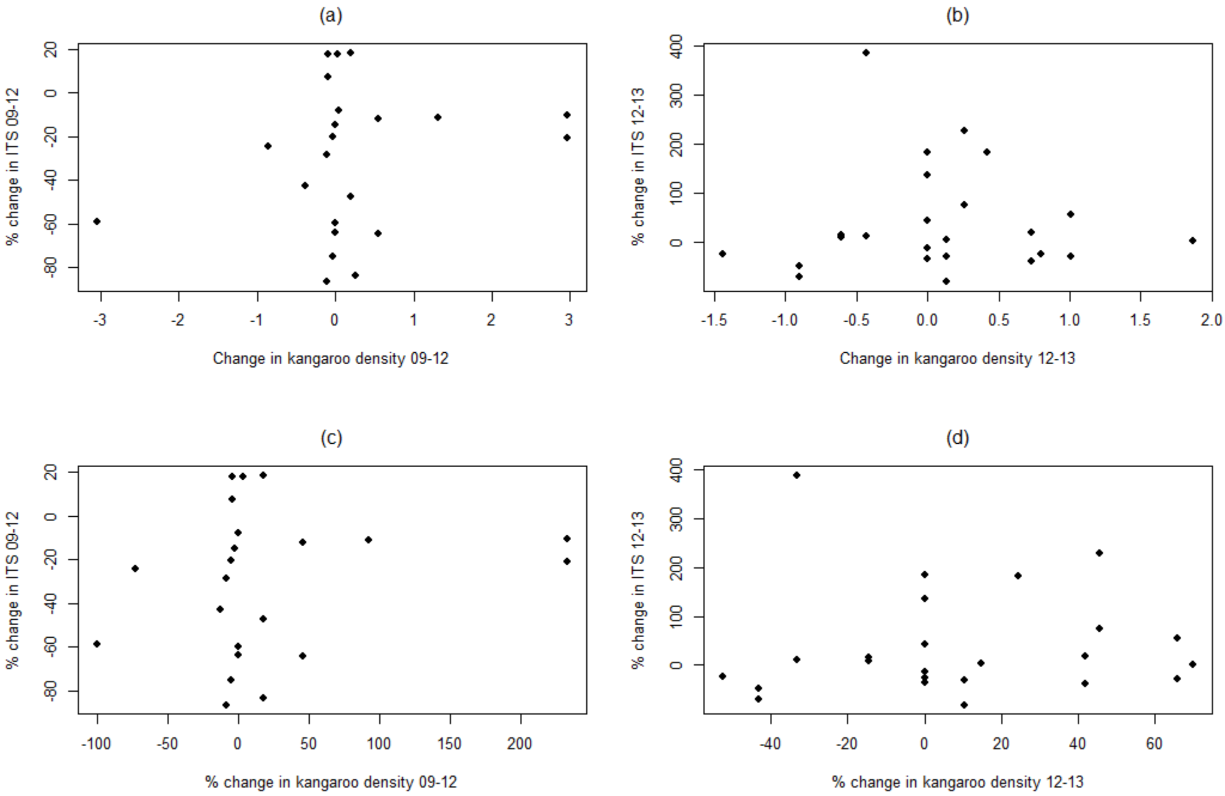


Figure 21: Comparison of the percentage change in inter-tussock space (ITS) with: (a) change in kangaroo density between 2009-2012; (b) change in kangaroo density between 2012-2013; (c) percentage change in kangaroo density between 2009-2012; and (d) percentage change in kangaroo density between 2012-2013.

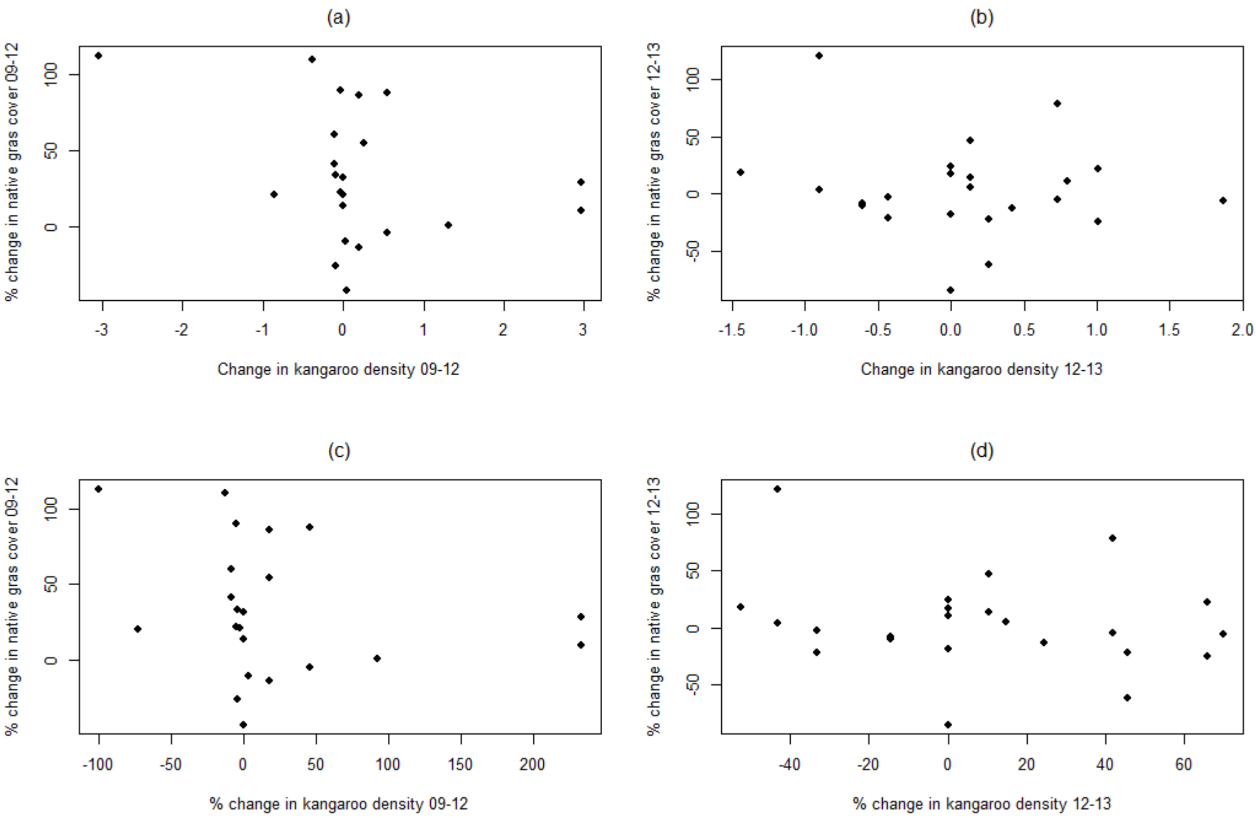


Figure 22: Comparison of the percentage change in native grass cover with: (a) change in kangaroo density between 2009-2012; (b) change in kangaroo density between 2012-2013; (c) percentage change in kangaroo density between 2009-2012; and (d) percentage change in kangaroo density between 2012-2013.

4.3.2 COMPARISON OF CHANGES WITHIN TIME INTERVALS: SITE-LEVEL RESULTS

The following section presents the data in the previous section for each site separately. As well as percentage change within each time period (2009-2012, and 2012-2013), means for each year are also provided. The data are similar to those presented in Baines and Jenkins (2013), except that means are separated by vegetation type (NTG, woodlands and secondary grasslands).

Belconnen Naval Transmission Station

Kangaroo density at Belconnen Naval Transmission Station increased between 2009 and 2012, and decreased between 2012 and 2013 (Table 12). All measures of species richness (including exotic species), FVS and native grass cover increased across both time intervals, although native forb richness and FVS increased by less than 10%. Inter-tussock space declined across both time intervals.

Table 12: Site-level means (within vegetation structure type), and percentage changes between years, for Belconnen Naval Transmission Station.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	1.42	2.74	1.3	93.0	-52.6
NTG (5 plots)					
Native species richness	17.4	21.6	23.8	24.1	10.2
Floristic Value Score	16.4	17.2	17.4	4.9	1.2
Exotic species richness	11.8	15.4	17.6	30.5	14.3
Native forb richness	13.0	13.8	15.0	6.2	8.7
Inter-tussock space (% of step point transect)	40.5	36.0	27.5	-11.1	-23.5
Native grass cover (% of step point transect)	59.5	59.9	71.0	0.6	18.6

Broadcast Australia

Kangaroo density increased across both time periods (Table 13). Native and forb species richness, FVS, and inter-tussock space decreased between 2009 and 2012, while native grass cover and exotic species richness increased. Between 2012 and 2013, FVS and both native and forb species richness remained relatively stable. The greatest change during this time period was observed in inter-tussock space, which increased almost 200%, although from a very low level.

Table 13: Site-level means (within vegetation structure type), and percentage changes between years, for Broadcast Australia.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	1.5	1.7	2.2	17.7	24.3
Secondary grassland (2 plots)					
Native species richness	27.0	23.5	24.0	-13.0	2.1
Floristic Value Score	31.5	27.5	27.0	-12.7	-1.8
Exotic species richness	12.0	14.5	10.5	20.8	-27.6
Native forb richness	20.5	16.5	16.0	-19.5	-3.0
Inter-tussock space (% of step point transect)	43.7	7.1	20.1	-83.7	182.3
Native grass cover (% of step point transect)	54.9	84.9	74.2	54.6	-12.6

Callum Brae Nature Reserve

Kangaroo density remained stable at Callum Brae NR (Table 14). During the first time interval (2009-2012), all measures of species richness (including exotic species), FVS and native grass cover increased, while inter-tussock space declined. During the second time interval (2012-2013) the opposite trend occurred, with the exception of native grass cover which continued to increase.

Table 14: Site-level means (within vegetation structure type), and percentage changes between years, for Callum Brae Nature Reserve.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	2.05	2.01	2.01	-2.0	0.0
Woodland (3 plots)					
Native species richness	20.7	29.7	26.3	43.5	-11.2
Floristic Value Score	17.7	29.0	24.0	64.2	-17.2
Exotic species richness	17.0	21.7	15.3	27.5	-29.2
Native forb richness	12.0	16.0	15.3	33.3	-4.2
Inter-tussock space (% of step point transect)	62.0	52.9	46.0	-14.7	-13.1
Native grass cover (% of step point transect)	38.0	46.0	54.0	21.0	17.4

Campbell Park

At Campbell Park, surveyed only in 2012 and 2013, kangaroo density increased between the two years (Table 15). The vegetation response differed in NTG and woodland plots; native species richness remained stable in NTG but declined in woodland, while FVS decreased in NTG plots but increased in the woodland plot. Changes in inter-tussock space and native grass cover also differed between NTG and woodlands.

Table 15: Site-level means (within vegetation structure type), and percentage changes between years, for Campbell Park.

	2012	2013	% change 2012-2013
Kangaroo density (per ha)	1.53	2.54	66.0
NTG (2 plots)			
Native species richness	22.5	22.5	0.0
Floristic Value Score	23.0	17.5	-23.9
Exotic species richness	17.0	16.0	-5.9
Native forb richness	14.5	15.5	6.9
Inter-tussock space (% of step point transect)	41.5	29.8	-28.3
Native grass cover (% of step point transect)	56.9	69.6	22.3
Woodland (1 plot)			
Native species richness	26.0	23.0	-11.5
Floristic Value Score	16.0	17.0	6.3
Exotic species richness	13.0	13.0	0.0
Native forb richness	15.0	14.0	-6.7
Inter-tussock space (% of step point transect)	30.7	47.8	55.5
Native grass cover (% of step point transect)	69.3	52.2	-24.6

Crace Nature Reserve

Kangaroo density at Crace NR increased in the two time intervals, although overall densities were low, at 1 kangaroo per ha or less (Table 16). Each response variable except for native grass cover increased between 2009 and 2012, especially exotic species richness. Most then declined between 2012 and 2013, although native grass cover and inter-tussock space both increased slightly.

Table 16: Site-level means (within vegetation structure type), and percentage changes between years, for Crace Nature Reserve.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	0.85	0.88	1.01	3.5	14.8
NTG (2 plots)					
Native species richness	23.5	29.0	21.0	23.4	-27.6
Floristic Value Score	30.5	33.0	28.5	8.2	-13.6
Exotic species richness	7.0	13.0	6.5	85.7	-50.0
Native forb richness	14.0	15.5	12.5	10.7	-19.4
Inter-tussock space (% of step point transect)	26.6	31.3	32.6	17.9	4.0
Native grass cover (% of step point transect)	56.3	50.7	53.6	-10.0	5.7

Dunlop Nature Reserve

Kangaroo density was low in all three years (< 1 per ha), with an increase between 2012 and 2013 (Table 17). Native species richness increased in NTG and woodland plots across both time periods. FVS increased in NTG across both time periods, but decreased in the woodland plot between 2012 and 2013. Inter-tussock space decreased between 2009 and 2012 but increased between 2012 and 2013, the latter due to high cover of exotic annual grass recorded in 2013.

Table 17: Site-level means (within vegetation structure type), and percentage changes between years, for Dunlop Nature Reserve.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	0.6	0.57	0.83	-5.0	45.6
NTG (3 plots)					
Native species richness	14.3	20.7	27.7	44.2	33.9
Floristic Value Score	10.7	16.7	21.0	56.3	26.0
Exotic species richness	13.0	20.0	18.0	53.8	-10.0
Native forb richness	10.0	12.3	16.7	23.3	35.1
Inter-tussock space (% of step point transect)	77.2	19.3	63.3	-75.0	227.9
Native grass cover (% of step point transect)	22.5	42.7	33.4	89.7	-21.8
Woodland (1 plot)					
Native species richness	18.0	21.0	22.0	16.7	4.8
Floristic Value Score	12.0	14.0	8.0	16.7	-42.9
Exotic species richness	12.0	21.0	20.0	75.0	-4.8
Native forb richness	12.0	10.0	11.0	-16.7	10.0
Inter-tussock space (% of step point transect)	56.3	44.9	78.5	-20.3	74.9
Native grass cover (% of step point transect)	42.7	52.2	20.0	22.2	-61.7

Googong Foreshores

Kangaroo density was higher in 2013 than in 2009 (data for 2012 not available) (Table 18). Native species and forb richness increased between both time periods, whereas FVS decreased between 2009 and 2012 but increased between 2012 and 2013.

Table 18: Site-level means (within vegetation structure type), and percentage changes between years, for Googong Foreshores.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	2.16	-	3.27	NA	NA
Secondary grassland (5 plots)					
Native species richness	30.4	34.6	37.6	13.8	8.7
Floristic Value Score	31.2	25.8	33.4	-17.3	29.5
Exotic species richness	13.4	16.8	15.4	25.4	-8.3
Native forb richness	19.4	20.6	23.2	6.2	12.6
Inter-tussock space (% of step point transect)	50.6	49.6	61.4	-1.9	23.8
Native grass cover (% of step point transect)	43.7	42.6	35.8	-2.6	-16.0

Goorooyaroo Nature Reserve

Kangaroo density decreased each year at Goorooyaroo NR (Table 19), especially between 2012 and 2013. Richness (native, forb and exotic) all increased between 2009 and 2012, and declined by a small percentage between 2012 and 2013. FVS also increased between 2009 and 2012 but then remained either stable (in the secondary grassland plot) or increased slightly (in the woodland plots). Native grass cover increased by more than 100% in the secondary grassland plot between 2012 and 2013, but changed little in woodland plots.

Table 19: Site-level means (within vegetation structure type), and percentage changes between years, for Goorooyaroo Nature Reserve.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	2.17	2.08	1.18	-4.1	-43.3
Secondary grassland (1 plot)					
Native species richness	16.0	30.0	28.0	87.5	-6.7
Floristic Value Score	9.0	17.0	17.0	88.9	0.0
Exotic species richness	9.0	17.0	12.0	88.9	-29.4
Native forb richness	9.0	17.0	16.0	88.9	-5.9
Inter-tussock space (% of step point transect)	49.1	52.7	15.6	7.5	-70.4
Native grass cover (% of step point transect)	50.9	37.7	83.3	-26.1	121.2
Woodland (4 plots)					
Native species richness	27.8	38.3	34.5	37.8	-9.8
Floristic Value Score	31.3	37.8	41.0	20.8	8.6
Exotic species richness	14.8	19.0	11.5	28.8	-39.5
Native forb richness	19.0	23.0	21.5	21.1	-6.5
Inter-tussock space (% of step point transect)	47.8	56.4	28.8	18.0	-48.9
Native grass cover (% of step point transect)	47.9	64.1	66.6	33.7	4.0

Gungaderra Nature Reserve

Gungaderra NR was surveyed only in 2013 (Table 20).

Table 20: Site-level means (within vegetation structure type) for Gungaderra Nature Reserve.

		2013
Kangaroo density (per ha)		1.92
NTG (1 plot)		
	Native species richness	25.0
	Floristic Value Score	20.0
	Exotic species richness	12.0
	Native forb richness	14.0
	Inter-tussock space (% of step point transect)	39.3
	Native grass cover (% of step point transect)	60.7
Secondary grassland (3 plots)		
	Native species richness	26.7
	Floristic Value Score	34.3
	Exotic species richness	12.7
	Native forb richness	20.0
	Inter-tussock space (% of step point transect)	61.0
	Native grass cover (% of step point transect)	39.0

Jerrabomberra East Nature Reserve

Outside of the exclosure at Jerrabomberra East NR, kangaroo densities decreased between 2009 and 2012 but increased to 4.5 per ha in 2013 (Table 21). Between 2009 and 2012, native grass cover, FVS and both native and exotic species richness increased while native forb richness declined. Between 2012 and 2013 most response variables declined or remained fairly stable.

In the exclosure, native species and forb richness, as well as inter-tussock space, declined between 2009 and 2012. FVS and native grass cover both increased, the latter by over 100%. Between 2012 and 2013 native species and forb richness increased, and FVS and inter-tussock space declined. Native grass cover increased slightly.

Table 21: Site-level means (within vegetation structure type), and percentage changes between years, for Jerrabomberra East Nature Reserve.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	3.1	2.7	4.5	-12.5	70.0
NTG – outside of exclosure (1 plot)					
Native species richness	22.0	26.0	23.0	18.2	-11.5
Floristic Value Score	21.0	24.0	26.0	14.3	8.3
Exotic species richness	14.0	17.0	15.0	21.4	-11.8
Native forb richness	17.0	15.0	13.0	-11.8	-13.3
Inter-tussock space (% of step point transect)	72.0	41.2	42.1	-42.7	2.1
Native grass cover (% of step point transect)	28.0	58.8	55.3	109.9	-6.0
Kangaroo density (per ha)	3.1	0.0	0.8	-100.0	NA
NTG – within exclosure (1 plot)					
Native species richness	17.0	15.0	20.0	-11.8	33.3
Floristic Value Score	14.0	16.0	14.0	14.3	-12.5
Exotic species richness	11.0	20.0	12.0	81.8	-40.0
Native forb richness	15.0	12.0	13.0	-20.0	8.3
Inter-tussock space (% of step point transect)	66.2	27.2	20.4	-58.9	-24.9
Native grass cover (% of step point transect)	33.8	71.9	79.6	112.7	10.6

Jerrabomberra West Nature Reserve

Kangaroo density increased in each time interval at Jerrabomberra West NR (Table 22). Most response variables increased between 2009 and 2012 (particularly the FVS in the NTG plot), and decreased between 2012 and 2013, except for the woodland plots where native species richness, FVS, forb richness and native grass cover all increased.

Inside the exclosure, native grass cover increased in the two time intervals. The remaining variables all decreased between 2009 and 2012, and increased in 2012-2013, except for inter-tussock space, which continued to decline.

Table 22: Site-level means (within vegetation structure type), and percentage changes between years, for Jerrabomberra West Nature Reserve.

