Browsing impact of boodies (Bettongia lesueur) and mala (Lagorchestes hirsutus) in a predator free enclosure at Matuwa

Technical Report · May 2020

DOI: 10.13140/RG.2.2.22111.00162

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Version number	Date approved DD/MM/YYYY	Approved by	Brief Description
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Matuwa Kurrara Kurrara Indigenous Protected Area and DBCA Fauna Translocation Project

November 2019

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The recommended reference for this publication is:
Department Biodiversity, Conservation and Attractions, 2019, *Browsing impact of boodies (Bettongia lesueur) and mala (Lagorchestes hirsutus) in a predator free enclosure at Matuwa*, Department of Biodiversity, Conservation and Attractions, Perth.

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Cover image by Shannon Treloar

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Acknowledgments

We acknowledge the Wiluna Martu peoples, who are the traditional custodians of the Matuwa Kurrara Kurrara Indigenous Protected Area, and appreciate the input of Tarlka Matuwa Piarku Aboriginal Corporation, and members of the Matuwa Kurrara Kurrara IPA Management Team. This research was funded by the Gorgon Barrow Island threatened and priority species translocation program. Additionally, we thank Tom Bragg, Ray Cranfield, Bruce Ward, and Dr Per Christensen for collecting data in 2009 and 2012. We thank Dr Matthew Williams for contribution to the analysis of the data.

Summary

Severe browsing of some plant species, particularly *Templetonia egena*, is occurring inside the predator-free enclosure at Matuwa. Browsing pressure outside the enclosure is significantly less presumably due to the lack of boodies (*Bettongia leseuer*) and mala (*Lagorchestes hirsutus*) outside the enclosure. Browsing exclusion plots may be used to monitor browsing pressure through comparison with browsed sites but unless the browsing exclosures are constantly maintained and repaired they will be breached by these digging animals undermining their scientific value. Monitoring browsing on indicator species may be a more appropriate technique for monitoring the impact browsing on a plant community. *Templetonia egena* appears to be a good indicator species of browsing pressure by native and feral fauna, but more research is required to set a threshold of acceptable browsing pressure.

1 Introduction

The Matuwa Indigenous Protected Area (IPA), located on the southern edge of the Little Sandy Desert (-26.274; 121.371) is a 244,000 hectare ex-pastoral station (ex-Lorna Glen) initially purchased by the Western Australian Government in 2000 (Burbidge & McKenzie, 1989; Morton, et al., 1995) but now held by Tarlka Matuwa Piarku Aboriginal Corporation (TMPAC) on behalf of the Wiluna Martu (Bode, et al., 2012). Informal joint-management has been occurring between the Wiluna Martu, TMPAC and the Department of Biodiversity Conservation and Attractions (DBCA) since 2000. Matuwa is the location of the largest science-based arid zone wildlife reconstruction project ever undertaken in Australia (O'Leary & Kealley, 2015).

An adaptive management framework must be employed during the implementation of conservation programs on a landscape scale (McCarthy & Possingham, 2007). Adaptive management is the systematic acquisition and application of reliable information to improve natural resource management over time (Wilhere, 2002). For adaptive management to be implemented the manager must be able to allocate effort to discrete units, measure the outcome of a management action quantitatively, and have at least two possible management options from which to choose (McCarthy & Possingham, 2007).

As an adaptive management response to the failure of two native mammal reintroductions to Matuwa (Lohr, 2019), an 1100 ha feral predator-free, fenced enclosure was constructed in 2009/10 (Bode, et al., 2012) at an approximate price of $250,000 (N. Wessels pers comm). The construction of the 15 km fence was completed in November 2009. The fence was constructed in a triangle, west of well #10. The top two wires of the fence are electrified and a 30cm skirt is buried underground (Miller, et al., 2010). In 2014, in response to three feral cat incursions, a third electrified wire was added half-way up the exterior of the fence. Within the enclosure, cats were extirpated using a combination of 1080 baits and trapping. Rabbits inhabiting unused boodie warrens were reduced using one shot oats, and varanids were reduced via noosing and trapping. Kangaroos within the enclosure were culled and extirpated.

The purpose of the enclosure was to provide a refuge for translocated animals where they could acclimatise to the arid environment, and/or provide a population of locally adapted F2 generation individuals that may then be successfully translocated to the open landscape. Releases of boodies (*Bettongia lesueur*), mala (*Lagorchestes hirsutus*), brushtail possums (*Trichosurus vulpecula*) and golden bandicoots (*Isoodon auratus*) into the predator-free enclosure occurred in 2010 and 2011, and their populations have rapidly increased in the absence of feral predators (Lohr, 2019).

Reintroducing locally extinct native mammals, especially digging species such as the bilby (*Macrotis lagotis*) and boodies will improve the conservation status of arid zone mammals and, in doing so, is likely to return many important ecological functions such as soil cultivation through digging and burrowing, nutrient recycling, seed dispersal, grazing and browsing. Pilot studies revealed that bilby burrows moderated the microclimate and nutrient availability in soil potentially providing more suitable habitats for the recruitment of native plant species (Chapman, 2013). Similarly, cotton bush (*Ptilotus obovatus*) shrubs present on actively dug boodie warrens had greater leaf biomass, with higher moisture and nutrient content compared to cotton bush growing on inactive warrens (Chapman, 2015). Boodies also exhibit a scatter-hoarding behaviour in relation to sandalwood nuts that likely facilitates the germination and recruitment of new sandalwood trees (Chapman, 2015).

Conversely, the reintroduction of native mammals may result in the decline in native plant species through excessive browsing, seed consumption, or excavation of plant roots. Excessive browsing pressure is most likely to become a problem in fenced reserves that inhibit the ability of fauna to disperse in response to environmental conditions and food availability.

Unfortunately, change in vegetation structure and species recruitment occurs very slowly in arid zone environments and it is very difficult to detect trends in the relative abundance of species from field measurements of biomass and floristic composition at the scale of the decade (Diouf & Lambin, 2001). Consistent with an adaptive management framework, we have continued to adapt our protocol for monitoring change in condition of vegetation at Matuwa.

In this report we describe the original protocol, established in 2009, for monitoring vegetation condition in and around the predator-free enclosure, results collected to date and the justification for the modified protocol for monitoring mammal browsing and associated vegetation condition.

2 Methods and results

2.1 Fenced versus unfenced plots

Consistent with an adaptive management framework and prior to the completion of the predator-free enclosure, a series of 18, 30m x 30m vegetation plots (Figure 1) were established within and outside the fenced predator-free enclosure (Burrows, 2014). The purpose of these vegetation plots was to monitor browsing and digging activity by reintroduced native mammals and any subsequent change in vegetation structure or recruitment of plant species. An additional 24 biological survey sites (Figure 1) were established across Matuwa with the purpose of monitoring the recovery of the ex-pastoral lease over time. These additional 24 sites are not considered in the remainder of this report.