		2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)		1.2	1.7	2.5	46.2	42.0
NTG – outside of exclosure (1 plot)						
	Native species richness	20.0	21.0	19.0	5.0	-9.5
	Floristic Value Score	7.0	17.0	12.0	142.9	-29.4
	Exotic species richness	12.0	15.0	13.0	25.0	-13.3
	Native forb richness	13.0	13.0	12.0	0.0	-7.7
	Inter-tussock space (% of step point transect)	57.7	20.6	24.4	-64.4	18.5
	Native grass cover (% of step point transect)	42.3	79.4	75.6	87.9	-4.8
Woodland – outside of exclosure (2 plots)						
	Native species richness	24.5	31.0	31.5	26.5	1.6
	Floristic Value Score	25.0	26.0	33.5	4.0	28.8
	Exotic species richness	12.0	15.5	14.0	29.2	-9.7
	Native forb richness	16.5	21.0	22.0	27.3	4.8
	Inter-tussock space (% of step point transect)	60.0	52.8	32.5	-12.1	-38.4
	Native grass cover (% of step point transect)	39.5	37.8	67.5	-4.3	78.6
Kangaroo density (per ha)		1.2	0.3	0.3	-72.3	0.0
NTG – within exclosure (2 plots)						
Exclosure	Native species richness	31.0	28.5	29.0	-8.1	1.8
	Floristic Value Score	34.5	23.0	31.5	-33.3	37.0
	Exotic species richness	11.5	9.5	10.5	-17.4	10.5
	Native forb richness	24.0	18.0	22.0	-25.0	22.2
	Inter-tussock space (% of step point transect)	49.1	37.2	24.0	-24.3	-35.5
	Native grass cover (% of step point transect)	50.9	61.3	76.0	20.5	24.0

Kama Nature Reserve

Kangaroo density was at low at Kama NR, with a small decline observed in each successive year (Table 23). Vegetation structure and composition differed in NTG and woodland plots, with inter-tussock space and species richness being consistently higher in woodland, especially in 2012 and 2013. Patterns over time also varied by vegetation type, with inter-tussock space increasing dramatically in NTG plots between 2012 and 2013.

Table 23: Site-level means (within vegetation structure type), and percentage changes between years, for Kama Nature Reserve.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	1.4	1.3	0.9	-7.9	-33.3
NTG (2 plots)					
Native species richness	23.0	21.0	21.0	-8.7	0.0
Floristic Value Score	31.5	20.5	21.5	-34.9	4.9
Exotic species richness	18.0	9.0	16.5	-50.0	83.3
Native forb richness	16.0	11.5	13.5	-28.1	17.4
Inter-tussock space (% of step point transect)	38.2	5.2	25.2	-86.5	387.4
Native grass cover (% of step point transect)	58.8	94.1	74.1	60.2	-21.3
Woodland (2 plots)					
Native species richness	24.0	31.0	33.5	29.2	8.1
Floristic Value Score	37.0	32.0	37.0	-13.5	15.6
Exotic species richness	15.0	22.0	21.5	46.7	-2.3
Native forb richness	16.5	19.0	19.0	15.2	0.0
Inter-tussock space (% of step point transect)	64.4	46.1	51.3	-28.4	11.2
Native grass cover (% of step point transect)	35.1	49.6	48.3	41.3	-2.7

Majura Nature Reserve

Majura NR was surveyed only in 2013 (Table 24).

Table 24: Site-level means (within vegetation structure type) for Majura Nature Reserve.

	2013
Kangaroo density (per ha)	0.9
Woodland (4 plots)	
Native species richness	36.8
Floristic Value Score	41.3
Exotic species richness	13.0
Native forb richness	22.3
Inter-tussock space (% of step point transect)	38.3
Native grass cover (% of step point transect)	58.4

Mt Painter Nature Reserve

Mt Painter NR was surveyed only in 2013 (Table 25).

Table 25: Site-level means (within vegetation structure type) for Mt Painter Nature Reserve.

	2013
Kangaroo density (per ha)	2.3
Secondary grasslands (2 plots)	
Native species richness	16.5
Floristic Value Score	9.5
Exotic species richness	13.5
Native forb richness	9.5
Inter-tussock space (% of step point transect)	22.8
Native grass cover (% of step point transect)	68.4

Mulangarri Nature Reserve

Kangaroo density increased slowly across survey years (Table 26). Native species richness increased between 2009 and 2012, but between 2012 and 2013 it declined in the NTG plot and increased in the secondary grassland plots. FVS increased by over 100% in the second time period in the secondary grassland plots. Inter-tussock space declined between 2009 and 2013 in NTG and between 2012 and 2013 in secondary grassland plots.

Table 26: Site-level means (within vegetation structure type), and percentage changes between years, for Mulangarri Nature Reserve.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	1.1	1.2	1.4	18.1	10.5
NTG (1 plot)					
Native species richness	36.0	38.0	30.0	5.6	-21.1
Floristic Value Score	47.0	49.0	41.0	4.3	-16.3
Exotic species richness	7.0	14.0	8.0	100.0	-42.9
Native forb richness	24.0	24.0	22.0	0.0	-8.3
Inter-tussock space (% of step point transect)	49.1	25.8	18.1	-47.5	-29.8
Native grass cover (% of step point transect)	38.2	71.1	81.0	86.2	14.0
Secondary grassland (2 plots)					
Native species richness	20.5	27.0	32.0	31.7	18.5
Floristic Value Score	20.5	19.0	41.0	-7.3	115.8
Exotic species richness	11.0	15.5	15.0	40.9	-3.2
Native forb richness	17.0	18.0	21.0	5.9	16.7
Inter-tussock space (% of step point transect)	29.6	35.1	6.7	18.6	-81.0
Native grass cover (% of step point transect)	70.4	60.6	88.9	-14.0	46.8

North Mitchell

North Mitchell had a very low and stable kangaroo density, consisting of either zero or one adult male (Table 27). Between 2012 and 2013 inter-tussock space, FVS and native, forb and exotic species richness all increased while native grass cover declined dramatically.

Table 27: Site-level means (within vegetation structure type), and percentage changes between years, for Kama Nature Reserve.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	0.0	0.04	0.04	NA	0.0
NTG (1 plot)					
Native species richness	16.0	15.0	21.0	-6.3	40.0
Floristic Value Score	11.0	12.0	17.0	9.1	41.7
Exotic species richness	10.0	16.0	19.0	60.0	18.8
Native forb richness	11.0	10.0	14.0	-9.1	40.0
Inter-tussock space (% of step point transect)	19.0	17.5	49.6	-7.9	183.4
Native grass cover (% of step point transect)	81.0	46.7	7.2	-42.4	-84.6

Pinnacle Nature Reserve

The Pinnacle NR was surveyed only in 2013 (Table 28).

Table 28: Site-level means (within vegetation structure type) for the Pinnacle Nature Reserve.

	2013
Kangaroo density (per ha)	1.8
Woodland (2 plots)	
Native species richness	36.5
Floristic Value Score	23.0
Exotic species richness	20.5
Native forb richness	18.5
Inter-tussock space (% of step point transect)	61.7
Native grass cover (% of step point transect)	27.9

St Mark's Cathedral

No kangaroos were recorded at St Mark's Cathedral, a small site which is burned annually (Table 29). This site is known for being an excellent example of a high quality and floristically diverse *Themeda triandra* dominated NTG (Baines & Jenkins 2013). Between 2009 and 2012 all response variables declined, except for native grass cover which increased. Native species richness and FVS remained relatively stable between 2012 and 2013, while inter-tussock space increased.

Table 29: Site-level means (within vegetation structure type), and percentage changes between years, for St Mark's Cathedral.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	0.0	0.0	0.0	0.0	0.0
NTG (1 plot)					
Native species richness	28.0	21.0	22.0	-25.0	4.8
Floristic Value Score	40.0	34.0	33.0	-15.0	-2.9
Exotic species richness	13.0	8.0	4.0	-38.5	-50.0
Native forb richness	22.0	13.0	15.0	-40.9	15.4
Inter-tussock space (% of step point transect)	36.0	13.0	30.7	-63.9	135.8
Native grass cover (% of step point transect)	64.0	84.6	69.3	32.1	-18.0

Wanniassa Hills Nature Reserve

This site experienced a large increase in kangaroo density between 2009 and 2012 and then a modest decline in 2013 (Table 30). In 2012 and 2013 density was high compared to most other sites. During the first time period (2009-2012), all response variables, with the exception of inter-tussock space, increased in both the secondary grassland and woodland plot. Between 2012 and 2013, FVS declined at the NTG plot but most other response variables remained relatively stable. In the woodland plots, native and forb species richness increased.

Table 30: Site-level means (within vegetation structure type), and percentage changes between years, for Wanniassa Hills Nature Reserve.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	1.3	4.2	3.6	233.1	-14.4
Secondary grassland (1 plot)					
Native species richness	27.0	31.0	31.0	14.8	0.0
Floristic Value Score	20.0	31.0	22.0	55.0	-29.0
Exotic species richness	13.0	19.0	20.0	46.2	5.3
Native forb richness	18.0	22.0	20.0	22.2	-9.1
Inter-tussock space (% of step point transect)	53.0	42.0	48.6	-20.8	15.7
Native grass cover (% of step point transect)	41.0	52.7	48.6	28.5	-7.8
Woodland (1 plot in 2009/2012, 3 plots in 2013)					
Native species richness	21.0	25.0	34.0	19.0	36.0
Floristic Value Score	23.0	30.0	32.3	30.4	7.8
Exotic species richness	13.0	18.0	15.7	38.5	-13.0
Native forb richness	15.0	16.0	19.3	6.7	20.8
Inter-tussock space (% of step point transect)	46.6	41.8	45.5	-10.3	8.8
Native grass cover (% of step point transect)	51.5	56.7	50.8	10.2	-10.4

Yarramundi Reach

There were no kangaroos present at this site (Table 31). Species richness and FVS was relatively low compared to other plots included in this study. Despite an increase in native species richness between 2009 and 2012, FVS and native forb richness declined, along with inter-tussock space. Between 2012 and 2013, inter-tussock space increased, while richness and FVS remained relatively stable.

Table 31: Site-level means (within vegetation structure type), and percentage changes between years, for Yarramundi Reach.

	2009	2012	2013	% change 2009-2012	% change 2012-2013
Kangaroo density (per ha)	0.0	0.0	0.0	0.0	0.0
NTG (2 plots)					
Native species richness	6.0	10.0	9.5	66.7	-5.0
Floristic Value Score	13.5	7.5	7.0	-44.4	-6.7
Exotic species richness	12.5	13.5	11.5	8.0	-14.8
Native forb richness	5.5	4.5	4.5	-18.2	0.0
Inter-tussock space (% of step point transect)	52.0	21.0	29.9	-59.7	42.8
Native grass cover (% of step point transect)	48.0	54.6	64.2	13.7	17.5

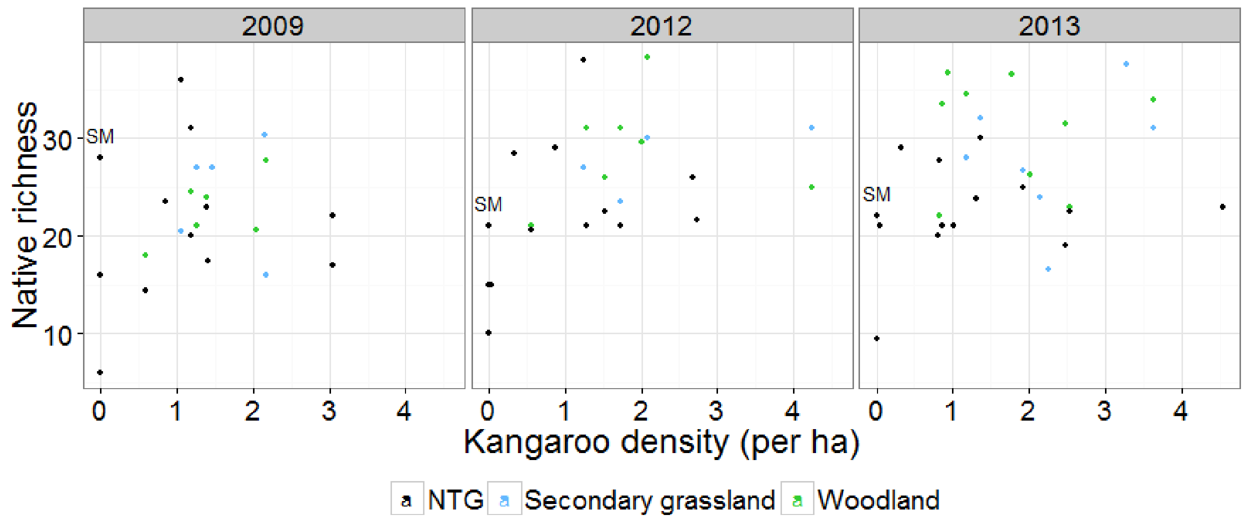
4.3.3 PREDICTION 1

Prediction 1 was *"A relationship will exist between kangaroo density and species richness/diversity. The IDH specifically predicts that the relationship will be humped-shaped, with the highest species richness/diversity evident under intermediate levels of kangaroo grazing pressure."*

St Mark's Cathedral as an outlier

St Mark's Cathedral consists of a small patch of NTG in the inner city which is burned annually, a disturbance regime that is unique to the site and which is likely to promote species diversity. Indeed, scatter plots of average site native richness and FVS against kangaroo density (Figure 23) indicate that this site is an outlier with high native species richness and FVS despite a total absence of kangaroos. To avoid this data point disproportionately influencing the analyses, all of the following analyses are conducted with the survey plot at St Mark's Cathedral removed.

(a) Native species richness



(b) Floristic Value Score

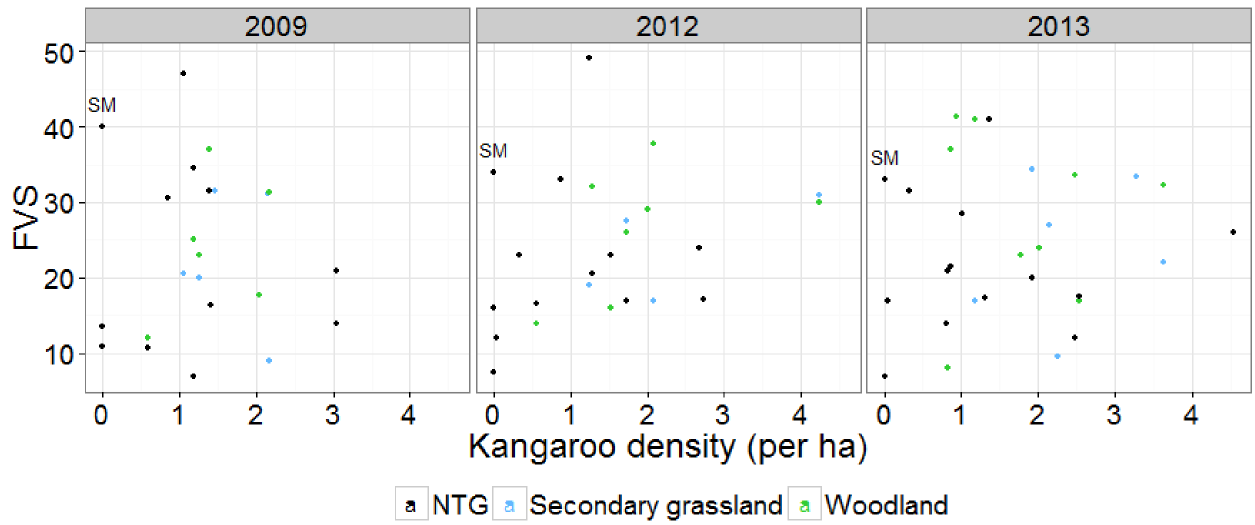


Figure 23: Scatter plots of average site-level (a) native richness and (b) Floristic Value Score in relation to kangaroo density. The plot at St Mark's Cathedral is labelled as "SM".

Relationships between kangaroo density and species diversity

ANCOVA indicated no significant interaction between kangaroo density and vegetation structure for either native species richness (Table 32a) or FVS (Table 32b). Therefore, further investigation of the relationships between kangaroo density and native species richness and FVS were examined for all sites pooled together. ANCOVA also suggested a significant linear relationship between kangaroo density and native species richness in 2012 only (Table 32a).

Table 32: ANCOVA results for (a) native species richness and (b) floristic value score. *P* values: *** = $P < 0.001$, ** = $P < 0.001$, * = $P < 0.05$, , # = $P < 0.08$, ns = non-significant.

		(a) Native species richness			(b) Floristic value score		
Year	**Predictor variable**	**d.f.**	**Mean Squares**	**F-statistic (*P* value)**	**d.f.**	**Mean Squares**	**F-statistic (*P* value)**
2009	**Kangaroo density**	1	65.3	1.314 (ns)	1	25.49	0.180 (ns)
	Vegetation structure	2	30.8	0.310 (ns)	1	12.73	0.090 (ns)
	Kangaroo density x vegetation structure	2	5.43	5.43 (ns)	2	29.21	0.207 (ns)
	Residuals	16	49.69		16	141.33	
2012	**Kangaroo density**	1	192.63	4.535 *	1	299.36	3.157 (ns)
	Vegetation structure	2	49.85	1.173 (ns)	2	22.12	0.233 (ns)
	Kangaroo density x vegetation structure	2	14.51	0.342 (ns)	2	1.62	0.017 (ns)
	Residuals	17	42.48		17	94.81	
2013	**Kangaroo density**	1	64.55	1.812	1	26.49	0.227 (ns)
	Vegetation structure	2	173.51	4.871 *	2	147.55	1.262 (ns)
	Kangaroo density x vegetation structure	2	9.44	0.265 (ns)	2	10.91	0.093 (ns)
	Residuals	23	35.62		23	116.93	

In 2009, although a linear relationship was not evident between kangaroo density and native species richness, GAM indicated a significant non-linear relationship, consisting of an initial positive relationship, followed by a plateau and slight decrease ($F = 3.874$, adjusted $R^2 = 0.32$, $P = 0.029$; Figure 24a). In 2012, there was a significant linear relationship between kangaroo density and native species richness ($F_{2,21} = 4.754$, adjusted $R^2 = 0.15$, $P = 0.041$; Figure 24b). However, GAM indicated a significant non-linear relationship, similar in shape to that found for 2009, although with increasingly larger confidence intervals at a higher kangaroo density ($F = 5.954$, adjusted $R^2 = 0.31$, $P < 0.001$; Figure 24b). No significant relationship existed between kangaroo density and native species richness in 2013 (Figure 24c).

In 2009 and 2012, scatter plots indicated that the initial steep increase in the curves were influenced by two NTG sites (North Mitchell and Yarramundi Reach) that could be considered outliers in relation to the remaining sites – both had no kangaroos and unusually low native species richness. Since outliers can affect model results, it can be informative to re-run analyses without outliers to examine how much influence they may be exerting (Quinn & Keough 2002). This is particularly important if there is any reason to suspect that the outliers may be unusual. Indeed, both North Mitchell and Yarramundi Reach are relatively small and isolated grasslands, surrounded by busy roads.

After removal of these two sites, GAMs indicated that there was no significant relationship between kangaroo density and native species richness, either linear or non-linear, in any year (Figure 24d-f). This indicates that these two sites are a key driver of the relationship between kangaroo density and native species richness in 2009 and 2012.