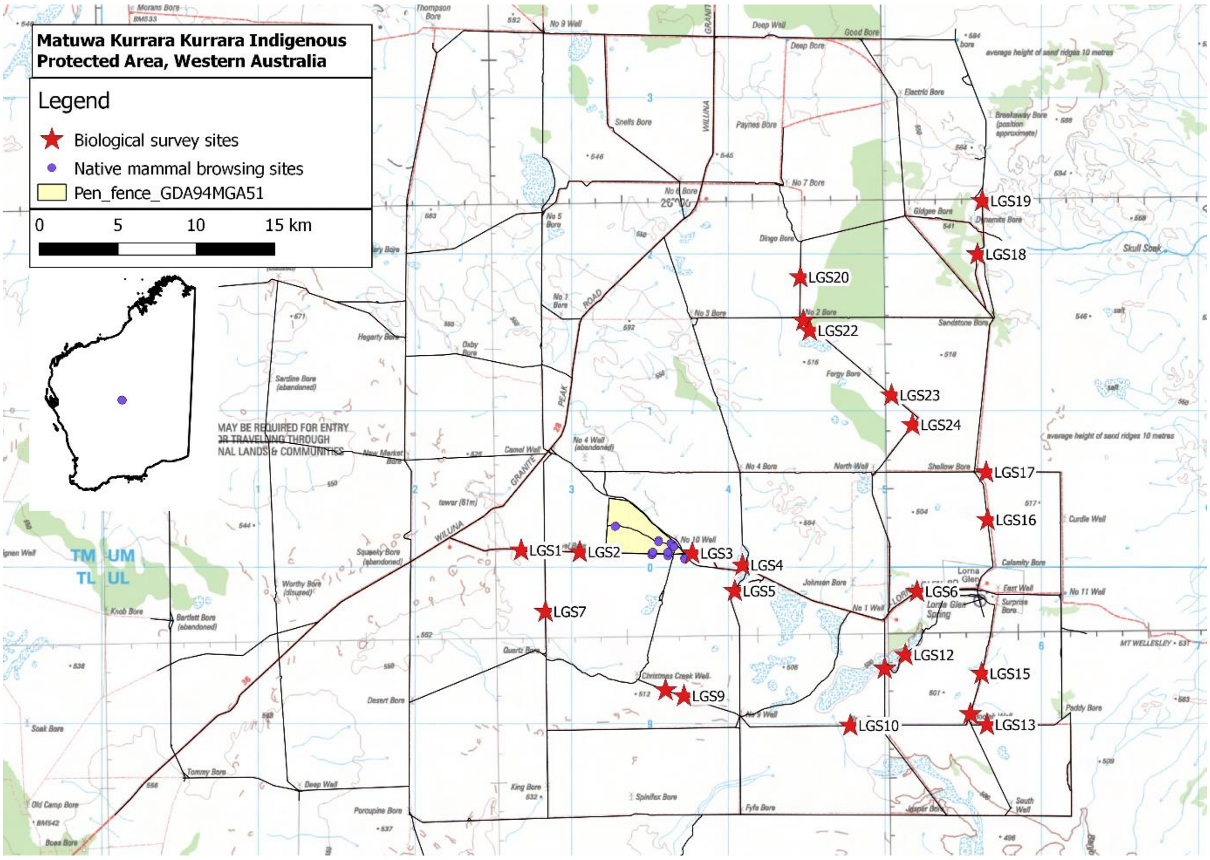

Figure 1. Map of Matuwa Kurrara Kurrara Indigenous Protected Area and inset map of Western Australia, with location of all 24 biological survey sites and 18 native mammal browsing plots.

The predator-free pen contains three major land systems; Eucalypt floodplains frequently seen on Carnegie landsystem (NEC 1.23; Elith and Bidwell (2004)), Cunyu and Bullimore landsystems. We installed two pairs of plots (one fenced browsing exclosure, and one unfenced plot) in each land system (3x2x2 = 12 plots) inside the compound. Additionally, we established one unfenced replicate pair in matching land systems outside the compound (3x2 = 6). Making a total of 18 plots where species richness, abundance, coverage, distribution rating and an estimate of flowering and seeding were measured (See Appendix).

Table 1. Exact coordinates of the native mammal browsing plots.

Plot Number	Type	*Latitude*	*Longitude*
LG-BIS-L1-O	Out of Predator-free pen	26 12.320S	121 22.235E
LG-BIS-L2-O	Out of Predator-free pen	26 12.361S	121 22.245E
LG-BIS-L1-F	Fenced	26 11.799S	121 21.715E
LG-BIS-L2-F	Fenced	26 11.899S	121 21.847E
LG-BIS-L1-U	Unfenced	26 11.869S	121 21.746E
LG-BIS-L2-U	Unfenced	26 11.923S	121 21.830E
LG-BIS-B1-O	Out of Predator-free pen	26 12.181S	121 20.999E
LG-BIS-B2-O	Out of Predator-free pen	26 12.183S	121 20.974E
LG-BIS-B1-F	Fenced	26 11.176S	121 19.614E
LG-BIS-B2-F	Fenced	26 12.109S	121 20.995E
LG-BIS-B1-U	Unfenced	26 11.194S	121 19.589E
LG-BIS-B2-U	Unfenced	26 12.090S	121 21.028E
LG-BIS-C1-O	Out of Predator-free pen	26 12.203S	121 21.613E
LG-BIS-C2-O	Out of Predator-free pen	26 12.235S	121 21.600E
LG-BIS-C1-F	Fenced	26 11.694S	121 21.253E
LG-BIS-C2-F	Fenced	26 12.115S	121 21.624E
LG-BIS-C1-U	Unfenced	26 11.745S	121 21.246E
LG-BIS-C2-U	Unfenced	26 12.102S	121 21.592E

L = Eucalypt floodplains on Carnegie landsystem; B = Bullimore landsystem; C = Cunyu landsystem.

The vegetation inside these fenced and unfenced plots was assessed in 2009 and 2012. Each assessment of the vegetation included two diagonal crosses to measure vegetation structure and species diversity, and a photo point of the plot from north-west towards south-east. For each species encountered, its lifeform, lifestyle, and fruiting or flowering status were recorded. The distribution, abundance and cover of each species within each plot was recorded as categorical data (Appendix 1).

Digging fauna (boodies and bandicoots) were repeatedly breaching the browsing exclosure plot fencing, devaluing the data collected from those plots. In 2019 we initiated a count of the number of faunal digs present within 5m of the inside of each plot boundary (total 500m^2 survey). Two people walked abreast around the perimeter of the plot and counted new digs (defined as digs with fresh spoil heaps, lack of leaves or webs inside the dig) and old digs. We hoped that correlations between indices of vegetation condition and a quantitative assessment of animal activity in the exclosure plots may restore value of data collected from the plots. Data were analysed via non-metric multidimensional scaling (nMDS), analysis of similarities statistical test (anosim), and envfit function for statistically comparing categorical environmental variables against the ordination in the 'vegan' package (Oksanen, et al., 2019) or ANOVA in RStudio (RStudio Team, 2016).

2.1.1 Results browsing assessment plots

In 2009 and 2012, a total of 112 plant species were detected inside the browsing assessment plots. The number of species detected increased from 54 in 2009 to 80 species in 2012. The increase in detected plant diversity may however be an artefact of variation in observers and/or environmental conditions such as precipitation as the proportion of species detected that were annuals increased from 14.8% in 2009 to 26.4% in 2012. Annual rainfall is not available for 2012, but the sum of rainfall recorded was 250.3mm, as compared to total annual rainfall in 2009 which was 167.7mm.

2.1.1.1 Plant abundance

The goodness of fit statistics (stress <0.05) and Shepard's diagram suggest that the Bray-Curtis dissimilarity matrix with three dimensions produced an ordination with a good fit (R^2 = 0.97) for analysis of plant abundance (Fig. 2).

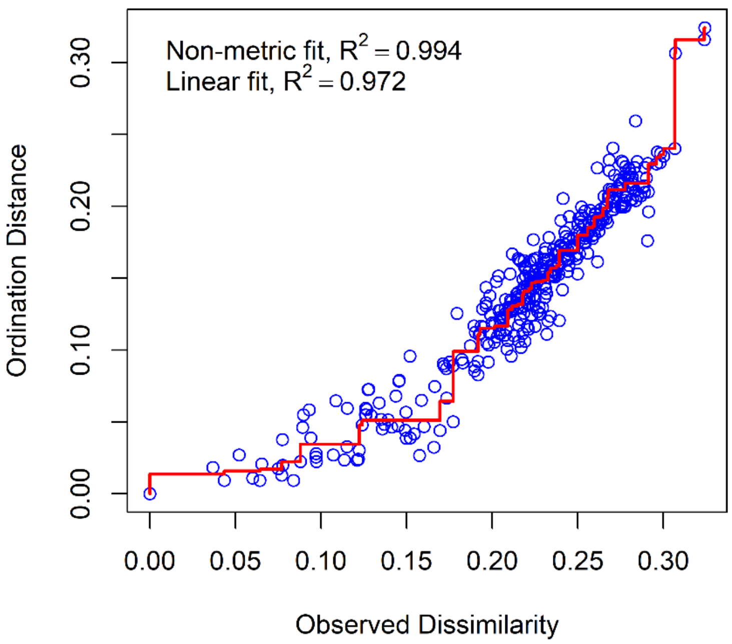

Figure 2. Shepard's diagram of the preservation of the original dissimilarities in the ordination of plant abundance in the browsing plots at Matuwa using three dimensions.

The number of individuals within each plant species significantly varied with landsystem (R = 0.39; p = 0.001; Fig. 3a) and year (R = 0.25; p = 0.001; Fig. 3b), but not due to the fencing treatment (R = -0.05; p = 0.94; Fig 3c). The R values for landsystem and year were, however, relatively weak. On average *Ptilotus obovatus* was more common on Cunyu (abundance = 4.58 = 10-50 plants; see Appendix 1) than either Bullimore (abundance = 1.16 = 1 plant) or Eucalypt floodplains (abundance = 1 = 0 plants). *Triodia basedowii* was more common (abundance = 3.75 = <10 plants) on Bullimore than on the Cunyu landsystem (cover = 2.66) or Eucalypt floodplains (abundance = 1), whereas *Psydrax latifolia*, *Acacia aneura* and *Solanum lasiophyllum* were more common on Cunyu (abundance = 2.8-3) than on either Bullimore (abundance = 1-2.75) or Eucalyptus floodplains (abundance = 1-1.16). Fifty-seven plant species increased in abundance between 2009 and 2012, whereas 42 species decreased. The magnitude of the change in plant abundance between 2009 and 2012 was small with the largest increase in *Aristida contorta* which increased from zero plants to <10 plants (abundance = 3.44). Fencing treatment did not significantly alter plant abundance.

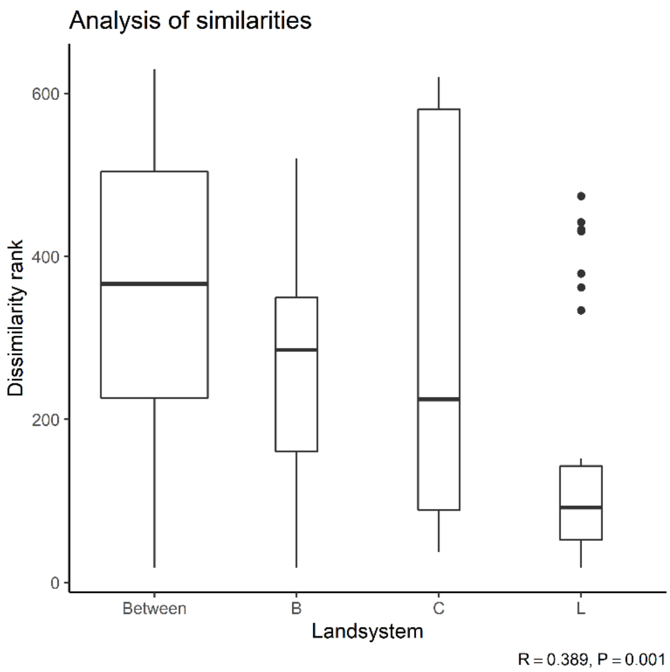

Figure 3a. Analysis of similarities of the abundance of plant species as compared to landsystem in 18 vegetation assessment plots (6 x fenced, 6 x unfenced, and 6 x outside the predator-free pen) at Matuwa. L = Eucalypt floodplains on Carnegie landsystem; B = Bullimore landsystem; C = Cunyu landsystem.