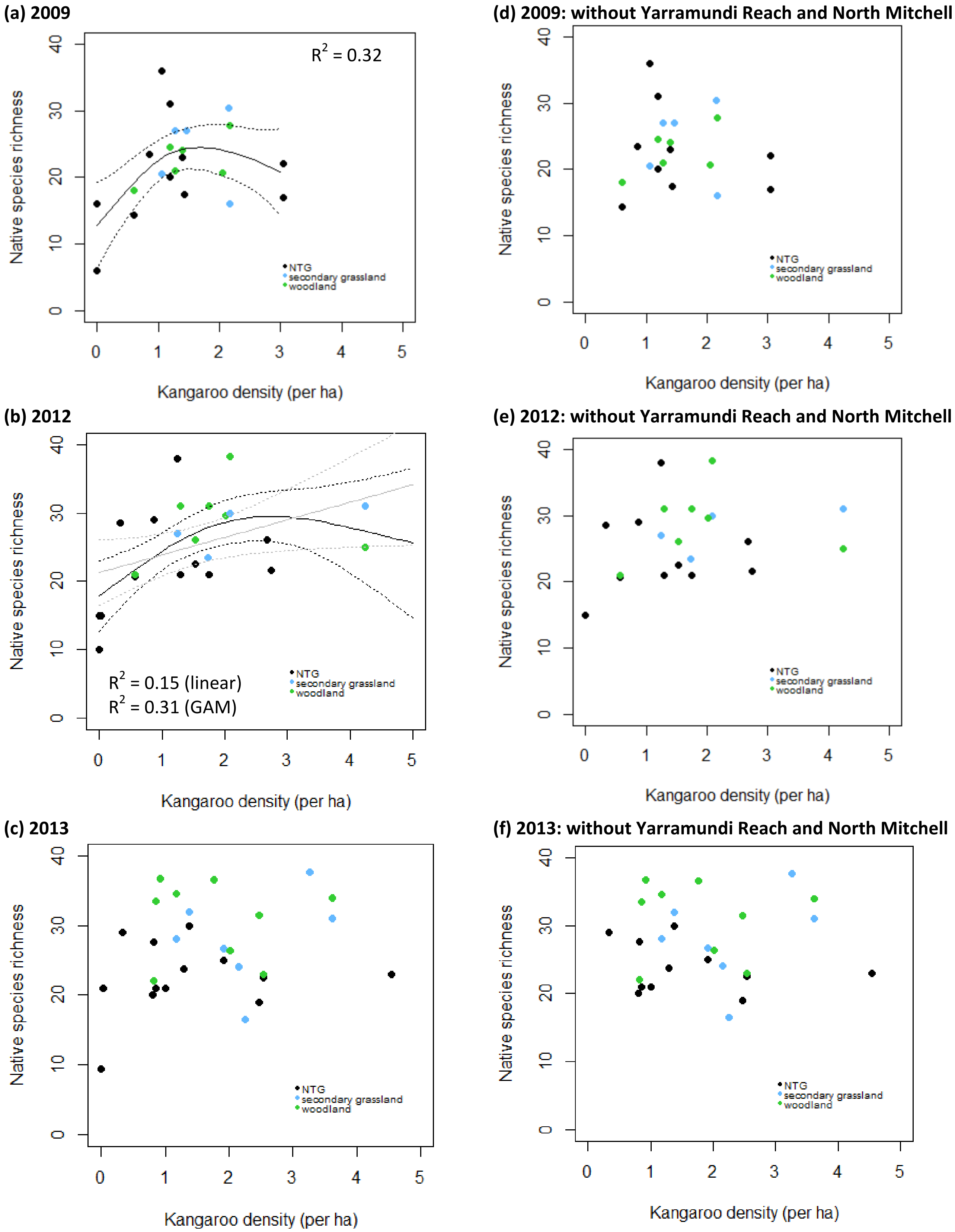


Figure 24: Relationships between kangaroo density and native species richness. (a) to (c) include all sites, whereas (d) to (f) are the same graphs but with Yarramundi Reach and North Mitchell removed as outliers. Fitted curves are predictions (± 95% confidence intervals) from significant GAMs; in (b) the grey curves are from a significant linear fit.

There was no evidence of a significant linear or non-linear relationship between FVS and kangaroo density in 2009 (Figure 25a) or in 2013 (Figure 25c). However in 2012 a marginally significant linear relationship between kangaroo densities and FVS was evident ($F_{1,21}$ = 3.788, adjusted R^2 = 0.11, P = 0.07; Figure 25b). Explanatory power was not improved by incorporation of non-linearity into the model. Mulangarri NR had a very high FVS in 2009 and 2012 and has previously been identified as an outlier (see Section 4.2.1).

Similar to the previous analyses examining native species richness, 2012 data were re-analysed without North Mitchell and Yarramundi Reach to examine any potential influence of these two sites. No significant relationship, either linear or non-linear, was detected (Figure 25e), again showing that data from these two sites are a key driver of the relationship between kangaroo density and FVS in 2012.

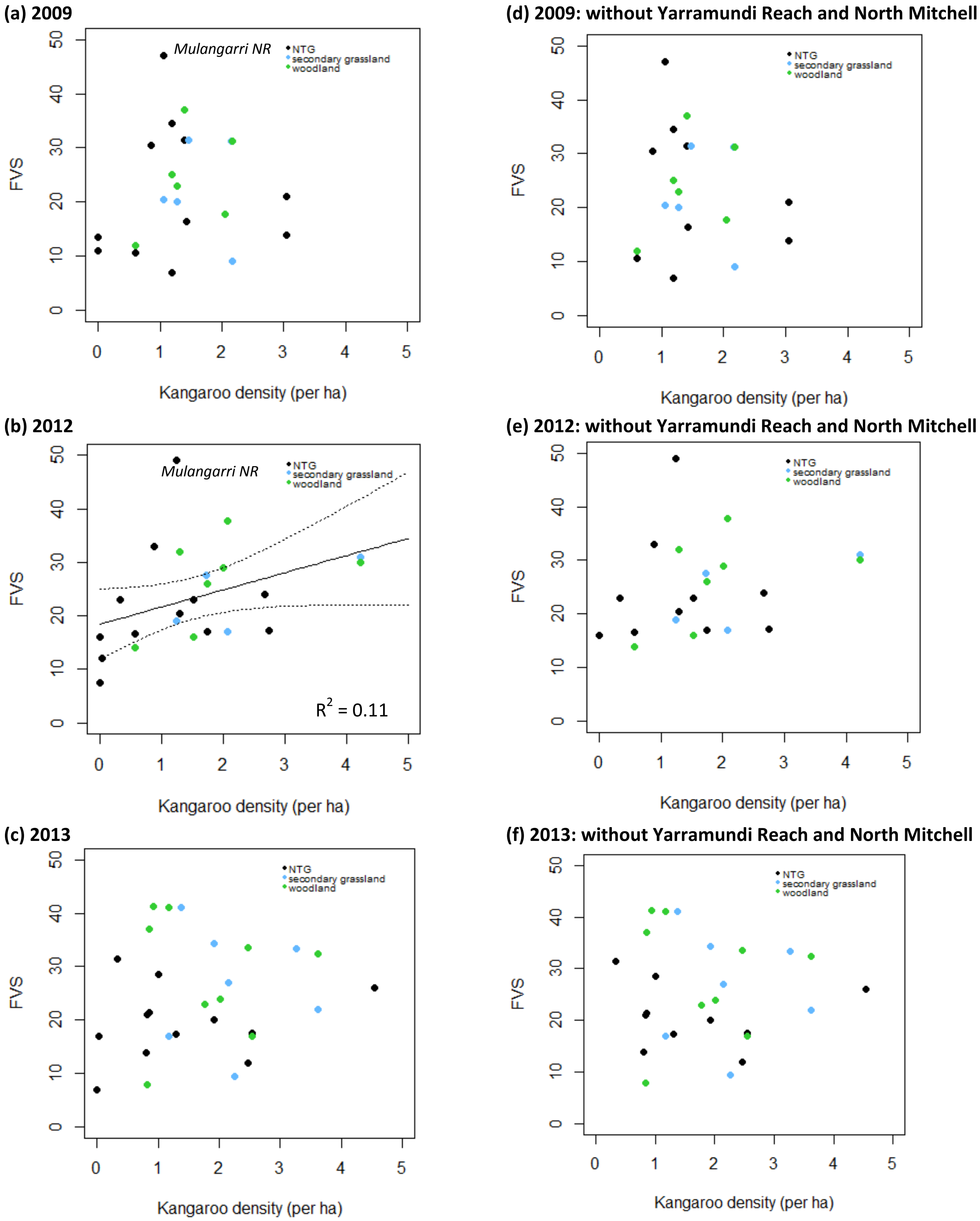


Figure 25: Relationships between kangaroo density and Floristic Value Score (FVS). (a) to (c) include all sites, whereas (d) to (f) are the same graphs but with Yarramundi Reach and North Mitchell removed as outliers. Fitted curves are predictions (± 95% confidence intervals) from significant linear regressions and/or GAMs.

Native forb richness and exotic species richness

Results from ANCOVA indicated that there was no significant interaction between kangaroo density and vegetation structure for either native forb (Table 33a) or exotic species richness (Table 33b). Therefore, further investigation of the relationship between kangaroo densities and native forb richness and exotic species richness were examined for all sites pooled together. ANCOVA indicated that kangaroo density was linearly associated with native forb richness in 2012 (Table 33a).

Table 33: ANCOVA results for (a) native forb richness and (b) exotic species richness. *P* values: *** = *P* < 0.001, ** = *P* < 0.001, * = *P* < 0.05, # = *P* < 0.08, ns = non-significant.

		(a) Native forb richness			` (b) Exotic species richness		
Year	**Predictor variable**	**d.f.**	**Mean Squares**	**F-statistic (*P* value)**	**d.f.**	**Mean Squares**	**F-statistic (*P* value)**
2009	**Kangaroo density**	1	40.39	1.789 (ns)	1	10.306	1.514 (ns)
	Vegetation structure	2	3.61	0.160 (ns)	2	11.208	1.646 (ns)
	Kangaroo density x vegetation structure	2	16.55	0.733 (ns)	2	4.403	0.647 (ns)
	Residuals	16	22.57		16	6.808	
2012	**Kangaroo density**	1	103.26	5.446 *	1	10.871	0.918 (ns)
	Vegetation structure	2	15.74	0.830 (ns)	2	24.305	2.051 (ns)
	Kangaroo density x vegetation structure	2	1.39	0.073 (ns)	2	5.169	0.653 (ns)
	Residuals	17	18.96		17	11.848	
2013	**Kangaroo density**	1	18.14	0.88 (ns)	1	3.998	0.269 (ns)
	Vegetation structure	2	38.95	1.906 (ns)	2	16.610	1.229 (ns)
	Kangaroo density x vegetation structure	2	3.70	0.181	2	17.758	1.314 (ns)
	Residuals	23	20.44		23	13.513	

In 2009, although the ANCOVA did not detect a significant relationship between kangaroo density and native forb richness, GAM indicated a marginally significant non-linear relationship with an initial positive relationship between the variables, followed by a plateau (F = 3.039, adjusted R^2 = 0.27, *P* = 0.06; Figure 26a).

In 2012, there was evidence of a linear relationship between kangaroo density and native forb richness ($F_{2,21}$ = 6.081, adjusted R^2 = 0.19, *P* = 0.02; Figure 26b). GAM indicated a significant non-linear fit, with a similar shaped curve to 2009 (F = 3.916, adjusted R^2 = 0.28, *P* = 0.03; Figure 26b).

No significant relationship (either linear or non-linear) was identified between kangaroo density and native forb richness in 2013 (Figure 26c).

After removal of data from North Mitchell and Yarramundi Reach, there was no significant relationship detected between kangaroo density and native forb richness in any year (Figure 26d-f).

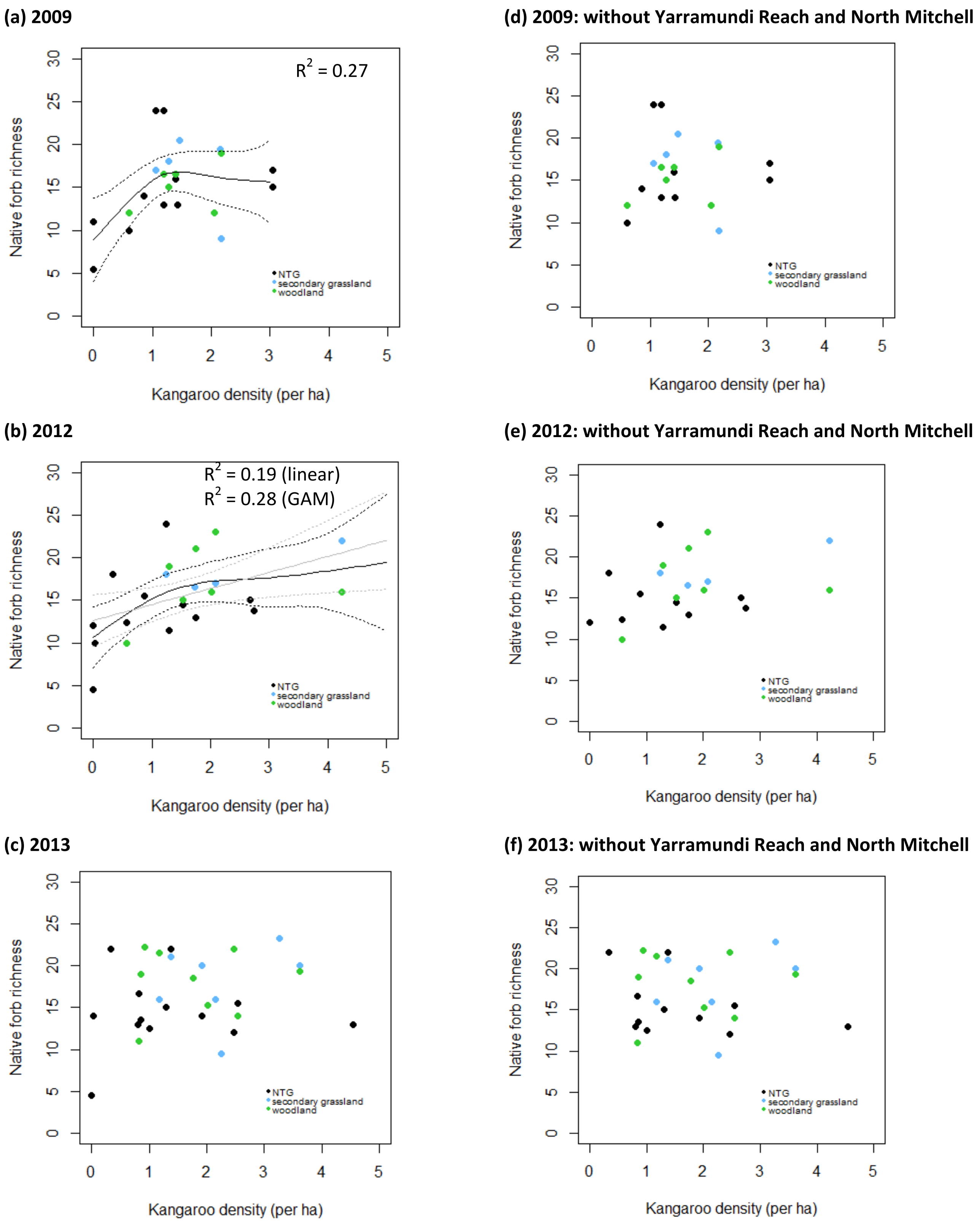


Figure 26: Relationships between kangaroo density and native forb richness. (a) to (c) include all sites, whereas (d) to (f) are the same graphs but with Yarramundi Reach and North Mitchell removed as outliers. Fitted curves are predictions (+ 95% confidence intervals) from significant GAMs; in (b) the grey curves are from a significant linear fit.

For exotic species richness, there was no evidence of any significant linear or non-linear relationship with kangaroo density in any year (Figure 27).

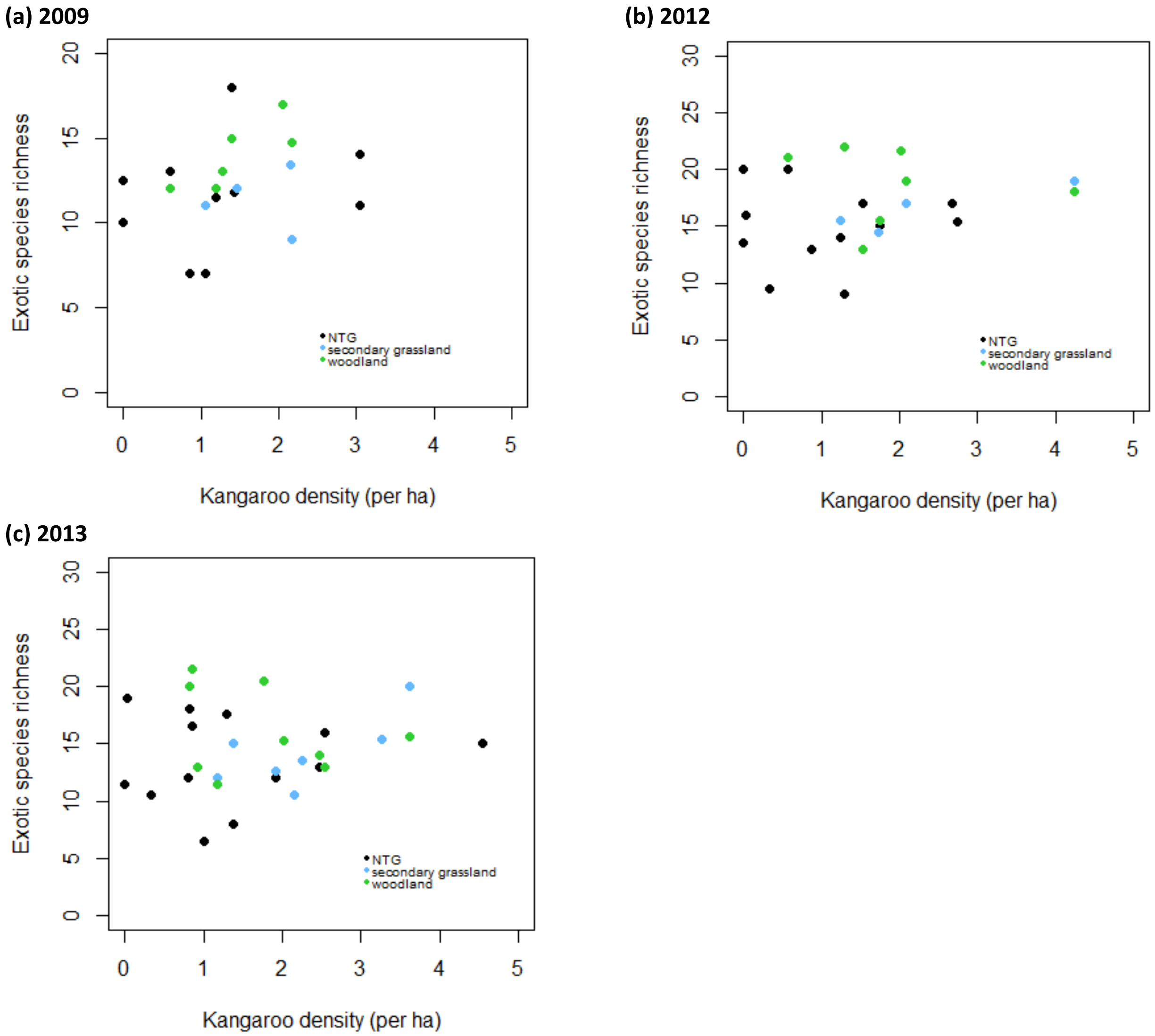


Figure 27: Relationships between kangaroo density and exotic species richness in (a) 2009, (b) 2012 and (c) 2013, with all sites pooled.

Counts of all individuals of all indicator species

ANCOVA indicated that was a marginally significant interaction between kangaroo density and vegetation structure in 2012, but no significant interaction for 2009 or 2013 (Table 34). Therefore, further investigation of the relationships between kangaroo density and indicator species counts were examined for all sites pooled together in 2009 and 2013, but for 2012 patterns were examined within each vegetation structure type separately.

Table 34: ANCOVA results for indicator species (counts of all individuals). P values: *** = $P < 0.001$, ** = $P < 0.001$, * = $P < 0.05$, # = $P < 0.08$, ns = non-significant.

Year	Predictor variable	d.f.	Mean Squares	F-statistic (*P* value)
2009	**Kangaroo density**	1	19555	2.149 (ns)
	Vegetation structure	2	9835	1.081 (ns)
	Kangaroo density x vegetation structure	2	13562	1.490 (ns)
	Residuals	16	9100	
2012	**Kangaroo density**	1	200	0.209 (ns)
	Vegetation structure	2	897	0.393 (ns)
	Kangaroo density x vegetation structure	2	3269	3.4525 #
	Residuals	17	954	
2013	**Kangaroo density**	1	2128	0.304 (ns)
	Vegetation structure	2	3263	0.466 (ns)
	Kangaroo density x vegetation structure	2	788	0.113 (ns)
	Residuals	23	6999	

There was no evidence of any relationship between kangaroo density and indicator species in 2009 (Figure 28a).

In 2012, there was evidence of a linear relationship only within woodland sites ($F_{1,5} = 9.396$, adjusted R^2 = 0.58, $P = 0.03$; Figure 29). However, this relationship was based on only seven data points and there was considerable scatter around the predicted curve.

In 2013, GAM indicated a marginally significant non-linear relationship between kangaroo density and indicator species, consisting of an initial negative relationship, followed by a positive increase ($F = 3.092$, adjusted $R^2 = 0.15$, $P = 0.06$; Figure 28b). Again, there was considerable scatter in the data points around the predicted curve.

(a) 2009 (b) 2013

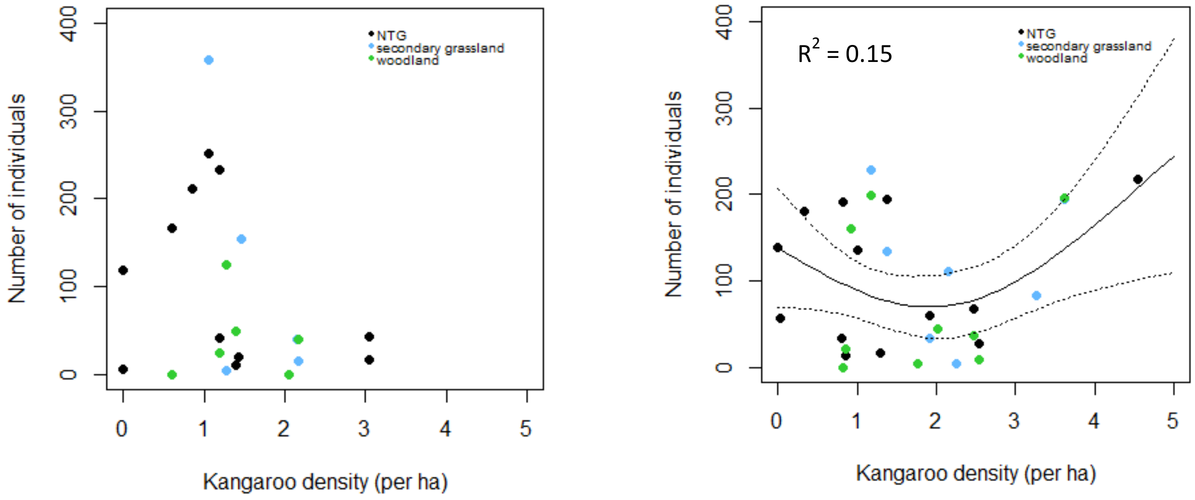


Figure 28: Relationships between kangaroo density and indicator species in (a) 2009 and (b) 2013, with all sites pooled.

(a) 2012 – NTG (b) 2012 – Secondary grasslands (c) 2012 - Woodlands

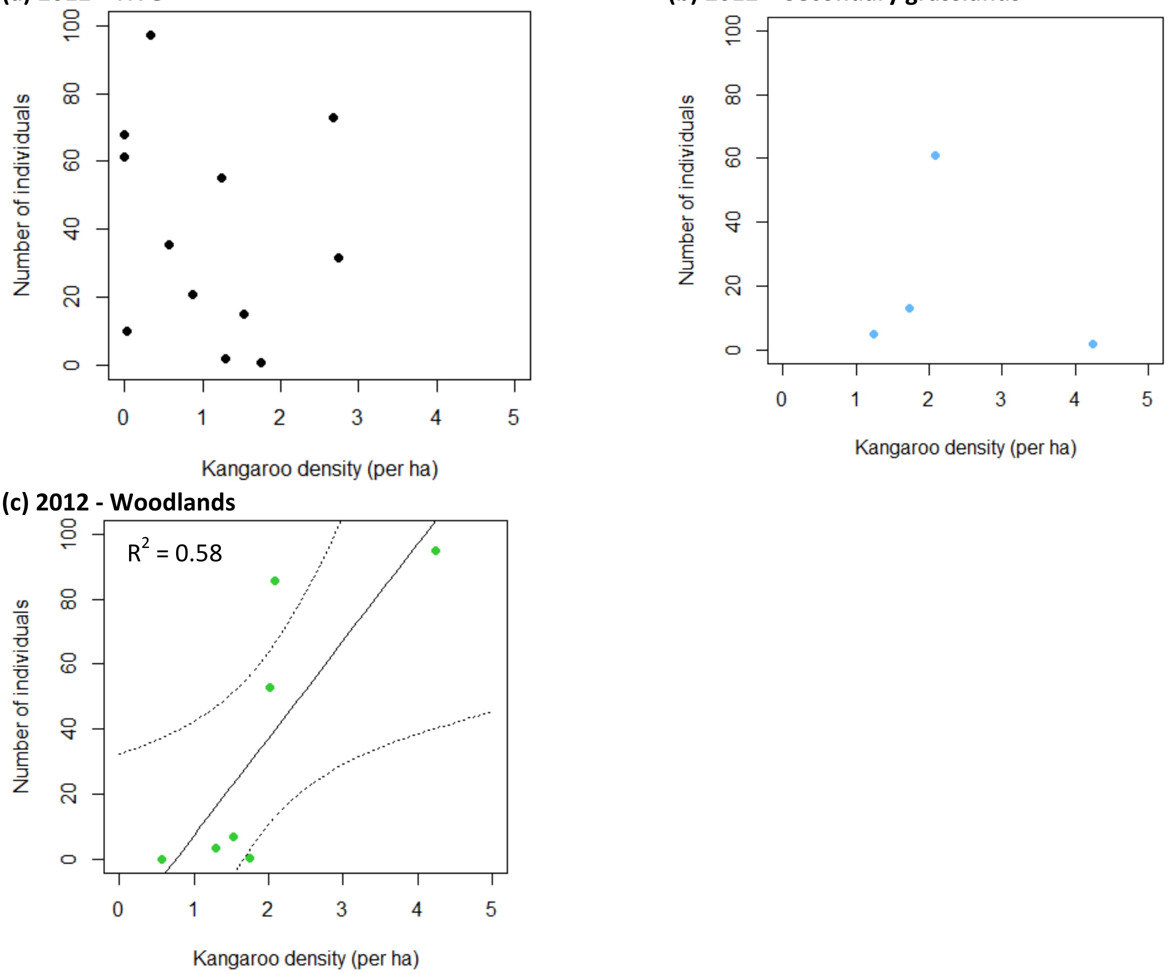


Figure 29: Relationships between kangaroo density and indicator species abundance in 2012 for (a) NTG, (b) secondary grasslands and (c) woodlands. Fitted curves are predictions (+ 95% confidence intervals) from significant linear regressions.

4.3.4 PREDICTION 2

Prediction 2 was *"Kangaroo density will be positively related to inter-tussock space."*

ANCOVA indicated that there was a marginally significant interaction between kangaroo density and vegetation type for inter-tussock space in 2013, but not in 2009 or 2012 (Table 35). Therefore, further investigation of the relationships between kangaroo densities and inter-tussock space were examined for all sites pooled together in 2009 and 2012, but for 2013 patterns were examined within each vegetation structure type. ANCOVA indicated evidence of significant linear relationships with kangaroo density in 2009 and 2012.

Table 35: ANCOVA results for inter-tussock space. *P* values: * = *P* < 0.001, ** = *P* < 0.001, * = *P* < 0.05, # = *P* < 0.08, ns = non-significant.**

Year	Predictor variable	d.f.	Mean Squares	F-statistic (*P* value)
2009	**Kangaroo density**	1	723.4	3.925 #
	Vegetation structure	2	208.3	1.130 (ns)
	Kangaroo density x vegetation structure	2	84.4	0.458 (ns)
	Residuals	16	184.3	
2012	**Kangaroo density**	1	703.1	4.638 *
	Vegetation structure	2	599.9	3.958 *
	Kangaroo density x vegetation structure	2	60.1	0.397 (ns)
	Residuals	17	151.6	
2013	**Kangaroo density**	1	166.0	0.712 (ns)
	Vegetation structure	2	650.8	2.792 (ns)
	Kangaroo density x vegetation structure	2	707.1	3.033 #
	Residuals	23	233.1	

Marginally significant linear relationships were evident in both 2009 ($F_{1,20}$ = 4.093, adjusted R^2 = 0.13, *P* = 0.06; Figure 30a) and 2012 ($F_{1,21}$ = 3.789, adjusted R^2 = 0.11, *P* = 0.07; Figure 30b). There was no improvement to the fit when using GAM to explore non-linear relationships. The site with the very high cover of inter-tussock space in 2009 was Dunlop NR, which was previously identified as an outlier (Section 4.2.1).

In 2012, although ANCOVA detected a significant difference in inter-tussock space between vegetation structures (which was higher in woodlands), there was no relationship with kangaroo density when examining each structure type separately (not shown).

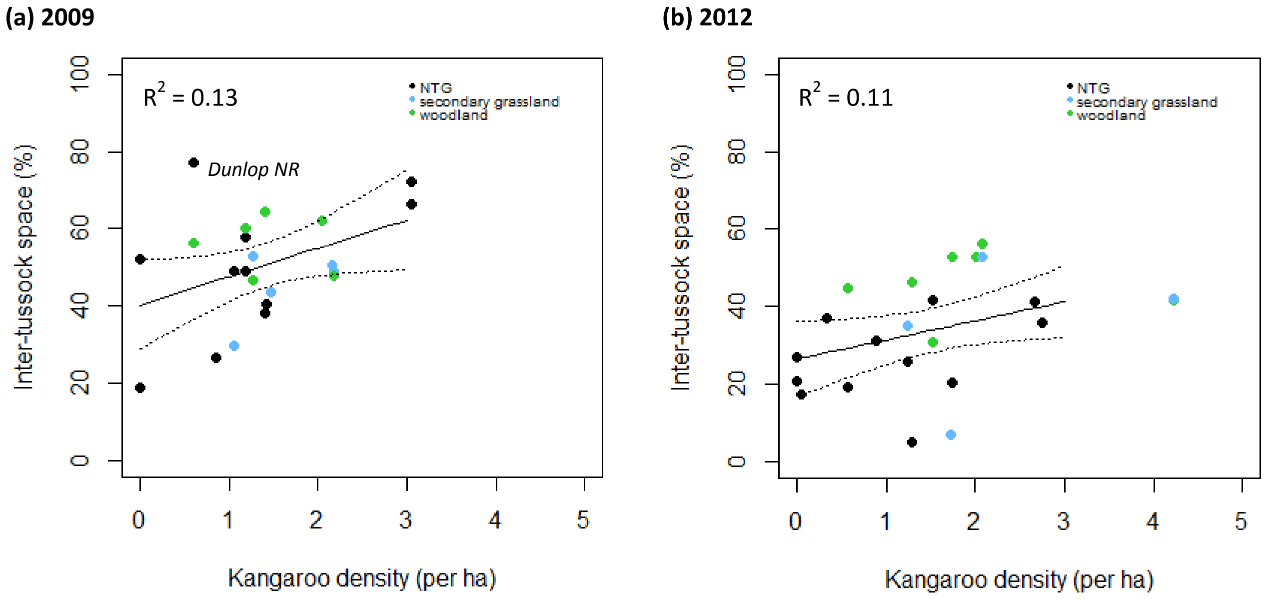


Figure 30: Relationships between kangaroo density and inter-tussock space in (a) 2009 and (b) 2013, with all sites pooled. Fitted curves are predictions (+ 95% confidence intervals) from significant regressions.

In 2013, no significant relationship was found between kangaroo density and inter-tussock space when examining vegetation types separately (Figure 31). There was also no evidence of a relationship with all sites pooled together (not shown).

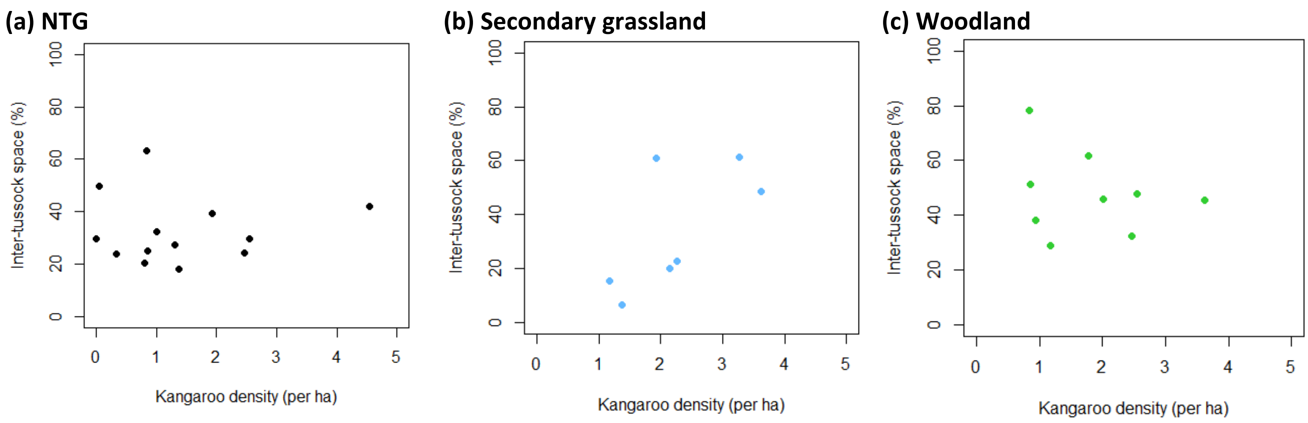


Figure 31: Inter-tussock space for 2012 and 2013, separated by vegetation structure.

4.3.5 PREDICTION 3

Prediction 3 was "*Kangaroo density will be negatively related to native grass cover and understorey vegetation height.*"

Native grass cover

ANCOVA indicated that there was no interaction between kangaroo density and vegetation structure type in any year (Table 36). Therefore, all sites were pooled together for further analyses. There was weak evidence of a significant linear relationship with kangaroo density in 2009.

Table 36: ANCOVA results for native grass cover. *P* values: *** = $P < 0.001$, ** = $P < 0.001$, * = $P < 0.05$, # = $P < 0.08$, ns = non-significant.

Year	Predictor variable	d.f.	Mean Squares	F-statistic (*P* value)
2009	Kangaroo density	1	613.8	3.641 #
	Vegetation structure	2	171.3	1.016 (ns)
	Kangaroo density x vegetation structure	2	62.1	0.369 (ns)
	Residuals	15	168.6	
2012	Kangaroo density	1	5.55	0.024 (ns)
	Vegetation structure	2	172.40	0.739 (ns)
	Kangaroo density x vegetation structure	2	110.02	0.472 (ns)
	Residuals	17	233.33	
2013	Kangaroo density	1	0.1	0.0 (ns)
	Vegetation structure	2	483.1	1.332 (ns)
	Kangaroo density x vegetation structure	2	884.7	2.440 (ns)
	Residuals	23	362.6	

A marginally significant linear relationship between kangaroo density and native grass cover was found in 2009 ($F_{1,20} = 3.879$, adjusted $R^2 = 0.12$, $P = 0.06$; Figure 32a). GAM did not show any significant non-linear relationship.

No evidence of any relationships, either linear or non-linear, were detected in 2012 (Figure 32b) or 2013 (Figure 32c).

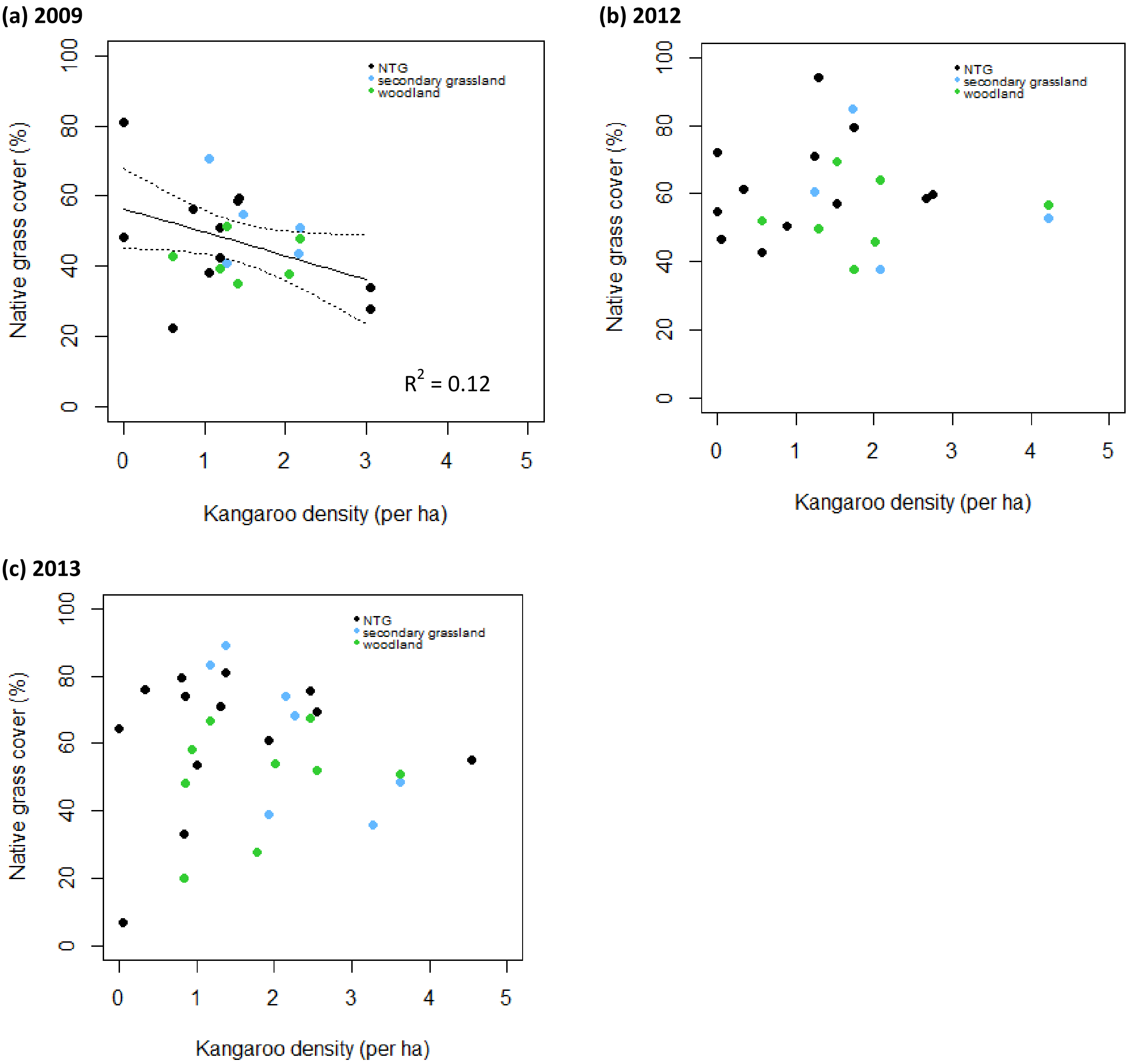


Figure 32: Relationships between kangaroo density and native grass cover. Fitted curves are predictions (± 95% confidence intervals) from significant linear regressions.