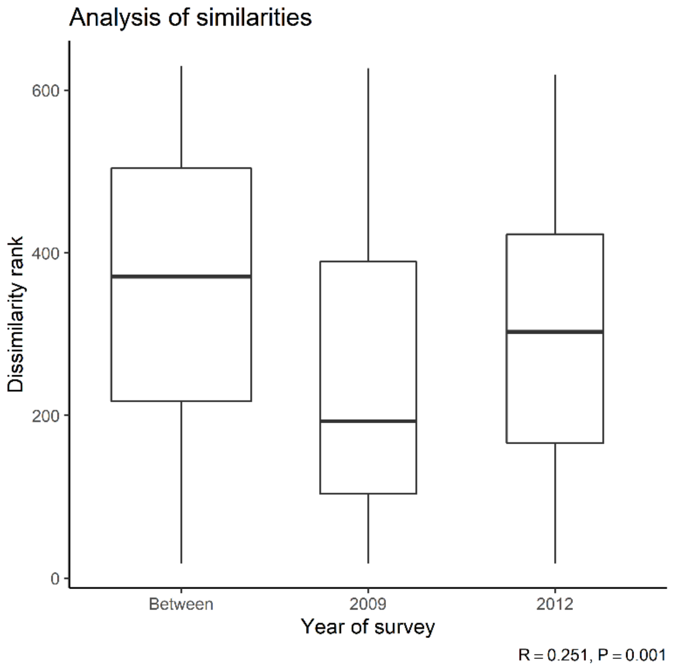

Figure 3b. Analysis of similarities of the abundance of plant species as compared to year in 18 vegetation assessment plots (6 x fenced, 6 x unfenced, and 6 x outside the predator-free pen) at Matuwa.

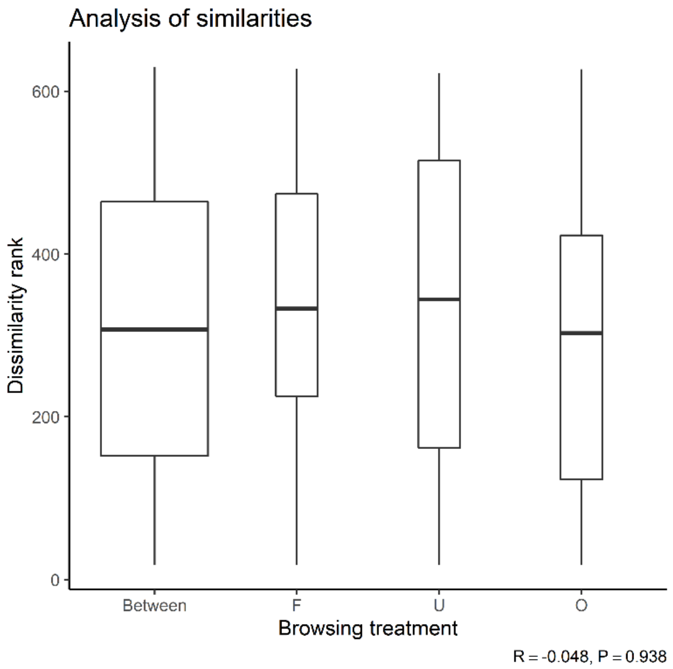

Figure 3c. Analysis of similarities of the abundance of plant species as compared to fencing treatment in 18 vegetation assessment plots (6 x fenced, 6 x unfenced, and 6 x outside the predator-free pen) at Matuwa.

2.1.1.2 *Plant cover*

The goodness of fit statistics (stress <0.1) and Shepard's diagram suggest that the Bray-Curtis dissimilarity matrix with three dimensions produced an ordination with a good fit ($R^2 = 0.99$) for analysis of plant cover (Fig. 4).

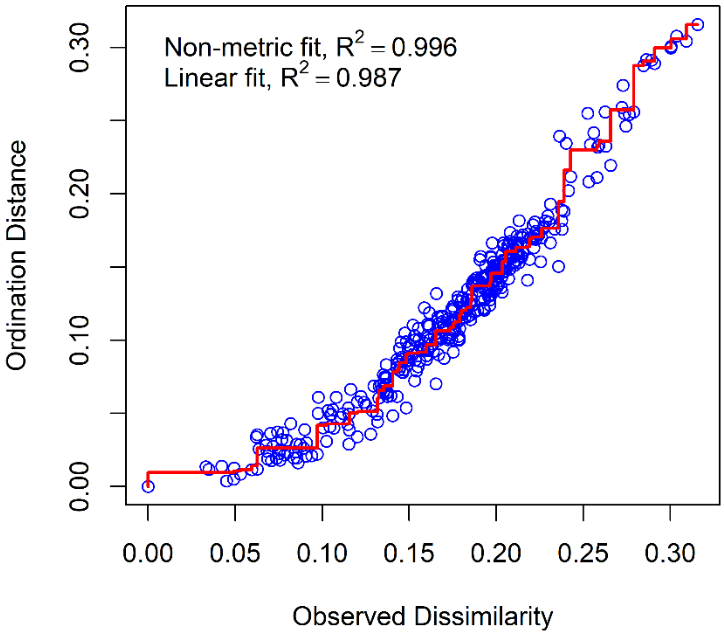

Figure 4. Shepard's diagram of the preservation of the original dissimilarities in the ordination of plant cover in the browsing plots at Matuwa using three dimensions.

The cover of each plant species significantly varied with landsystem (R = 0.25; p = 0.001; Fig. 5a) and year (R = 0.15; p = 0.004; Fig. 5b), but not due to the fencing treatment (R = -0.04; p = 0.92; Fig 5c). The R values for plant coverage were lower than similar tests against plant abundance suggesting plant coverage is a weaker metric. On average *Triodia basedowii* was more common (cover = 3.5 = 1-5%) on Bullimore than on Cunyu landsystem (cover = 2.3 = <1%) or Eucalypt floodplains (cover = 1 = no plants), whereas *Eucalyptus camaldulensis* was more common on Eucalypt floodplains (cover = 3.75 = 1-5%) than on either Bullimore or Cunyu landsystems (no plants). *Ptilotus obovatus* was more common on Cunyu (cover = 2.91) than either Bullimore (cover = 1.25) or Eucalypt floodplains (cover = 1). Similarly, *Acacia aneura* was more common on Bullimore (cover = 2.83) or Cunyu landsystems (cover = 2.41) than Eucalypt floodplains (cover = 1.17).

The greatest differences between 2009 and 2012 were seen in *Aristida contorta* which increased from no plants observed (cover = 1) to <1% cover (cover = 2.72).

Fencing treatment did not significantly alter plant cover with the maximum differences seen in *Acacia tetragonaphylla* which was highest in fenced plots (cover = 1.83) over unfenced plots (cover = 1.75) and outside plots (cover = 1.08). In contrast *Enneapogon caerulescens* was lowest in fenced plots (cover = 1) than unfenced plots (cover = 1.41) and outside plots (cover = 1.66).