Vegetation height

ANCOVA indicated a marginally significant interaction between kangaroo density and the percentage cover of short vegetation in 2013 (< 10 cm in height), as measured using the LiSM (Table 37a). As a consequence, the relationship between short vegetation and kangaroo density was examined for each vegetation structure type separately. ANCOVA also indicated a significant effect of kangaroo density.

There was no significant interaction between kangaroo density and the percentage cover of tall vegetation in 2013 (> 30 cm in height), as measured using the LiSM (Table 37b). ANCOVA also indicated a significant effect of kangaroo density; all sites were pooled to examine this further (Figure 34).

Table 37: ANCOVA results for the percentage cover of (a) short vegetation (< 10 cm in height) and (b) tall vegetation (> 30 cm in height). *P* values: *** = *P* < 0.001, ** = *P* < 0.001, * = *P* < 0.05, # = *P* < 0.08, ns = non-significant.

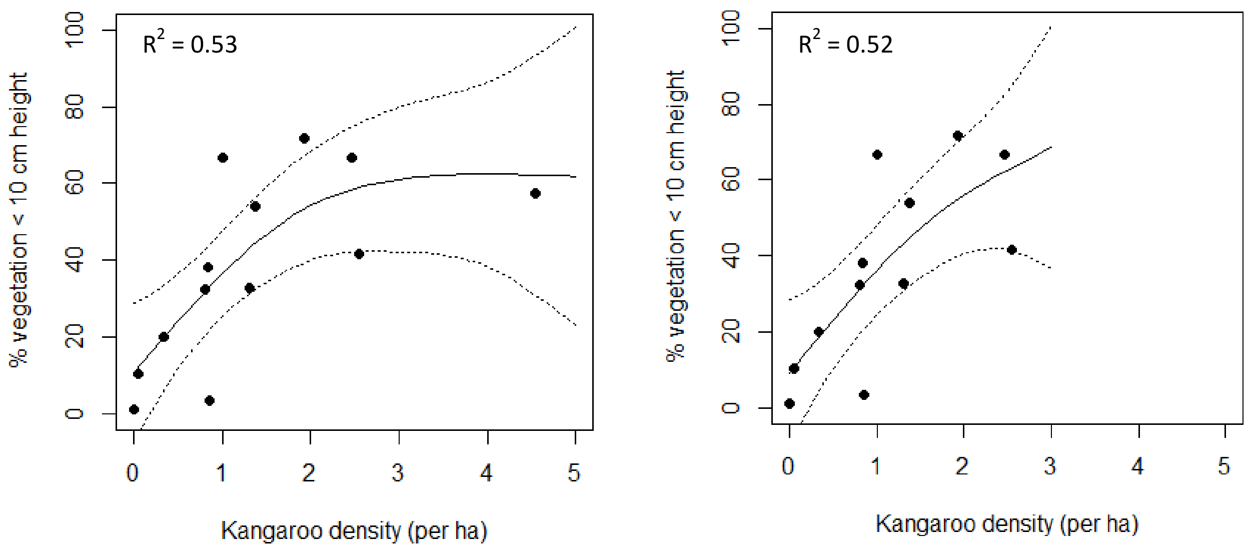
		(a) Short vegetation			(b) Tall vegetation		
Year	**Predictor variable**	**d.f.**	**Mean Squares**	**F-statistic (*P* value)**	**d.f.**	**Mean Squares**	**F-statistic (*P* value)**
2013	**Kangaroo density**	1	2286.0	6.163 *	1	1348.9	9.424 **
	Vegetation structure	2	225.5	0.608	2	101.0	0.705 (ns)
	Kangaroo density x vegetation structure	2	1111.1	2.995 #	2	378.5	2.644 (ns)
	Residuals	23			23	195.0	

GAM indicated a significant non-linear relationship between kangaroo density and the percentage cover of short vegetation in NTG, with an initial positive increase followed by a plateau above ~ 2 kangaroos per ha (F = 6.018, adjusted R^2 = 0.53, *P* = 0.02; Figure 33a). However the shape of the relationship was strongly influenced by one site (Jerrabomberra East outside of the kangaroo exclosure) which had a very high kangaroo density. Excluding this site strongly altered the shape of the relationship, albeit with similar model R^2 (F = 8.028, adjusted R^2 = 0.52, *P* = 0.01; Figure 33b). However, without this site there is no information about the response of short vegetation at kangaroo densities over 2.5 per ha.

No relationship was evident in secondary grasslands (Figure 33c) or woodlands (Figure 33d).

(a) NTG

(b) NTG – with Jerrabomberra East excluded



(c) Secondary grasslands

(d) Woodlands

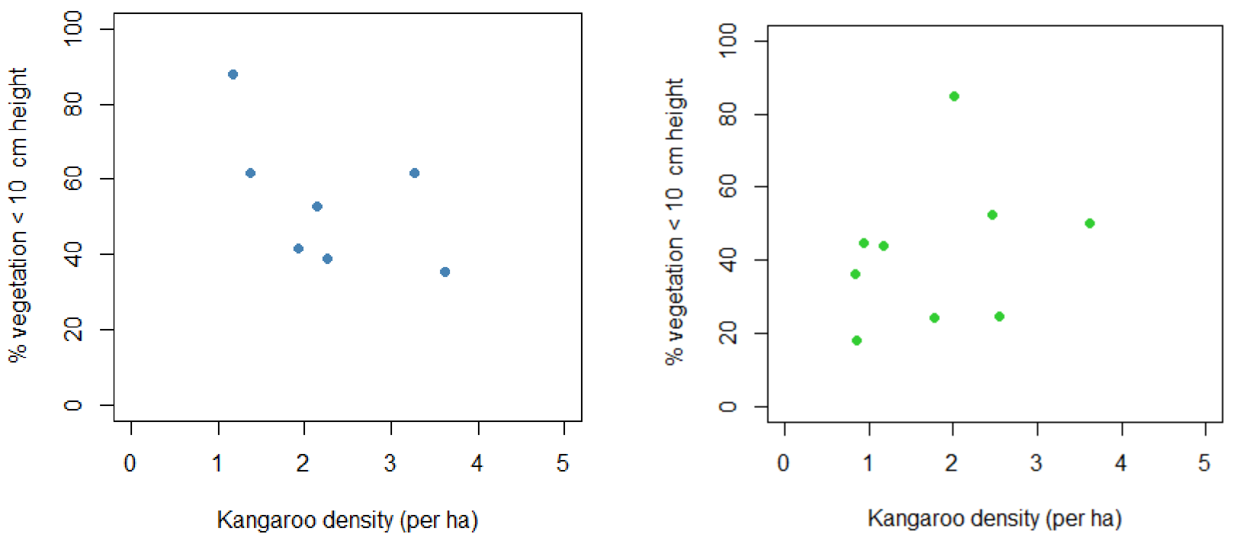


Figure 33: Relationships between kangaroo density and short vegetation in 2013 (< 10 cm, measured as the % of height class categories 5 and 6 using the LiSM); separate analyses for each vegetation structure. Fitted curves are predictions (+ 95% confidence intervals) from significant GAMs.

A significant negative linear relationship was found between kangaroo density and the percentage cover of tall vegetation ($F_{1,27}$ = 8.568, adjusted R^2 = 0.24, *P* < 0.001; not shown). GAM showed an improved fit with a significant non-linear relationship, consisting of an initial decrease in the percentage cover of tall vegetation with increasing kangaroo density, followed by a flattening of the curve above 2 per ha (F = 6.22, adjusted R^2 = 0.42, *P* < 0.001; Figure 34).

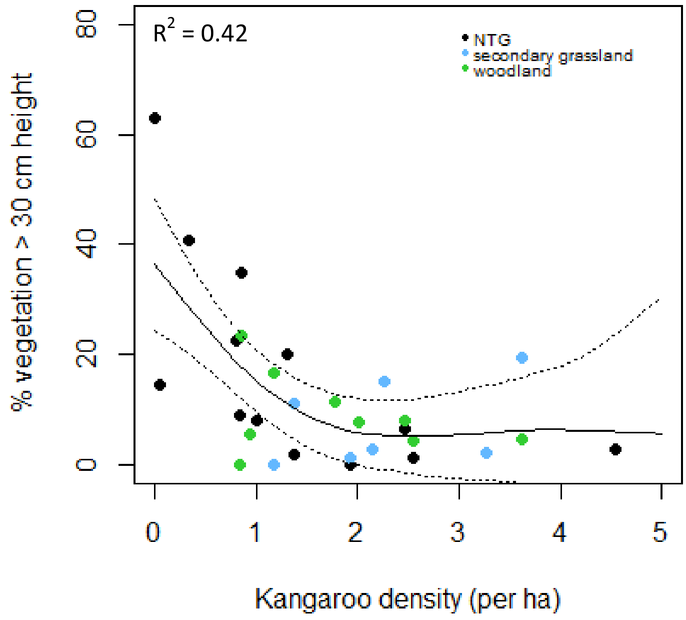


Figure 34: Relationship between kangaroo density and tall vegetation in 2013 (> 30 cm, measured as the % of height class categories 5 and 6 using the LiSM). Fitted curves are predictions (± 95% confidence intervals) from significant GAMs.

5 Discussion

5.1 Overview of findings

The aim of this report was to determine whether relationships exist between kangaroo density and vegetation condition in Canberra's lowland grasslands and grassy woodlands, using data collected in 2009, 2012 and 2013.

Overall, few statistically significant relationships were identified between kangaroo density and a range of response variables relating to plant species richness, diversity and vegetation structure. Many relationships that were identified tended to have low or marginal levels of statistical significance and explained little variation in the data, and hence had large confidence intervals and poor predictive power. Therefore, using these relationships to predict how vegetation at a specific site might respond to a particular kangaroo density or change in density would involve a high degree of uncertainty. These and other caveats are discussed in more detail below.

The key statistically significant results from the analyses are as follows:

1. Relationships between kangaroo density and species diversity/richness

- Native species richness and native forb richness were related to kangaroo density in 2009 and 2012. The relationships were non-linear and characterised by a positive relationship between richness and kangaroo density at low kangaroo densities (0 to ca. 2 per ha) followed by a plateau (no relationship) above ca. 2 per ha. These positive relationships disappeared when the two NTG sites with zero (or near to zero) kangaroo densities were excluded from the analysis.
- Species diversity in this study was assessed with the Floristic Value Score. There was a marginally positive linear relationship between FVS and kangaroo density in 2012. FVS varied widely across sites (range <10 to >40) in all years.
- There was a marginally significant non-linear relationship between abundance (counts) of indicator species and kangaroo density in 2013, with minimum abundance occurring at medium kangaroo densities.

2. Relationships between kangaroo density and vegetation structure

- There was a positive linear relationship between inter-tussock space and kangaroo density in 2009 and 2012 but not 2013. The slope of the relationship was steeper (i.e. inter-tussock space rose more rapidly with kangaroo density) in 2009 than in 2012.
- A negative relationship between native grass cover and kangaroo density was found in 2009 (a drought year).
- Kangaroo density was related to vegetation height: as kangaroos increased in density, the percentage cover of short vegetation increased, and the percentage cover of tall vegetation decreased. For tall vegetation this relationship was non-linear with a rapid decline in tall vegetation between 0 and 2 kangaroos per ha but no relationship between 2 and 4 per ha.

In addition:

- There was no consistent relationship across the two survey time periods (2009-2012 or 2012-2013) between changes in vegetation response variables and changes in kangaroo densities. For example, relatively large changes in kangaroo densities were not consistently associated with relatively large changes in vegetation response variables.

5.2 Addressing the predictions

This report posed several predictions by applying the Intermediate Disturbance Hypothesis to the dynamics of lowland grassy ecosystems in the ACT. An important outcome was to identify whether there are upper and lower kangaroo densities that result in a decline in species richness/diversity and overall vegetation condition, and whether there is an optimal kangaroo density that results in the maximum species richness/diversity and vegetation condition.

Prediction 1: *A relationship will exist between kangaroo density and species richness/diversity. The IDH specifically predicts that the relationship will be humped-shaped, with the highest species richness/diversity evident under intermediate levels of kangaroo grazing pressure.*

- There was partial support for this prediction. Native species (and forb) richness and the FVS were positively related to kangaroo density at lower levels of kangaroo density (0 to ca. 2 per ha) but not across higher densities. These data suggest that the presence of at least *some kangaroos* is important for maintaining diversity. Previous research in south eastern Australia also suggests that species diversity may decline in undisturbed grassy ecosystems, particularly in productive *Themeda*-dominated grasslands (Morgan 1998; Schultz *et al.* 2011; Lunt *et al.* 2012).
- However, this result was largely driven by data from two unusual sites, North Mitchell and Yarramundi Reach. Both are relatively small and isolated NTG sites surrounded by busy roads. Other factors relating to site size, habitat continuity, and location may also account for their poor vegetation quality (particularly Yarramundi Reach) rather than solely a lack of kangaroo grazing. For example, species richness can be lower in small sites because of the absence of infrequent species and increased exotic species invasion, even when grazing pressure is low (Prober & Thiele 1995).
- There was no decline in species richness or diversity (measured as FVS) detected at higher kangaroo densities (> ca. 2 per ha). There are several possible explanations for this result, including:
  - No such relationship exists. For example, native forb and grass species of south-eastern Australian grassy ecosystems tend to respond differently to gradients of grazing pressure, with some favoured by higher levels of grazing, whereas others can decline, even under low grazing levels (e.g. Prober & Thiele 1995). This could result in little change when examining overall species richness, even though the species composition may be changing in relation to grazing pressure. However, the FVS – which takes into account the abundance of Indicator Species that are sensitive to grazing, as well as species richness – also showed no relationship at higher levels of grazing pressure.
  - Maximum kangaroo densities were too low for an effect to be found. Sites with higher densities are required to examine any impact at densities above that examined in this study.
  - Relationships exist but were undetectable due to the confounding influence of variation in other site-level factors. This issue is discussed further below, with suggestions of experimental designs to improve detectability of kangaroo grazing impacts.
- Overall this study could not identify any upper limit of kangaroo density that results in a decline in species richness or diversity and overall vegetation condition, nor an optimal kangaroo density that maximises species richness or diversity and vegetation condition. Additional sites (if available) with higher kangaroo densities are probably necessary to examine vegetation responses at very high densities. Inferences from this study can only extend to ca. 4 kangaroos per ha, and to only ca. 3 ha kangaroos in drier years such as 2009.

Prediction 2: *Kangaroo density will be positively related to inter-tussock space.*

- Evidence for this prediction was found in 2009 and 2012. The relationship was apparently steeper in 2009 (regression equations: 2009: *% inter-tussock space = 7.307 x kangaroo density + 40.318*; 2012: *% inter-tussock space = 4.908 x kangaroo density + 26.550*). Notably, inter-tussock space also tended to be greater in 2009 than in 2012 and 2013. Collectively these data suggest that the relationship between inter-tussock space and kangaroo density may be more apparent in drier years. Plausible mechanisms for this result include an increased impact of grazing in years of lower pasture productivity, and a shift to a less selective diet in dry years.

Prediction 3: *Kangaroo density will be negatively related to native grass cover and understorey vegetation height.*

- There was weak (marginally significant) evidence that native grass cover declined with kangaroo density in 2009. No relationships were found in other years. Again, similarly to the previous prediction, it may be that such a relationship is stronger in dry years, when pasture growth tends to be lower.
- Increasing kangaroo density was significantly associated with a decline in the cover of taller vegetation (over 30 cm) across all sites in 2013 (when data were available). However, this relationship was weak or absent across higher kangaroo densities (2-4 per ha). Short vegetation (less than 10 cm) increased with kangaroo density; but this was only evident in NTG sites. The lack of a relationship in woodlands and secondary grasslands may be due to the overriding effect of the tree canopy (or legacy of a tree canopy, for secondary grassland sites), on grass growth and cover, although this was not explicitly tested. The lack of a result could also be due to low sample sizes in woodland and secondary grassland habitats.
- Data for examining the effect of kangaroo density on vegetation height was only available for 2013. Further examination of the response of vegetation height in future surveys would therefore be useful to determine whether there are year to year differences in this relationship.

5.2.1 SUMMARY OF RESULTS IN RELATION TO PREDICTIONS

Overall, these results indicate that there is little association between kangaroo density and vegetation richness and diversity across lowland grassy ecosystems of the northern ACT. There tended to be a consistent association between kangaroo density and vegetation structure, and in particular a shift in the dominance of taller to shorter vegetation, a decline in native grass cover, and an increase in inter-tussock space with increasing kangaroo density. However, these relationships varied by year and often also varied by vegetation type.

A closer examination of whether structural changes in vegetation are linked to changes in the understorey fauna of these grassy ecosystems is a topic for possible future research.

5.3 Caveats

5.3.1 UNCERTAINTIES IN PREDICTIONS

- Although some relationships were statistically significant, *predictions* from these relationships of vegetation characteristics at a particular kangaroo density are likely to be uncertain. Most relationships had very low or marginal levels of statistical significance, low goodness-of-fit, large amounts of scatter and wide confidence intervals. Indeed, vegetation composition varied greatly across years irrespective of kangaroo numbers; for example sites in which kangaroo density changed by less than one per ha between 2009 and 2012 experienced anywhere from a 50% decrease and more than 100% increase in FVS (Figure 18a).
- ***High kangaroo densities***: As the results showed no relationship between most vegetation response variables and higher levels of kangaroo densities (e.g. above ca. 2 per ha), it is difficult to extrapolate the relationships to higher densities. Furthermore, kangaroo densities reached a lower maximum in 2009 (the year at the end of the prolonged drought) than in 2012 and 2013, making any extrapolation to higher kangaroo densities in dry years particularly uncertain.
- ***Low kangaroo densities****:* The results showed that native species (and forb) richness and the FVS only increased across lower kangaroo densities (between 0 and ca. 2 per ha). This suggests that the presence of at least *some kangaroos* is important for maintaining diversity. However this result was largely driven by data from two small NTG sites, North Mitchell and Yarramundi Reach, and so surveying additional sites that have zero (or close to zero) kangaroo densities in other vegetation types, and in larger and less

isolated reserves, would help clarify this relationship. Additionally it is not certain that the reintroduction of kangaroos into poor quality sites where they are currently absent will result in a subsequent increase in native species richness and diversity. Improved floristic diversity or richness following grazing reintroduction is dependent on a range of factors, such as the presence of a viable native seed bank, the nature of canopy gaps, and the response of invasive species (Lunt *et al.* 2007). As St Mark's Cathedral illustrates, floristic diversity in small, isolated sites in urban areas may perhaps be maintained via other disturbance regimes, such as frequent prescribed burning.

5.3.2 YEAR TO YEAR VARIABILITY

The results indicated that the relationships between kangaroo density and variables relating to vegetation condition can vary depending on the year of survey, with relationships present in some years, but not in others. Indeed, the strongest patterns were usually most evident in 2009, at the end of a long drought. Since only one drought year was sampled, this hypothesis would need to be tested in other dry years to determine whether the result is repeatable.

Clearly, however, the data show that the any effect of kangaroo density on vegetation structure needs to be considered within the context of the prevailing climate at the time. This finding supports previous research which has found complex relationships between year to year differences in climate, grazing and vegetation response (e.g. Leigh *et al.* 1989). Ultimately, management of this system may need to be conducted over longer timeframes that recognises the importance of complex or cyclical vegetation dynamics.