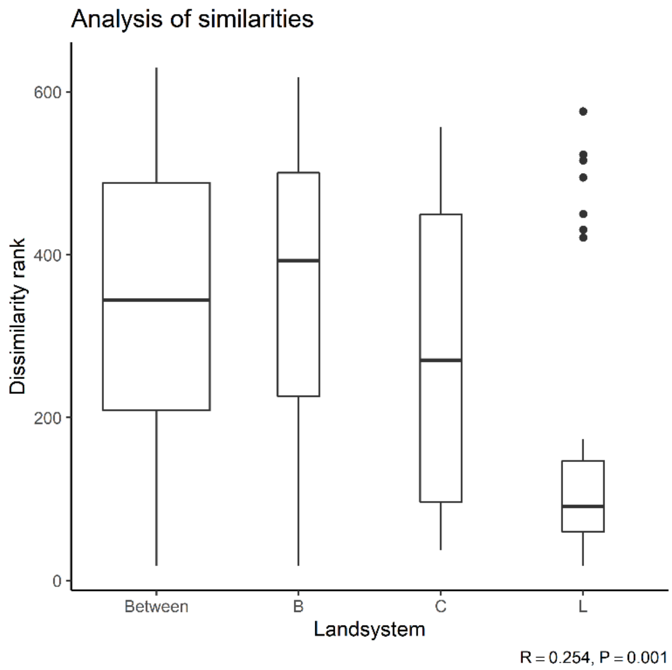

Figure 5a. Analysis of similarities of the cover of plant species as compared to landsystem in 18 vegetation assessment plots (6 x fenced, 6 x unfenced, and 6 x outside the predator-free pen) at Matuwa. L = Eucalypt floodplains on Carnegie landsystem; B = Bullimore landsystem; C = Cunyu landsystem.

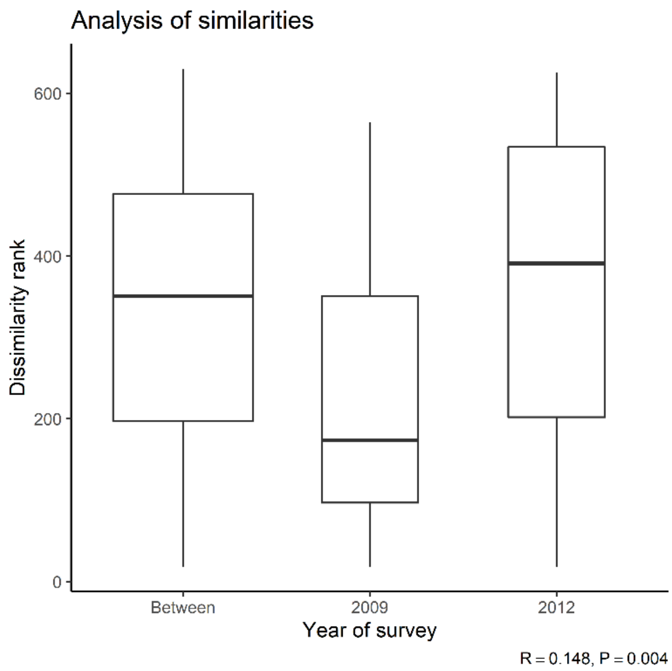

Figure 5b. Analysis of similarities of the cover of plant species as compared to year in 18 vegetation assessment plots (6 x fenced, 6 x unfenced, and 6 x outside the predator-free pen) at Matuwa.

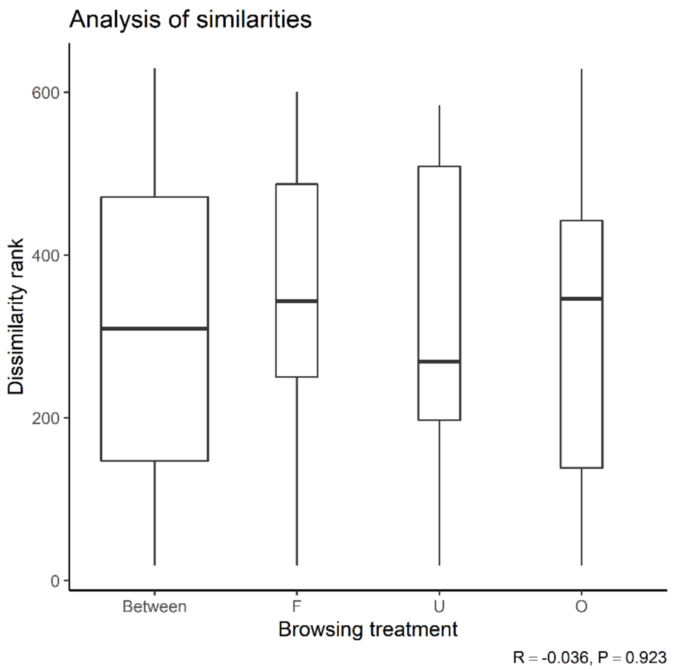

Figure 5c. Analysis of similarities of the cover of plant species as compared to fencing treatment in 18 vegetation assessment plots (6 x fenced, 6 x unfenced, and 6 x outside the predator-free pen) at Matuwa.

2.1.1.3 Plant distribution

The goodness of fit statistics (stress <0.05) and Shepard's diagram suggest that the Bray-Curtis dissimilarity matrix with four dimensions produced an ordination with a good fit ($R^2 = 0.99$) for analysis of plant distribution (Fig. 6).

The distribution of each plant species across each browsing plot significantly varied with landsystem (R = 0.41; p = 0.001; Fig. 7a) and year (R = 0.26; p = 0.001; Fig. 7b), but not due to the fencing treatment (R = -0.05; p = 0.95; Fig 7c). Landsystem explained 40.7% of the variation in the Bray-Curtis dissimilarity matrix of plant distribution. As was seen with other plant metrics *Ptilotus obovatus* was more common on Cunyu (distribution = 4.83 = 4/4 quarters of browsing plot; Appendix 1) than either Bullimore (distribution = 1.25 = 0/4 quarters of browsing plot) or Eucalypt floodplains (distribution = 1 = 0/4 quarters of browsing plot). *Triodia basedowii* was more common (distribution = 3.33) on Bullimore than on Cunyu landsystem (distribution = 2.33) or Eucalypt floodplains (distribution = 1), whereas *Eucalyptus camaldulensis* was more common on Eucalypt floodplains (distribution = 3 = 2/4 quarters of browsing plot) than on either Bullimore or Cunyu landsystems (distribution = 1).

Fifty-six species increased their average distribution across the browsing plots between 2009 and 2012, whereas 40 decreased (Fig. 7b). The greatest differences between 2009 and 2012 were seen in *Aristida contorta* which increased from no plants observed (distribution = 1) to 2/4 quarters of browsing plot (distribution = 3.28).

No particular species were responsible for dissimilarity between treatments with at least 52 species required to explain 50% of the variation in the Bray-Curtis dissimilarity matrix. Fencing treatment did not significantly alter plant distribution with the maximum differences seen in *Acacia tetragonaphylla* which was highest in fenced and unfenced plots (distribution = 2.25 = 1/4 quarter of browsing plot) over outside plots (distribution = 1.16 = 0/4 quarters of browsing plot). In contrast *Enneapogon caerulescens* was lowest in fenced plots (distribution = 1 = 0/4 quarters) than unfenced plots (distribution = 1.58 = 0/4 quarters) and outside plots (distribution = 2 = 1/4 quarter).

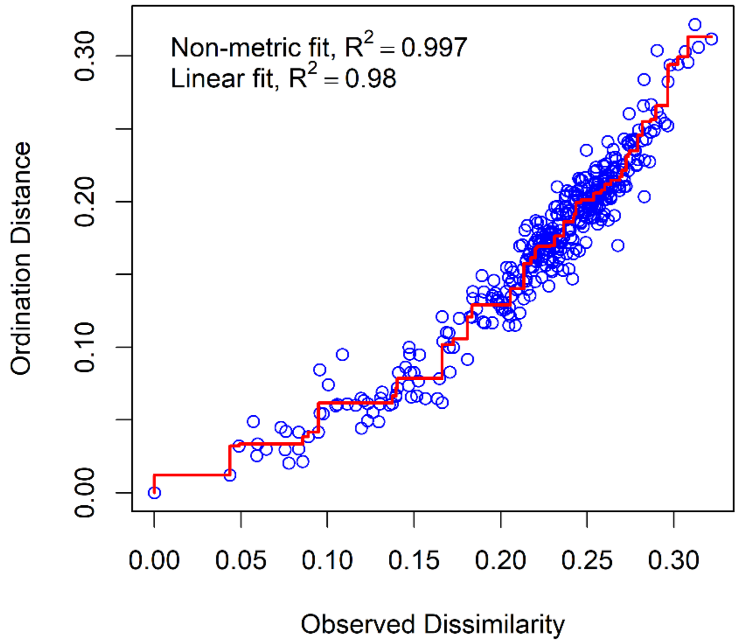

Figure 6. Shepard's diagram of the preservation of the original dissimilarities in the ordination of plant distribution in the browsing plots at Matuwa using four dimensions.

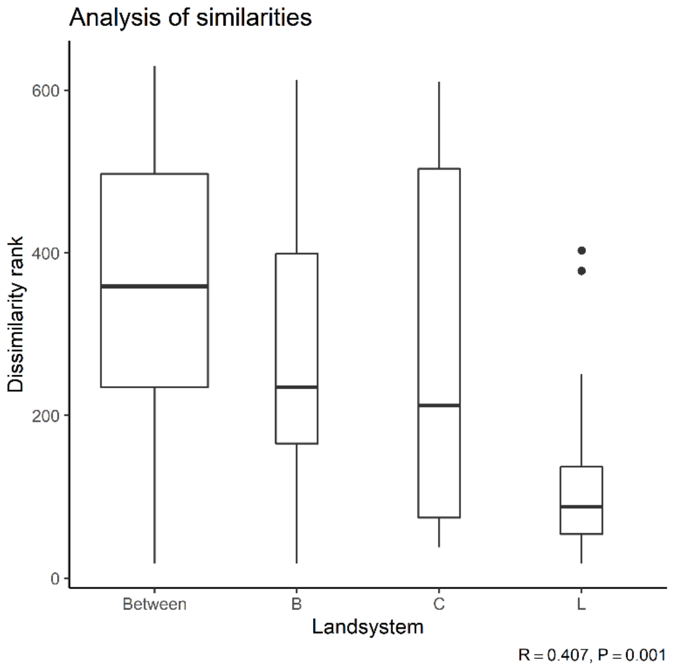

Figure 7a. Analysis of similarities of the distribution of plant species across each browsing plot as compared to landsystem in 18 vegetation assessment plots (6 x fenced, 6 x unfenced, and 6 x outside the predator-free pen) at Matuwa. L = Eucalypt floodplains on Carnegie landsystem; B = Bullimore landsystem; C = Cunyu landsystem.

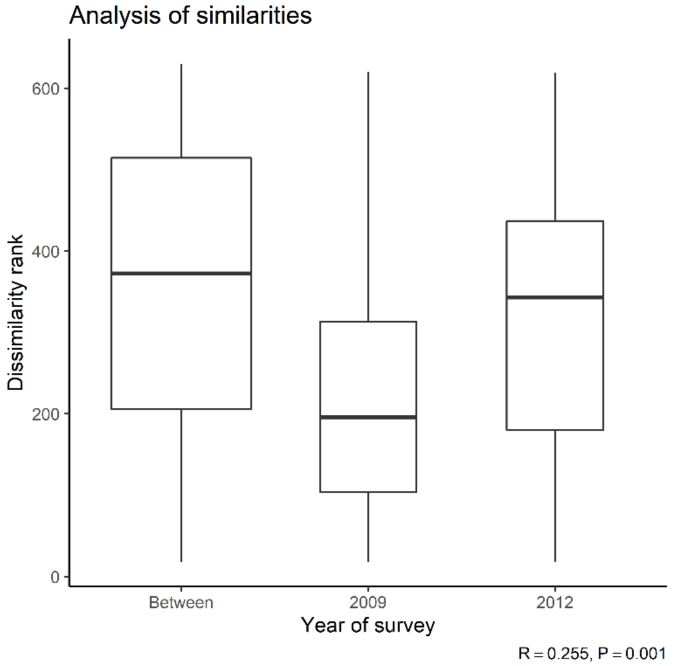

Figure 7b. Analysis of similarities of the cover of plant species as compared to year in 18 vegetation assessment plots (6 x fenced, 6 x unfenced, and 6 x outside the predator-free pen) at Matuwa.

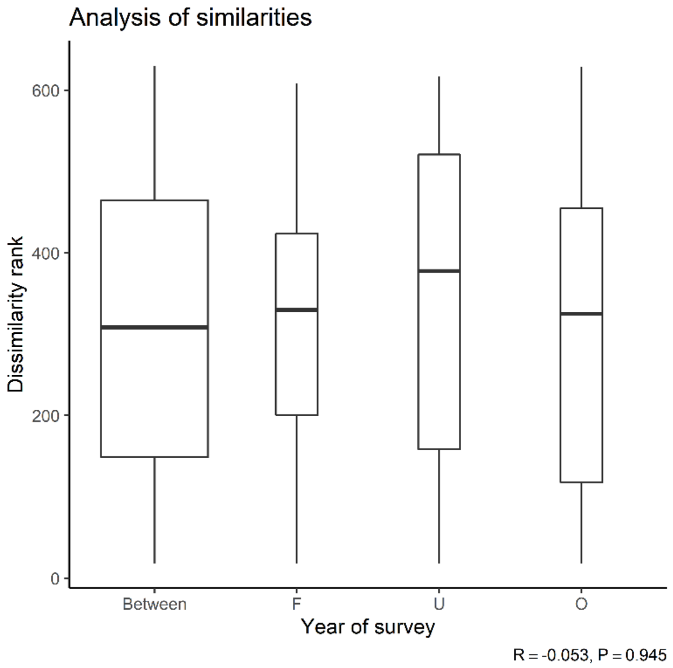

Figure 7c. Analysis of similarities of the cover of plant species as compared to fencing treatment in 18 vegetation assessment plots (6 x fenced, 6 x unfenced, and 6 x outside the predator-free pen) at Matuwa.