5.3.3 EXPERIMENTAL DESIGN

- Survey plots were purposely located in high quality vegetation patches. Therefore, results from this study are relevant only for high quality vegetation. It is possible that poorer quality vegetation may respond differently to kangaroo grazing pressure; for example, if high numbers of exotic species are present or if there is no viable seed bank for native species to recover from.
- The results of this study assume that kangaroo density estimates are accurate. Any variability around the estimates of the predictor variable is likely to reduce the strength of the relationship with the response variables. It is beyond the scope of this study to comment on the methods for estimating kangaroo densities.
- The first time period (2009-2012) was a three year period, whereas the second time period (2012-2013) was a one year time period. The lack of data from 2010 and 2011 limits any conclusions that can be drawn about post drought recovery of vegetation and the relationship to kangaroo densities. There is also no information on any potential year to year changes within the three year period between 2009 and 2012.
- This study focused on differences between broad vegetation structure types: NTG, woodland and secondary grassland. However, other site to site differences may influence the effect of kangaroo grazing and could warrant further investigation (see next section). For example, grassland sites dominated by *Themeda triandra* tend to occur on sites with different soil types, land use histories, landscape position and microclimate than those dominated by *Austrostipa* and *Rytidosperma* species (NSW Office of Environment and Heritage 2011). Thus it is possible that the effects of kangaroo grazing may be more evident within particular grassland types (e.g. Schultz *et al.* 2011). Refinement of models by incorporation of these variables might increase the ability to detect relationships between kangaroo grazing pressure and vegetation condition.

5.3.4 POTENTIAL INFLUENCE OF OTHER FACTORS

It can be very difficult in correlative studies to detect the influence of a particular variable in multivariate situations where many factors influence the variable simultaneously. In this study there was a high degree of site to site variation; for example sites ranged from very large reserves located away from urban areas (e.g. Googong Foreshores and Goorooyaroo NR), to small isolated inner city sites (e.g. St Mark's Cathedral). It is therefore likely that a range of other factors influence vegetation diversity and condition, and indeed kangaroo grazing pressure. Isolating the effect of kangaroo density may therefore be better approached through an experimental design (see next section). Other factors that may be influencing vegetation diversity and condition include:

- Land use history, such as historical grazing practices and present day grazing pressure from other animals. For example, sheep were observed grazing in the woodland plot at Dunlop NR during the 2013 surveys. However, data on recent grazing by domestic animals at each site was not available for this report. There may also be differences in rabbit grazing pressure across sites.
- Site to site differences, such as soil type and nutrient content, landscape position (e.g. slope position), tree cover, and grassland type (e.g. *Themeda triandra* vs. *Austrostipa* or *Rytidosperma*-dominated grasslands). For example, grass biomass production and species interactions in south-eastern Australian grassy ecosystems can be strongly influenced by tree cover (suppressing grass growth) and soil N availability (Schultz *et al.* 2011)
- Site connectivity and size.
- Variability in the movement and grazing pressure of kangaroos within a site.

5.4 Comments on the Jerrabomberra East and West exclosures

It is difficult to draw conclusions from the single large kangaroo exclosures at Jerrabomberra East and West Nature Reserves, particularly at Jerrabomberra East which contains only one survey plot inside and one survey plot outside of the fence. This represents a case of confounding, where the effect of the treatment (kangaroo exclusion) cannot be separated from other potentially influential factors; i.e. any differences in response variables could simply be due to differences in the two plots, such as where they are located. Nevertheless, some observations can be made from the results from these two sites.

At Jerrabomberra East in 2009, when the fence was first installed, native grass cover and inter-tussock space was fairly comparable between the plots (Table 21). By 2012 and 2013 inter-tussock space decreased, and native grass cover increased, in both plots. However, at the plot inside the exclosure, inter-tussock space declined to lower levels compared to outside (ca. 20% vs. ca. 40%), and native grass cover increased to higher levels compared to outside (ca. 70-80% vs. ca. 55%). This is consistent with other studies that have found increases in grass biomass and cover with grazing exclusion, particularly in *Themeda*-dominated grasslands (Prober & Thiele 1995; Morgan & Lunt 1999; Prober *et al.* 2007). However, more replicates are needed to support this result.

At Jerrabomberra West, differences in inter-tussock space and native grass cover over time between the plots were less clear and not necessarily supportive of the hypothesis that grass cover will increase in the absence of grazing. In 2012 and 2013 inter-tussock space was actually lower, or approximately the same, at the NTG site outside of the exclosure compared to the average of the two sites within the exclosure (Table 22). Similarly, native grass cover increased both inside and outside of the exclosure, and was higher in 2012 outside of the exclosure compared to the sites within.

However, it is interesting to compare the ground cover photographs taken at the two reserves (Figure 35, Figure 36). Although these are only photographs, the presence of larger grass tussocks suggest that grass biomass, and grass height, is greater in 2012 and 2013 in the plots inside the grazing exclosures. They also illustrate the year to year differences in vegetation, particularly the lower overall cover in 2009. This indicates that differences may instead be more evident when examining grass biomass and height, rather than assessing change by cover only.

Indeed, comparison of the percentage cover of tall and short vegetation (using the LiSM; data available for 2013 only) shows that short vegetation is reduced and tall vegetation increased inside the grazing exclosures (Figure 37).

This suggests that variables relative to vegetation/grass height, and potentially biomass, may be informative data to examine in future research.

OUTSIDE EXCLOSURE (GRAZING)	INSIDE EXCLOSURE (GRAZING EXCLUDED)
2009	2009

2012	2012

2013	2013

Figure 35: Ground cover photographs from Jerrabomberra East Nature Reserve.

OUTSIDE EXCLOSURE (GRAZING)	INSIDE EXCLOSURE PLOT 1 (GRAZING EXCLUDED)	INSIDE EXCLOSURE PLOT 1 (GRAZING EXCLUDED)

2009

2012

2013

Figure 36: Ground cover photographs from Jerrabomberra West Nature Reserve.

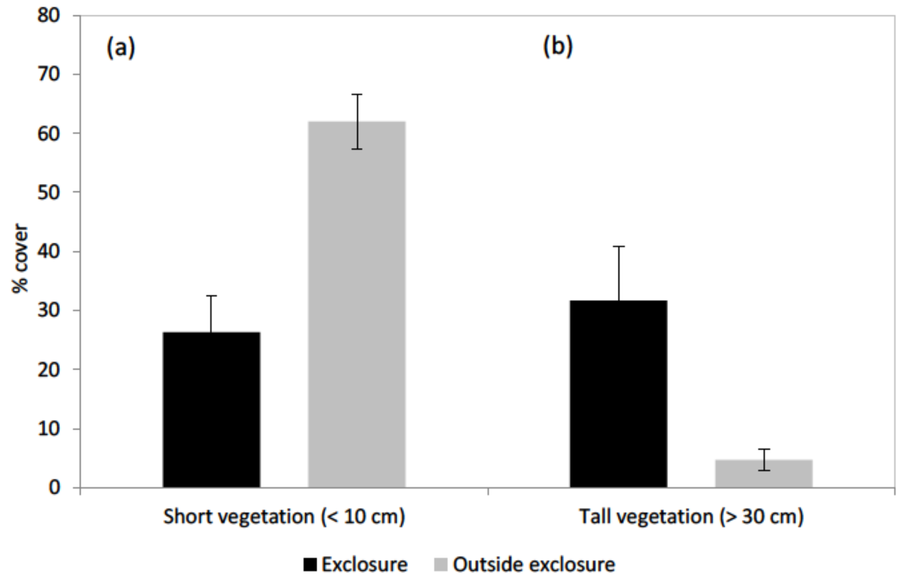


Figure 37: Comparison of vegetation height classes (measured using the LiSM in 2013) between the plots inside and outside of the kangaroo exclosures at Jerrabomberra East and West Nature Reserves. Values are the mean of the plots at the two sites, with standard error. (a) Short vegetation < 10 cm in height; (b) Tall vegetation > 30 cm in height.

5.5 Future research

5.5.1 POSSIBLE EXPERIMENTAL APPROACH TO DETERMINE THE EFFECTS OF KANGAROO GRAZING

A manipulative experimental approach is likely to be more effective at isolating the effect of kangaroo grazing on vegetation structure and composition compared to continuing the present correlative study in future years.

In an experimental approach, kangaroo grazing would be excluded from experimental plots, with the vegetation response of each exclosure compared to a nearby 'paired' plot, located in as similar vegetation as possible, that is unfenced and open to kangaroo grazing. These paired plots would be replicated several times within a site to capture within-site variation.

An ideal experimental design would also include additional plots that allow intermediate levels of kangaroos to graze, by partial exclusion of kangaroos. Because the results from this report suggest that the relationships between kangaroo density and floristics are likely to be non-linear, intermediate densities would help to elucidate the shape of the relationship. However, it is recognised that controlling kangaroo densities in plots is likely to be practically difficult, and that a more realistic design is total exclusion versus non-exclusion, using a fence.

As such, an alternative approach would be to replicate the paired exclosure plots and non-exclosure plots across multiple sites to capture between-site variation across the spectrum of kangaroo densities that exist in the northern ACT region. Surveys conducted prior to fencing and at subsequent time intervals after fencing would then be able to record the trajectories of change in vegetation diversity and structure. Any differences in the trajectories of change between exclosures and non-exclosures could thus be more able confidently attributed to the effects of kangaroo grazing. The different kangaroo densities across sites could act as a comparison of the effect size: for example, it may be hypothesised that the greatest difference in vegetation response between exclosures and non-exclosures would be evident at mid to high kangaroo densities. The limitation of this approach is the potential confounding effect of site to site differences.

It may also be informative to include a third plot for each 'pair' that excluded both kangaroos and rabbits, so that the relative grazing impact of kangaroos and rabbits could be determined, and to counter any interaction that could potentially exist between kangaroo exclusion and rabbit grazing pressure.

Due to the year to year differences in relationships identified in this report, multiple years of surveying – even using an experimental approach – is likely to be required to detect any kangaroo density x year interactions. For example, results from a single year of study may not necessarily apply to other years where climatic conditions differ.

This type of experimental approach is likely to greatly benefit from prior discussions with biostatisticians to ensure that the design, the number of sites and the number of plots are sufficient to answer the questions of interest and to ensure that associated statistics have sufficient power. In particular, issues to consider when designing experiments include: avoiding confounding (i.e. separating differences due to the experimental treatment from other potential influential factors), ensuring sufficient replication at the appropriate scales (e.g. survey plots within sites, and the number of sites), randomisation/unbiased plot selection and treatment allocation, having controls, and ensuring independence of observations (Quinn & Keough 2002).

Alternatively, if a correlative approach is to be continued, additional sites at lower and higher densities of kangaroos could yield more data on the effects of very low and very high kangaroo densities; particularly because in the current study the positive relationships between several response variables and kangaroo densities were driven by only two NTG sites with zero (or close to zero) densities. If future sites and plots are added, it may also be useful to ensure a more even spread among the types of landscapes of interest: e.g. comparisons among woodland vs. grassland sites, or *Themeda* vs. other types of grasslands.

In any future study, it will be important to record as much information as possible about the prior state of the sites, such as land use and grazing history, to reduce uncertainty.

5.5.2 RESPONSE VARIABLES

A large number of response variables were measured in detail at each survey plot in each year. Time could potentially be saved by considering how each variable is to be analysed, and removing those which are either too difficult to analyse, or are correlated with other variables. This study suggests that the Indicator Species count was not particularly useful for analysis, as most species were not well distributed across sites and years. It also raised some issues with the LiSM (see next section).

Measuring structure

The results of this report suggest that kangaroo grazing may exert more influence on understorey vegetation structure than floristics (e.g. species richness and diversity). This is supported by photographic evidence of understorey changes which illustrate potential differences in grass biomass, height and tussock size between sites and years. These changes may not necessarily be captured by assessing cover alone (e.g. Figure 35, Figure 36, and see Appendices). Thus, focusing on variables that assess these types of structural changes could be most informative for future surveys.

Types of response variables

In general, it is easier to analyse response variables that are continuous (e.g. percentage cover, height measured in centimetres, or counts of individuals) rather than categorical (e.g. height classes, broad cover classes), although statistical methods exist for the latter. Often, a categorical response variable is converted to a continuous measure by, for example, taking a mid-point value. If the categories are even and relatively small (e.g. cover classes taken in 10% intervals: e.g. 1-10%, 11-20% etc), then midpoint values can be assigned to each value for analysis. However, for categories that are broad and uneven, such as the height classes in the LiSM, taking midpoint values can be problematic. In many cases, it may be more accurate to record the actual value in the field, and then convert to a category later, if required.

Care should also be taken when constructing variables that have both a continuous and a categorical component. For example, Indicator Species were recorded as counts, up until a value of 100 after which a category ("> 100") is calculated. When analysing these data, the category of ">100" requires a value to be assigned, with no information about whether the counts are a little, or a lot, higher than 100. This approach therefore is likely to underestimate high counts and reduce variability in the estimates between sites at counts of over 100.

5.5.3 LINE-INTERSECT TRANSECT METHOD

The Line-intersect Structure Method (LiSM) was implemented in the 2012 and 2013 surveys to record grassland structure within a site (Armstrong 2013). In this method changes in plant life form categories and foliage height class categories are recorded along a five metre line transect.

Comparison of results between 2012 and 2013 suggests that there is variability in how different surveyors estimate the distance that a particular life form by height class category extends along the line transect, with surveyors in 2012 recording fewer divisions, or changes along the transect, than those in 2013 (Figure 38). This suggests differences in how this method is applied between people (observer error).

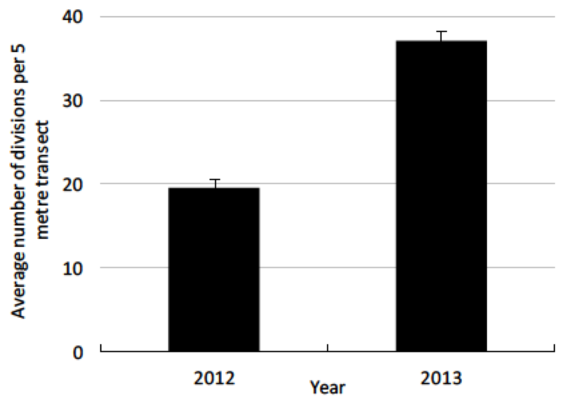


Figure 38: Comparison of LiSM method between observers in 2012 and 2013

A comparison of measurements of native grass cover – one of most frequently recorded categories – between 2012 and 2013 also reveals some key differences. For example, the two most extreme height classes (1 and 6) were rarely recorded in the 2012 survey; however, there was a much more widely spread distribution of values in these height classes in 2013 (Figure 39a,e).

Several other issues were found with the LiSM:

- Number of categories: if all combinations of life forms (12), exotic/native categories (3) and height classes (6) are calculated, then this creates 216 separate variables, too many to be analysed separately. Instead, it would be more efficient to decide which variables are most important for analysis (e.g. native grass, or vegetation height) and focus on measuring fewer variables using a quicker method.
- Tussock size and shape: although these may be good descriptors of the appearance of a grass tussocks there is no simple way to analyse changes in a shape.
- There is no easy way to graph the 2D conceptual model of the grassland structure, nor statistically compare changes between years.
- Finally the method asks for two five metre transects (replicates) to be placed within a floristically and structurally representative vegetation sub-type within the 20 x 20 m site. However, this creates difficulty for statistical analysis because there is no record of the relative weightings of the different sub-types (Figure 40). Alternatives could include:
  - Weighting the vegetation sub-types by their percentage cover of the site.
  - Randomly placing transects in a different location each year (and having at least three transects to ensure sufficient replicates to capture plot-level variation).

- Randomly placing transects in a different location in the first year (and having at least three transects to ensure sufficient replicates to capture plot-level variation), and taking repeated measures in subsequent years. However, this approach may result in cumulative trampling of the vegetation.

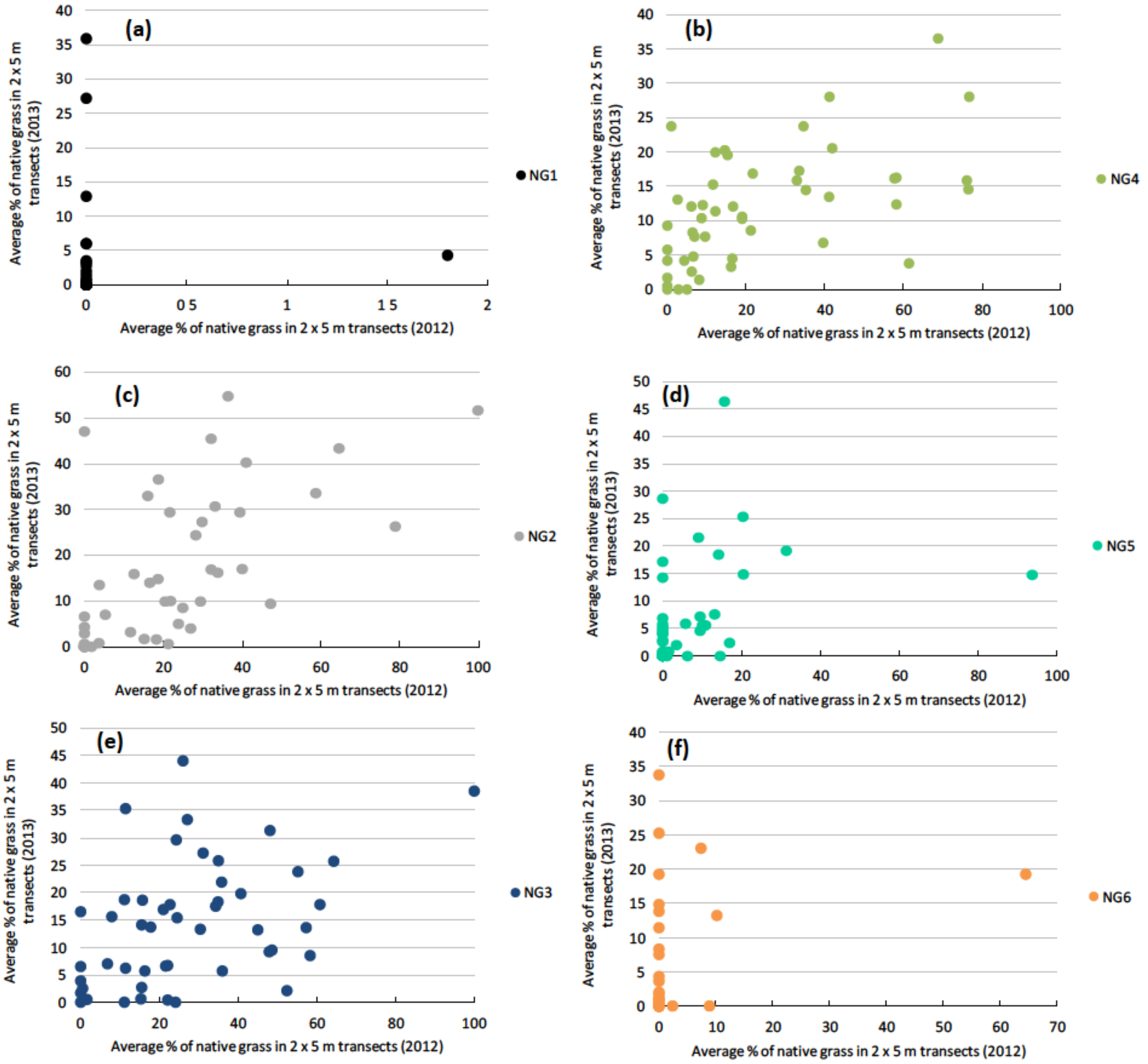


Figure 39: Correlation between 2012 and 2013 measurements of native grass (within height classes); values are average percentage present along two five metre transects located within each site. (a) NG1 = native grass height class 1 (0 cm); (b) NG2 = native grass height class 2 (0 to 5 cm); (c) NG3 = native grass height class 3 (5 to 10 cm); (d) NG4 = native grass height class 4 (10 to 20 cm); (e) NG5= native grass height class 5 (20 to 30 cm); (f) NG6= native grass height class 6 (30+ cm)

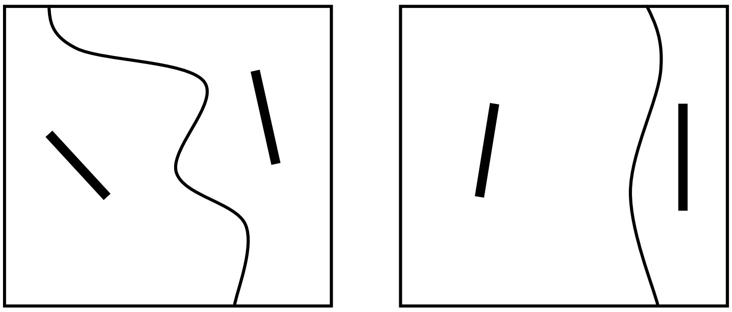


Figure 40: Stylised examples of 20 x 20 m sites with two five metre transects positioned to capture two different vegetation subtypes. Without weighting the sub-types, the smaller sub-type in the right-hand example will disproportionally influence the average.

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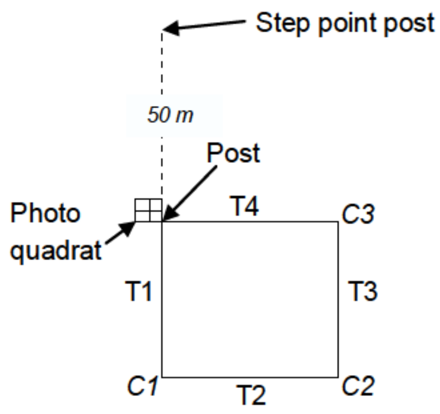
Appendix A Details on survey plot layout and locations

A.1 Layout of survey plots

Each survey plot consisted of a 20 x 20 metre square quadrat, with each side labelled T1 to T4. Each corner is labelled C1 to C4. A star picket is located at C1, and at most sites the remaining three corners are marked by small yellow corner pegs hammered into the ground with nails, enabling them to be searched for with a metal detector. A 50 m long step point transect extends out from C1 to another permanently marked star picket.



Apx Figure A.1: Layout of survey plots.

A.2 Survey plot locations and notes

Locations of all survey plots are provided in the table below. The T4 bearing is the compass bearing along the plot side T4 (see diagram above) when standing at the star picket (C1). Useful notes for locating the and orientating the plots are also provided. For example, in some cases, not all corner pegs were found. At some sites the photo quadrat was located on the inside of the step point transect i.e. alongside T4.

Apx Table A.1: Survey plot locations and comments on location and set up

SITE	SURVEY PLOT ID	EASTING	NORTHING	T4 BEARING	NOTES ON LOCATION / SET UP
Belconnen Naval Transmission Station	BN01	690906	6099827	Not recorded	All corner pegs located. Photo quadrat located alongside T4.
Belconnen Naval Transmission Station	BN02	690034	6100630	Not recorded	All corner pegs located.
Belconnen Naval Transmission Station	BN03	689825	6100714	Not recorded	Two corner pegs not found. Plot runs downhill from post.
Belconnen Naval Transmission Station	BN04	689978	6099947	Not recorded	Only one corner peg located (C3). Photo quadrat located alongside T4.

Belconnen Naval Transmission Station	BN05	690689	6100512	Not recorded	All corner pegs located. Photo quadrat located alongside T4.
Callum Brae NR	CB01	694160	6085711	80°	Survey site lays between both star pickets (i.e. along the step point transect).
Callum Brae NR	CB02	694349	6085439	78°	
Callum Brae NR	CB03	694888	6084670	Not recorded	
Campbell Park	CP01	697280	6093110	Not recorded	All corner pegs found. Lots of St Johns wort in surrounding area. Lots of serrated tussock, most of which has been sprayed.
Campbell Park	CP02	697419*	6093178*	Not recorded	* Co-ordinates not recorded in the field and 2012 datasheet lost. Co-ordinates need to be re-recorded in 2014 surveys. These co-ordinates are estimate off ArcGIS. All corner pegs found. Lots of St Johns wort in surrounding area.
Campbell Park	CP03	697280	6093189	Not recorded	No corner pegs present, need to be put in in 2014
Crace NR	CR01	693746	6099134	Not recorded	Blackberry on step point increased in size. Needs spraying.
Crace NR	CR02	693920	6099719	Not recorded	
Dunlop NR	DU01	683878	6104571	80°	Very hard to locate corner pegs but 2 are present (C1 and C2). Grass has grown over them. Very degraded. Photo quadrat located alongside T4.
Dunlop NR	DU02	684799	6105181	90°	
Dunlop NR	DU03	684681	6105001	186°	Peg present for T1, the other two pegs on T2 and T3 are now replaced.
Dunlop NR	DU04	685257	6104112	112°	Sheep grazing area. Swooping magpie in plot!
Googong Foreshores	GG01	704633	6077736	Not recorded	Old GPS reference is incorrect – now updated. Plot slopes downhill from corner post.
Googong Foreshores	GG02	704675	6076972	Not recorded	
Googong Foreshores	GG03	704407	6076534	Not recorded	
Googong Foreshores	GG05	703628	6075983	Not recorded	
Googong Foreshores	GG06	703554	6074743	Not recorded	
Goorooyarroo NR	GO01	698784	6101469	220°	
Goorooyarroo NR	GO02	700108	6102065	Not recorded	
Goorooyarroo NR	GO04	698784	6102538	65°	Two corner pegs have been replaced but do not have nails.
Goorooyarroo NR	GO08	698970	6104976	Not recorded	
Goorooyarroo NR	GO10	698792	6104738	Not recorded	Large rabbit hole at T1. Lower 2 pegs replaced – old ones not found.

Gungaderra NR	GU01	693610	6102114	Not recorded	Site runs downhill. No star picket placed for step point or corner post due to the presence of other research sites
Gungaderra NR	GU02	693171	6101872	90°	Bearing to T1 = 0°, bearing along step point = 180°. Site runs downhill from track/fence line to the east. Large log located just 3m downslope of corner post.
Gungaderra NR	GU03	693111	6101864	Not recorded	Site slopes uphill from track/fence to north west. Step point runs uphill to north from corner post.
Gungaderra NR	GU04	692941	6101939	166°	Bearing to T1 = 262°, bearing along step point = 78°. Site slopes uphill from track/fence toward rocky outcrop
Jerrabomberra East NR	JE01	698135	6082851	58°	Aligned plot upslope as per photographs from 2012. Could not locate pegs on T3 (C3 and C2) so we have put in two new ones.
Jerrabomberra East NR	JE02	698017	6083759	60°	Corner peg on C1 located under grass. Survey site located near roo fence, mowed track along fence line and where T3 is located. Replaced the two pegs along T3.
Jerrabomberra West NR	JW01	696911	6082978	70°	Mowed track along T3. Couldn't find corner peg C3. Rabbit warren located near corner of T2.
Jerrabomberra West NR	JW02	696625	6083617	322°	T1 peg located but remaining pegs not found, possibly due to grass density. Plot located uphill based on photographs and measurements. No missing pegs replaced as old ones are probably still here but just not visible.
Jerrabomberra West NR	JW03	696061	6083072	238°	
Jerrabomberra West NR	JW04	695973	6082772	277°	All pegs found.
Jerrabomberra West NR	JW06	696417	6084055	351°	All pegs present.
Kama NR	KA01	684350	6095546	229°	Couldn't find the two corner pegs on C3 and C2 but it is very grassy so could be buried. Not replaced in case they are here.
Kama NR	KA02	684134	6095250	25°	Very grassy. Two corner pegs at C3 and C2 not found. Not replaced in case they are here.
Kama NR	KA03	683735	6095188	82°	Grassy. Two corner pegs at C3 and C2 not found. Not replaced in case they are here.
Kama NR	KA04	684187	6095036	59°	Very grass. Snake near plot. Two corner pegs at C3 and C2 not found. Not replaced in case they are here.
Majura NR	MA01	697221	6097778	Not recorded	Plot located close to houses. Corner post near to fallen tree
Majura NR	MA02	698329	6099746	Not recorded	Plot slopes uphill towards access track from corner post. Step point runs downhill to the west

Majura NR	MA03	697930	6099976	Not recorded	From access track plot slopes uphill towards shrubby/rocky area
Majura NR	MA04	698041	6100177	Not recorded	Plot slopes downhill from track. Line of rocks runs through plot.
Mulangarri NR	MU02	694314	6103201	104°	Couldn't find corner pegs so these were replaced (all three).
Mulangarri NR	MU03	694210	6102632	Not recorded	
North Mitchell	NM01	695341	6102057	340°	Corner pegs not found so all three replaced. Bearing along T1 235°. Small blackberry in plot.
Broadcast Australia	NT01	693074	6100655	60°	Refer to diagram in 2013 rapid assessment. Photos taken from C3 not from C1 where post is located, to match the photos taken in previous years.
Broadcast Australia	NT02	693154	6100687	170°	Refer to diagram in 2013 rapid assessment. Quadrat photos taken within main survey plot to replicate 2012 photos. No star picket at end of step point transect. Measured out 50 m towards radio station building.
Mt Painter NR	PA01	687694	6095321	Not recorded	Plot located on steep slope. From corner peg slopes downhill in ENE direction. Additional post info: T1 = 0687697/6095310 T2 = 0687716/6095315 T3 = 0687712/6095334. Some species have been planted in plot e.g. *Hardenbergia*.
Mt Painter NR	PA02	687751	6095231	176°	Bearing to T1 = 266°, bearing along step point = 81°. Plot slopes to south from corner post. Rocky site (> 15%). *Hardenbergia* possibly planted.
Pinnacle NR	PI01	685554	6096235	Not recorded	Plot slopes uphill from corner post in a southerly direction. Two cassinia bushes within plot.
Pinnacle NR	PI02	685255	6096275	226°	Bearing to T1 = 323°, bearing along step point = 151°. Plot runs uphill from corner post.
St Mark's Cathedral	SM01	694459	6091013	Not recorded	All pegs present. Site runs downhill. Pre-autumn burn conducted – site still recovering.
Wanniassa Hill NR	WH01	691359	6081074	98°	All corner pegs found but no step point post present.
Wanniassa Hill NR	WH02	692538	6082027	Not recorded	Corner peg found in tree, replaced at corner of T2 and T3 (very rocky). Other corner pegs present.
Wanniassa Hill NR	WH03	693104	6081469	221°	Bearing to T1 = 315°, bearing along step point = 127°. Plot recently sprayed for St Johns Wort.
Wanniassa Hill NR	WH04	693242	6081247	118°	Bearing to T1 = 200°, bearing along step point = 14°. Plot recently sprayed for St Johns Wort. Plot runs parallel to fence line.
Yarramundi Reach	YA01	689339	6092687	58°	Very grassy, used metal detector to find corner posts.
Yarramundi Reach	YA02	689389	6092632	Not recorded	Corner pegs very hard to locate – T1 found but T2 and T3 not located due to dense *Themeda* cover.

Appendix B Data sheets

The following five pages contain copies of the data sheets used in the field.

1. Grassy Ecosystem vegetation survey – species cover and abundance. Used for recording the survey plot floristics and corresponding cover value.
2. A rapid assessment sheet containing information on site structure, dominant species and climax community. The information in this sheet would remain largely similar for each survey plot between years.
3. A data sheet for recording the type of substrate or species present along the 100 m step point transect.
4. A data sheet for recording counts of any indicator species present along two 1 m wide belt transects.
5. A data sheet for the 2D line-intersect structure method (LiSM).

Grassy Ecosystem vegetation survey – species cover and abundance

V. Oct 2012

Site name: ______ Polygon ID: ______ Surveyor(s): ______ Date: ______ VegID: ______

Cover /abundance score: **5** > 75%; **4** 50 – 75%; **3** 25 – 50%; **2** 5 – 25%; **1** numerous/scattered < 5%; **+** few (approx 4-15) <5%; **r** solitary (ap. 1-3) < 5%; **p** patchy distribution

Species and page no.	
Acetosella vulgaris **124**	
Ailanthus altissima (Tree of Heaven)	
Aira sp. **46**	
Anagalis arvensis	
Arctotheca calendula **88**	
Avena sp.	
Briza maxima/ minor **46**	
Bromus sp. **46**	
Carthamus lanatus (Saffron thistle)	
Celtis australis	
Centaurium sp. **122**	
Cerastium sp.	
Chondrilla juncea	
Cirsium vulgare (Spear thistle)	
Conyza sp.	
Cotoneaster sp.	
Crepis capillaris/ foetida	
Crataegus sp.	
Cynodon dactylon **34**	
Cynosurus echinatus	
Cyperus eragrostis	
Dactylis glomerata **44**	
Echium plantagineum/ vulgare **106**	
Eragrostis curvula **42**	
Erodium botrys/ bracy/ cicutar **104**	
Festuca elatior **44**	
Galium aparine/ divar/ murale	
Gnaphalium americanum **130**	
Hirschfeldia incana	
Holcus lanatus **42**	
Hordeum (Critesion) sp. **46**	
Hypericum perforatum **72**	
Hypochaeris glabra/ radicata **86**	
Juncus acutus/ articulatus **48**	
Juncus bufonius/ capitatus **48**	
Lactuca serriola	
Ligustrum sp.	
Linaria arvensis/ pelisserana **104**	
Lolium perenne / rigidum **44**	
Lonicera japonica	
Lycium ferocissimum	
Malva sp.	
Marrubium vulgare	
Modiola caroliniana	
Moenchia erecta	
Myosotis discolor	
Nassella *neesiana/ trichotoma* **40**	
Onopordum acanthium (Scotch)	
Orobanche minor	
Parentucellia latifolia **122**	
Paronychia brasiliana	

Species and page no.	
Paspalum dilatatum	
Petrorhagia nanteuilii **120**	
Phalaris aquatica **44**	
Pinus sp.	
Plantago lanceolata **128**	
Poa annua/ bulbosa **46**	
Polygonum aviculare	
Prunus sp.	
Pyracantha sp.	
Romulea rosea **58**	
Rosa rubiginosa	
Rubus fruticosus	
Rumex crispus	
Salix sp.	
Salvia verbenaca **106**	
Sanguisorba minor **136**	
Sherardia arvensis	
Silene gallica	
Sonchus sp. *(Sow thistle)*	
Spergularia rubra	
Taraxacum officinale	
Tolpis umbellata **88**	
Tragapogon dubius/ porrifolius	
Trifolium sp. **116**	
Verbascum thapsus/ virgatum **126**	
Vicia sp.	
Vulpia sp. **46**	
Acacia *bailyana/ buxifolia*	
Acacia dawsonii/ dealbata / decurr	
Acacia genistifolia / gunnii	
Acacia implexa / mearns / melanox	
Acacia parram/ pravis / pycn'tha	
Acacia rubida/ ulicifolia	
Acaena novae-zelandiae/ ovina **136**	
Acrotriche serrulata	
Agrostis avenacea	
Ajuga australis **106**	
Allocasuarina vert/ cunningh/ litt	
Alternanthera nana/ dentata	
Amyema sp.	
Aristida ramosa **34**	
Arthropodium mille/ minus **58**	
Asperula conferta / scorparia **92**	
Astroloma humifusum **140**	
Astrotricha ledifolia	
Austrodanthonia sp. **16**	
Austrostipa bigen/ densi/ scabra **14**	
Billardiera scandens	
Bossiaea buxifolia/ prostrata **142**	
Bothriochloa macra **24**	
Brachychiton populneus	

Species and page no.	
Brachycome het'donta/ rigidula **96**	
Brachyloma daphnoides **140**	
Bracteantha viscosa **84**	
Bulbine bulbosa/ glauca **62**	
Bursaria lasiophylla	
Caladenia caerulea/ carnea/ cucull	
Calocephalus citreus **76**	
Calotis anthemoides /lapp/ scab **98**	
Carex appressa / bichenoviana **52**	
Carex breviculmis/ inversa **52**	
Cassinia longifol/ quin'faria/ acule	
Cassytha sp.	
Chamaesyce drummondii	
Cheilanthes aust'folia/ sieberi **138**	
Chloris truncata **34**	
Chrysocephalum apic/ semipap **74**	
Clematis microphylla	
Comesperma ericinum/ volubile	
Convolvulus erubescens **120**	
Craspedia variabilis **82**	
Crassula sieberana/ helmsii	
Cryptandra amara **140**	
Cullen(syn Psoralea)microce/tenax **114**	
Cymbonotus laws'us/ preissi'us **88**	
Cymbopogon refractus	
Cynoglossum australe/ suaveolens	
Daucus glochidiatus **138**	
Daviesia geni / lept/ mimo/ ulic **142**	
Derwentia perfoliata /derwentiana	
Desmodium brachy/ varians **112**	
Dianella longifolia / revoluta **56**	
Dichelachne crin'ta/ micr'/ rara **26**	
Dichondra repens **134**	
Dichopogon fimbriatus **58**	
Dillwynia sericea / phylicoides	
Discaria pubescens **142**	
Diuris chrs'psis(syn lanc)/ behrii **68**	
Diuris dendrobioides/ punctata **68**	
Diuris semilunulata/ sulphurea	
Dodonea viscosa	
Drosera peltata **92**	
Einadia nutans	
Eleocharis acuta/ pusilla	
Elymus scaber **20**	
Enneapogon nigricans **32**	
Epilobium billardierianum **120**	
Eragrostis brownii/ trachycarpa	
Eriochilus cucullatus **66**	
Erodium crinitum **104**	
Eryngium ovinum **108**	
Eucalyptus blakelyi/ bridgesiana	

Species and page no.	
Eucalyptus dives/ goniocalyx	
Eucalyptus macro/ mannif/ melliod	
Eucalyptus nortonii	
Eucalyptus pauciflora/ poly'themos	
Eucalyptus rossii/ rubida / viminalis	
Euchiton sp. *(native)* **130**	
Exocarpus cupressiformis	
Galium gaudichaudii **92**	
Geranium antro./ solan./ retro. **118**	
Glossodia major	
Glycine clandestina/ tabacina **112**	
Gompholobium huegelii	
Gonocarpus tetragynus **124**	
Goodenia hederacea/ pin'tifida **70**	
Grevillea alpina/ lanig/ juniperina	
Haloragis heterophylla **134**	
Hardenbergia violacea	
Helichrysum rutidolepis/ scorp'des	
Hibbertia obtusi./ ripar./ calyc. **144**	
*Hovea heterophylla***114**	
Hydrocotyle laxiflora/ pedunc **134**	
Hypericum gramineum **72**	
Hypoxis hygrometrica **62**	
Indigofera australis / adesmiifolia	
Isoetopsis graminifolia **132**	
Isotoma fluviatilis **102**	
Joycea pallida **18**	
Juncus australis **48**	
Juncus subsecundus/ filicaulis **48**	
Kunzea ericoides/ parvifolia	
Lepidosperma laterale	
Leptorhynchos elong/ squam. **80**	
Leptospermum sp.	
Leucochrysum albicans **94**	
Leucopogon fletcheri/ virg/ micro.	
Linum marginale **104**	
Lissanthe strigosa **140**	
Lomandra bract/ fili / cori **54**	
Lomandra longifolia / multiflora **54**	
Luzula densiflora **50**	
Lythrum hyssopifolia	
Melichrus urceolatus **140**	
Mentha diemenica	
Microlaena stipoides **22**	
Microseris lanceolata **86**	
Microtis unifolia **64**	
Mirbelia sp. **142**	
Monotoca scorparia	
Opercularia hispida	
Ophioglossum lusitanicum **138**	
Oxalis perennans **116**	