Unfortunately, treatment of plots (fenced, unfenced, or outside the predator-free pen) did not have a significant relationship with any of the assessed plant metrics. Species formed distinct clusters when compared to landsystem, but this is to be expected given the inherent variation in geology and plant communities among landsystems and inherent variation in biology of plant species. Similarly, our measures of plant abundance, cover and distribution formed distinct clusters when compared to year, but this is to be expected given the extreme environmental variability that may occur in the arid zone from year to year (Low, 1979; McAllister, 2012; Morton, et al., 1995). This study did not produce any evidence that protecting plant species from either introduced or native fauna may be beneficial to vegetation. However, other studies have shown that change in vegetation structure and species recruitment occurs very slowly in arid zone environments and it is very difficult to detect trends in the relative abundance of species from field measurements of biomass and floristic composition at the scale of the decade (Diouf & Lambin, 2001). Different metrics are required to detect true trends in vegetation in response to browsing. Analysis of vegetation greenness index (e.g. (Lohr, et al., 2014)) from satellite imagery may provide more comprehensive data on change in vegetation at Matuwa.

Additionally, the fences have been breached by the native digging mammals (Fig. 8 and 9), particularly boodies and golden bandicoots and despite repairs being carried out on the browsing exclosure fences in April 2019 the animals continue to enter the fenced plots, devaluing the measures of vegetation and limiting the usefulness of the browsing exclosures. As may be expected, there were significantly fewer new digs counted in August 2019 after the fences were repaired ($p = 0.04$, Table 2), but fauna was still breaching the browsing exclosures. Significantly fewer digs were counted in plots on the Cunyu landsystem, which is characterised by calcrete platforms and rocky calcrete soil with sparse vegetation, than either the Eucalypt floodplains or Bullimore landsystems ($p = 0.01$, Table 2-3), which are characterised by sandplains and claypans supporting spinifex, Eucalypts and mulga shrublands. While the fenced plots had fewer digs than unfenced plots the difference was not significant ($p = 0.58$, Table 3). There were significantly more digs counted at both fenced and unfenced plots inside the 1100ha predator-free pen than in plots outside the predator-free pen ($p = 0.01$, Table 3). Boodies do not have an established population outside the predator-free pen, and while golden bandicoots are occasionally observed outside the pen their density is extremely low. A similar pattern of results was generated by analysis of the number of old digs (Table 4-5). Future counts of faunal digs should focus on new digs rather than old digs as they are a measure of recent faunal activity. Whereas, old digs are cumulative and may be misleading.

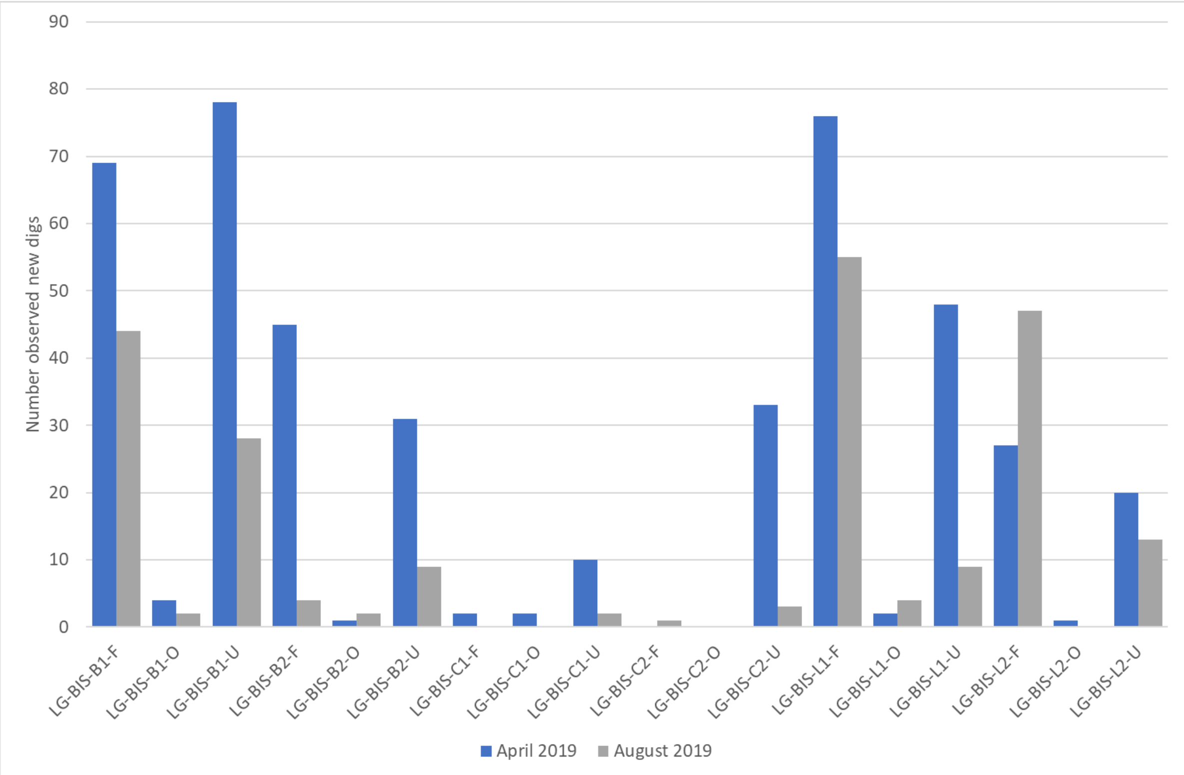

Figure 8. Number of new native fauna digs counted around the inside perimeter of each of the browsing assessment plots (F = fenced, U = unfenced, and O = outside) in April and August 2019.

Table 2. Anova results from comparison of the number of new digs counted in April and August 2019, on each of the browsing assessment plots installed in and around an 1100ha predator-free pen at Matuwa.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Month	1	1419	1418.8	4.55	0.04*
Landsystem	2	3664	1832.2	5.87	7.04^{-2}**
Treatment	2	5613	2806.3	8.99	8.69^{-3}***
Residuals	30	9358	311.9		

Table 3. Tukey pairwise comparison of the number of new digs counted in April and August 2019, on each of the browsing assessment plots installed in and around an 1100ha predator-free pen at Matuwa.