Species and page no.	
Panicum effusum **28**	
Persicaria decipiens/ prostrata	
Pimelia curvi/ glauca/ linifolia **90**	
Plantago gaudichaudii/ varia **128**	
Poa labill./ meionec./ sieb. **12**	
Podolepis hieracioides/ jaceoides	
Pomaderris sp.	
Poranthera microphylla	
Pseudognaphalium luteoalbum	
Pterostylis sp. **64**	
Pultenaea micro/ proc/ subspic **142**	
Ranunculus lapp/ papul/ sessil	
Rubus parvifolius	
Rumex brownii / dumosus **124**	
Rutidosis leptorhynchoides **78**	
Schoenus apogon **52**	
Scleranthus biflorus/ diander **132**	
Senecio hisp'lus/ quadridentatus	
Solanum cinereum/ linearifolium	
Solenogyne dominii/ gunnii **130**	
Sorghum leiocladum **38**	
Stackhousia monogyna **90**	
Stellaria pungens	
Stylidium graminifolium **122**	
Stypandra glauca	
Styphelia triflora	
Swainsona monti rectal sericea **110**	
Thelymitra pauciflora/ ixiodes **66**	
Themeda triandra **10**	
Thysanotus patersonii/ tubero **56**	
Tricoryne elatior **62**	
Triptilodiscus pygmeaus **80**	
Typha sp.	
Velleia paradoxa **70**	
Veronica calycina/ gracilis	
Viola betonicifolia/ hederacea **100**	
Vittadinia cuneatalmuellerilgracilis	
Wahl'bergia com / grac/ lut / stri	
Wurmbea dioica **60**	
Further species on back (Y/N)	

Date: | Site Name: | Polygon ID:

Location: | GPS datum | E | N

Surveyor(s): | Time start: | Time finish:

All Sheets Checked (✓/×): | Signed (All Surveyors):

Stratum	Vegetation structure, cover and height class						Dominant species and frequency
	d	c	i	r	bc	bi	List up to five spp. for each stratum. Annotate each with a dominance indicator within that stratum. Dominant Codominant Subdominant
Crown cover	>75%	50-75%	20-50%	0.25-20%	<0.25%	<0.25%	Note - tree regeneration may occur in any stratum
Mature trees/ha	> 40	28 - 40	11 - 28	1 - 11	clumps	isolated	
	cl forest	op forest	w'land	op w'land			For tree species in upper stratum only, indicate % frequency
Emergent							
Upper 1							
Upper 2							
Mid 1							
Mid 2							
Lower 1							
Lower 2							

Height class: **1** < 0.5 m **2** 0.5 - 1 m **3** 1 - 2 m **4** 2 - 5 m **6** 5 - 10 m **7** 10 - 30 m **8** > 30 m

Life forms: Tree Shrub Forb Grass

***Climax veg. community**
- Stipa grassland
- Danthonia grassland
- Dry themeda grassland
- Wet themeda grassland
- Poa grassland
- YB-RG woodland
- Dry shrubby box w'l
- Snow Gum Lowland w'l
- Riparian she-oak w'l
- Riparian Ribbon Gum w'l
- Scribbly Gum Dry Forest
- Other

UMC veg ID

Modified vegetation
- Native pasture
- Exotic crop*
- Exotic pasture*

*fill out this sheet and fauna sheet no plant list required

***Structural formation**

Tick only one
- Grassland
- Sec. grassland
- Open woodland
- Woodland
- Open forest
- Closed forest

Grazing level
- Low
- Medium
- High

Grazers
- Cattle
- Sheep
- Horses
- Roos
- Othr

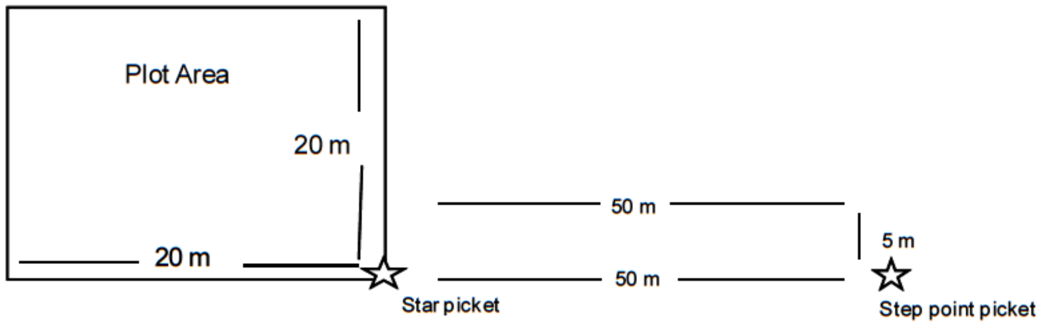
Notes eg. weeds being controlled, other observations, issues to follow up

Cover/abundance
- 5 > 75 %
- 4 50 - 75 %
- 3 25 - 50 %
- 2 5 - 25 %
- 1 numerous <5%
- + few <5%
- r solitary <5%
- p patch

Date:________________ **Site:** ________________________ **Plot ID:** ________________ **Surveyors:** ________________________

Species	Tally	Total
Cryptogams (Moss/Lichen)		
Bare Earth		
Rocks		
Litter/Dead Vegetation		
Annual Exotic Grass		
Perennial Exotic Grass		
Exotic Broadleaf		
Perennial Native Grass		
Other native		

Step point transects



NB. Not all plots will be laid out in this exact configuration. The Star picket may be located at another corner.

Date:___/___/20___ Site: ______________________ Plot ID: __________ Surveyors: ____________

Species	Tally: outside plot		
	T 1	T 3	Total
Ajuga australis			
Arthropodium milleflorum			
Dichopogon fimbriatus			
Austrostipa densofolia			
Brachyscome heterodonta			
Bulbine bulbosa			
Burchardia umbellata			
Calocephalus citreus			
Craspedia variabilis			
Dichelachne spp			
Eryngium ovinum			
Goodenia pinnatifida			
Leucochrysum albicans			
Microseris lanceolata			
Microtis parvifolia/unifolia			
Pimelea curviflora			
Ranunculus/Geranium spp			
Scleranthus biflorus			
Sorghum leiocladum			
Stackhousia monogyna			
Stylidium graminifolium			
Swainsona spp			
Thysanotus tuberosus			
Wurmbea dioica			
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.			
.			
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.			
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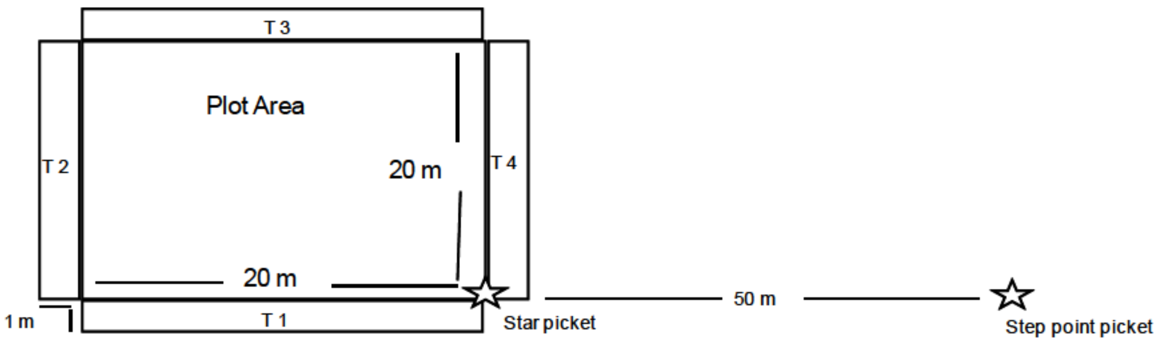
.			

Jessop Stick monitoring areas



NB. Not all plots will be laid out in this exact configuration. The Star picket may be located at another corner. However, **T 1** will **always** be **parallel and closest** to the Step point Transect and **T 4** will **always** be **perpendicular and closest** to the Step point Transect.

Date:___/ ____/ 20____ **Site:**______________________ **Plot ID:**__________ **Surveyors:** _____________

Datum: GDA94, z____ **Easting:**______________ **Northing:** ________________ **Bearing:** _______°

Native / Exotic categories: **N** = native; **X** = exotic annual; **Y** = exotic perennial

Lifeform categories: **G** = tussock grass; **F** = forb; **V** = sedge; **R** = rush; **E** = fern; **S** = shrub; **B** = bare earth; **Ro** = rock; **C** = cryptogams; **L** = leaf litter; **W** = woody debris; **O** = other

Foliage height categories (HC*): **1** = 0cm; **2** = >0 - 5 cm; **3** = 5 - 10cm; **4** = 10 - 20cm; **5** = 20 - 30cm; **6** = 30+ cm

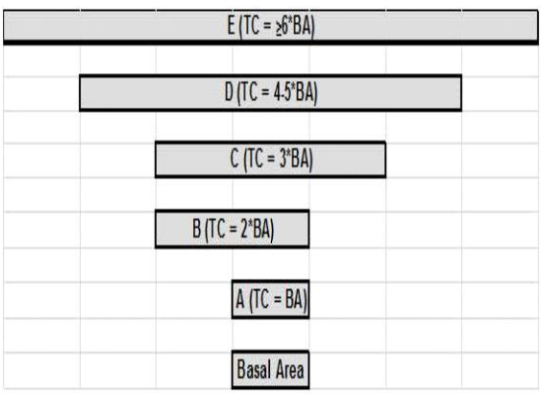
Category[1]	Length[2]	Category[1]	Length[2]	Category[1]	Length[2]	Category[1]	Length[2]
e.g. NG3	e.g. 0.21		-		-		-
C1	0.28		-		-		-
	-		-		-		-
	-		-		-		-
	-		-		-		-
	-		-		-		-
	-		-		-		-
	-		-		-		-
	-		-		-		-
	-		-				
	-		-	Native tussock grass (NG) character for each HC			
	-		-	HC	Mean canopy ratio	Tussock Shape	Est. tussock width
	-		-				
	-		-				
	-		-				
	-		-				
	-		-				
	-		-				
	-		-				
	-		-				
	-		-				
	-		-				
	-		-				
	-		-				
	-		-				
	-		-				
	-		-				

[1] Category = combination of Native/Exotic, Height and Lifeform categories (e.g. NG3 = Native Tussock grass, 5 - 10cm)

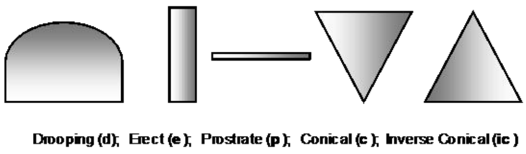
[2] Length = measurement from zero in metres (e.g. 0.41, 2.53)

* HC = height of the leaf tussock at which the canopy droops or ceases to contain significant biomass. Culms and other less-palatable biomass are not included.

Mean TC:BA ratio

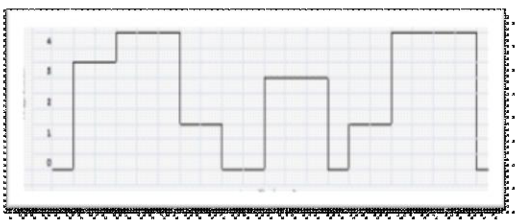


Tussock shapes



Drooping (d); Erect (e); Prostrate (p); Conical (c); Inverse Conical (ic)

eg. of 2D transect ***(without TC:BA ratio and tussock shape)***



Estimated tussock width (cm)

(<5, 5 - 10, 10 - 15, 15 - 20, 20 - 30, 30 - 40, > 40)

Notes

Appendix C Methodology for LiSM

2D Line-intersect structure measurements (LiSM)

a simple method for measuring structure in natural temperate grassland

Version 1.1, December 10, 2012

Method

1. Run a measuring tape 5m across a floristically and structurally representative transect within the full-floristic quadrat.

Note: (a) this does not have to be a permanent line-transect, as representative areas can be selected in following years in a different (adjacent) location if a line-transect is disturbed. (b) ideally, the line-transect should be within the 20*20m full-floristic quadrat, but may be adjacent. (c) do not cross a vegetation sub-type ecotone, and ensure that the vegetation sub-type is representative of the full-floristic quadrat.

The tape should be suspended above the ground vegetation to minimise disturbance to foliage. Avoid walking or disturbing the linear zone to be measured.

2. Separate the native perennial grass tussocks (and other graminoids) into foliage height categories [>30cm; 20-30cm; 10-20cm; 5-10cm; >0-5cm; 0 (broken down into bare earth/cryptogam/rock)]. Additional measures include other native, exotic broadleaf, perennial exotic grass, annual exotic grass, cryptograms, leaf litter, woody debris and other). As the area is only 5m, there is likely to only be a few height classes, and 2-3 additional variables). Codes include:

   Native / Exotic categories: N = native;   **X** = exotic annual;   **Y** = exotic perennial

   Lifeform categories: **G** = tussock grass;   **F** = forb;   **V** =sedge;   **R** = rush;   **E** = fern;   **S** = shrub;
   B = bare earth;   **Ro** = rock;   **C** = cryptogams;   **L** = leaf litter;   **W** = woody debris;   **O** = other

   Foliage height categories (HC): 1 = 0cm; 2 = >0 - 5 cm; 3 = 5 - 10cm; 4 = 10 - 20cm;
   5 = 20 - 30cm; 6 = 30+ cm

   Note: Foliage height (HC) is defined as the height of the leaf tussock at which the canopy droops or ceases to contain significant biomass. Culms and other less-palatable biomass are not included.

   e.g. **NG3** = Native Tussock grass, 5 - 10cm;   **C1** = cryptogam

3. Measure along the tape, recording changes in category (native/exotic, lifeform and foliage height categories as outlined in Step 2) to the nearest cm.

Category	Length	Category	Length	Category	Length
e.g. NG3	0.21	etc etc	.		.
NG4	0.46		.		.
NX2	0.63.		.		.
C1	0.7				
NG(F)4	0.91				

In instances where two lifeforms are co-dominant and effecting vegetation structure (e.g. the forb *Haloragis heterophylla* providing structural compliment to a sward of the tussock grass *Austrostipa bigeniculata*) record the assisting lifeform in brackets [e.g. NG(F)4].

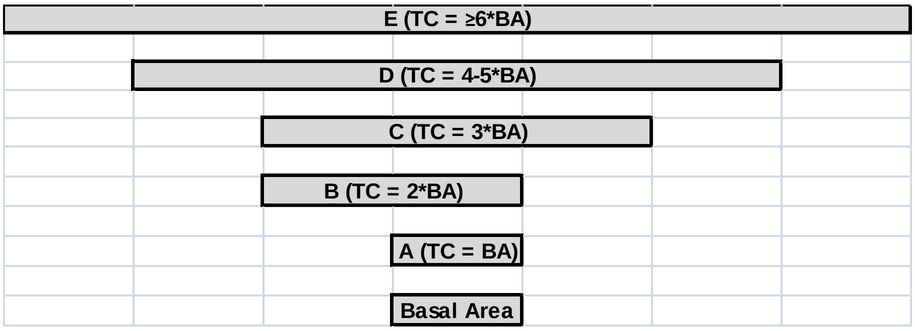
Heights can be measured using a height stick divided into the relevant categories rather than a metric ruler.

4. Once Step 3 is completed, *estimate* the mean tussock canopy to basal area (TC:BA) ratio, mean tussock shape and tussock canopies / linear metre for each height class.

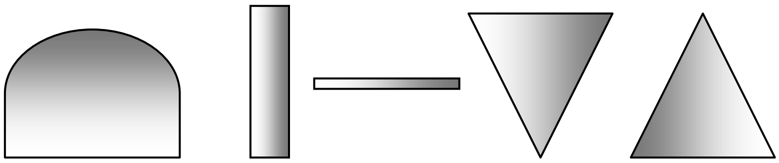
HC	Mean TC:BA ratio	Mean tussock shape	Est. Tussock width
2	e.g. B	c	15 - 20
3			
4			
5			
6			

Each measure (and category within) is outlined below.

Mean TC:BA ratio is intended as an estimate (as metric measurements may be subjective also). The below diagram can guide assessment.



Mean tussock shape is intended to assess the general structure of tussock grasses (*tussock foliage only*, not culms etc) within each height class. Tussock shapes are as follows:



drooping *(d)* *erect (e)* *prostrate (p)* *conical (c)* *inverse conical (i)*

While species can change shape based on grazing or other disturbance, in an undisturbed low to medium grazing regime the following is *generally* expected of common tussock grass species:

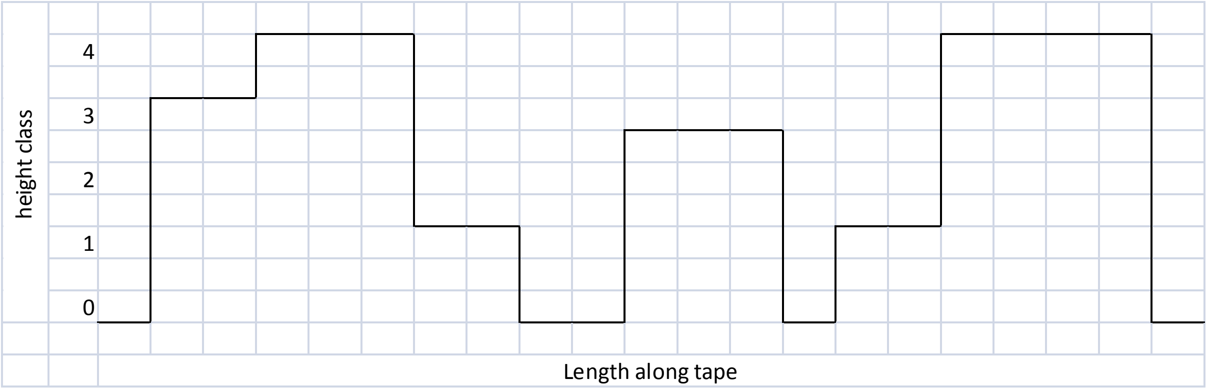
Drooping	Erect	Prostrate	Conical
Austrostipa bigeniculata *Themeda australis* *Rytidopsperma* spp. (large) *Poa sieberiana*	*Elymus scaber*	*Bothriochloa macra* (partially grazed) *Microlaeana stipoides* (partially grazed) *Rytidopsperma* spp. (heavily grazed)	*Aristida ramosa* *Austrostips scabra* *Rytidopsperma* spp. (small)

Inverse conical tussocks are generally found in robust tussocks grasses subject to high grazing intensity.

Estimated tussock width is grouped into <5. 5 – 1-, 10 – 15, 15 – 20, 20 – 30, 30 – 40, > 40cm classes.

Outputs

- A 2-D representation of grassland structure within the 5m linear transect. For example:



The above can be coded based on tussock shape, growth form etc.

- *Estimates* on the mean tussock canopy : basal area (TC:BA) ratio, mean tussock shape and tussock canopiy width for each height class

Replicates

A total of two replicates may be collected per vegetation survey plot (e.g. n = 100 across 50 plots). It is suggested that each replicate selected based on a *floristically* and *structurally* representative 5m transect within a full-floristic plot so the data can be related. Depending on the project, it may not be necessary to identify these with a permanent marker.

As each 5m replicate will represent a vegetation sub-type (refer to point 1), this data can be grouped with other replicates of the same vegetation sub-type from other reserves for analysis.

Estimated Time

Approximately 5 - 15 minutes per transect in the field depending on structural complexity

Data Outputs

- Mean height;
- Proportion in each foliage height category (grouped by height, growth form and native/perennial exotic/annual exotic);
- Mean (estimated) tussock structure and tussock canopy:basal area ratio for each height category;
- Estimated tussock width (size as tusscoks are generally circular) in each foliage height class; and
- Estimates (subjective) on the mean tussock size and tussock canopy:base ratio for each foliage height class.

Advantages

- Provides useful information on tussock and inter-tussock structure;
- The 5m linear sample can be aligned to not cross a vegetation sub-type ecotone;
- Allows replicates of common vegetation sub-types to be compared with others across reserves;
- Provides a 2D conceptual model of tussock canopy spacing, as well as the relationship between tussock basal area and tussock canopy area;
- Indicates spatial arrangement of height classes and inter-tussock (inter-canopy) space; and
- Rapid.