Variables	Difference	Adjusted P-value
August-April	-12.55	0.04
Cunyu-Bullimore	-22	0.01
Lake-Bullimore	-1.25	0.98
Lake-Cunyu	20.75	0.01
Outside-Fenced	-29.33	0
Unfenced-Fenced	-7.16	0.58
Unfenced-Outside	22.16	0.01

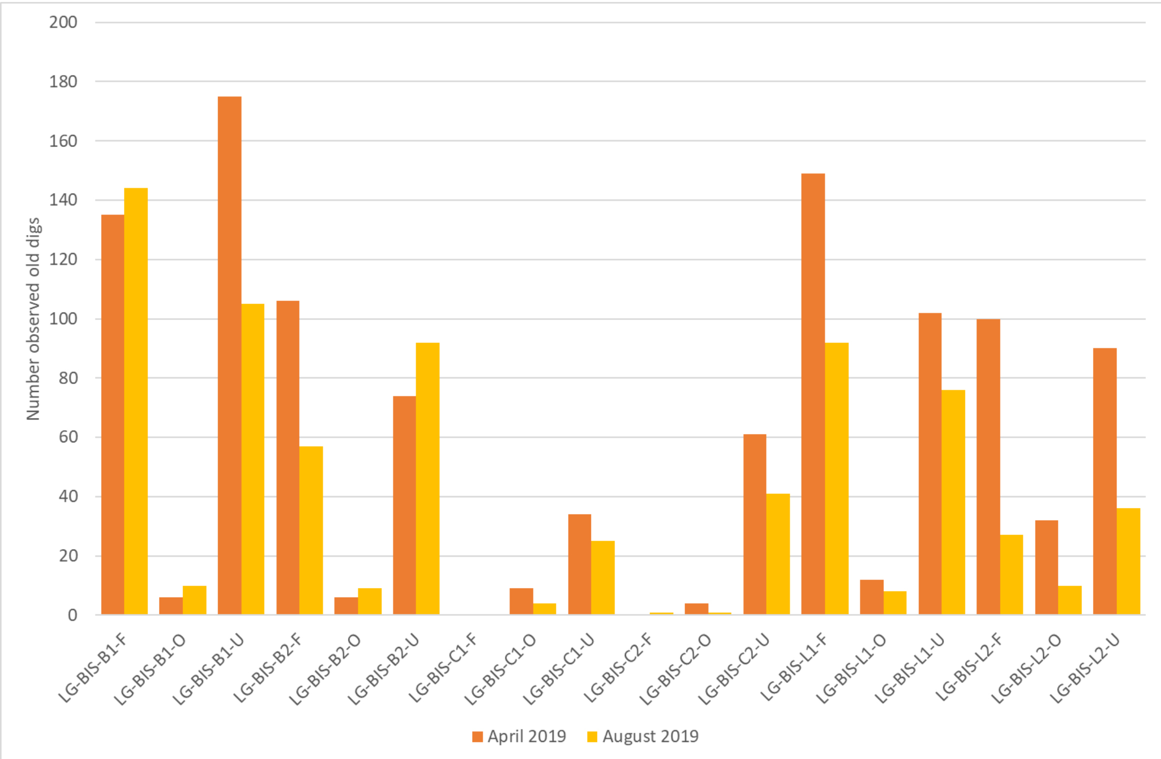

Figure 9. Number of old native fauna digs counted around the insider perimeter of each of the browsing assessment plots (F = fenced, U = unfenced, and O = outside) in April and August 2019.

Table 4. Anova results from comparison of the number of old digs counted in April and August 2019, on each of the browsing assessment plots installed in and around an 1100ha predator-free pen at Matuwa.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Month	1	3540	3540	3.35	0.07
Landsystem	2	24646	12323	11.66	1.79^{-4}***
Treatment	2	31667	15833	14.98	3.08^{-5}***
Residuals	30	31706	1057		

Table 5. Tukey pairwise comparison of the number of old digs counted in April and August 2019, on each of the browsing assessment plots installed in and around an 1100ha predator-free pen at Matuwa.

Variables	Difference	Adjusted P-value
August-April	-19.83	0.08
Cunyu-Bullimore	-61.58	1.85^{-4}
Lake-Bullimore	-15.41	0.48
Lake-Cunyu	46.16	4.33^{-3}
Outside-Fenced	-58.33	3.64^{-4}
Unfenced-Fenced	8.33	0.81
Unfenced-Outside	66.66	6.34^{-5}

The method of vegetation assessment used in 2009 and 2012 is very coarse and we conclude that the method would be unlikely to detect significant changes in the vegetation due to grazing/browsing within a decade, especially since the browsing exclosures are being breached by digging fauna. Additionally, there is very limited replication (2 replicates per treatment) of the plots which undermines the value of any statistical analysis and associated conclusions. That said, we do recommend a third assessment of the vegetation in the browsing plots to test this conclusion. In the interim, and in response to the probable lack of information being supplied by the breached browsing exclosures we initiated an assessment of browsing on indicator plant species.

2.2 Indicator species

The increase in abundance of native browsers inside the pen appears to be having an impact on the vegetation inside the enclosure. One plant species, Templetonia *egena*, a broom-like leguminous shrub, is common both inside and outside the enclosure and appears to be especially favoured by the boodies (Figure 10a-b). The impact of browsing is very apparent on Templetonia in the form of gnawed and snapped stems, torn vegetative material, and adjacent mammal scat, yet the plants seem to be able to survive heavy browsing (Figures 11a-f). This species was chosen as an indicator species to determine future browsing impact of native and feral fauna around the predator-free enclosure, due to its wide distribution across arid and semi-arid Australia, common occurrence at Matuwa, ease of identification (Thompson, 2010) and apparent palatability to both native and feral fauna (Wilson, et al., 1976).

Observers can rapidly assess the amount of browsing that has occurred at each Templetonia using a categorical scoring system (Table 6) and each individual Templetonia can serve as a replicate. A similar system of recording browsing on individual plants, including on Templetonia has been used to monitor the browsing impact of sheep and feral goats in western New South Wales (Wilson, et al., 1976).

Templetonia plants both inside and outside the predator proof enclosure were assessed in April 2019 and again in August 2019. Plants were chosen as they were encountered, with no bias towards healthy, unhealthy, browsed or unbrowsed plants. Each plant was photographed, given a GPS location and a grazing impact score (Figures 11a-f, Table 6) from 0 (not browsed) to 5 (dead due to browsing).

One of the 30m x 30m paired grazing/browsing exclusion plots had several Templetonia inside and outside the fence and despite the fence being breached prior to the April 2019 vegetation assessment, the fence was repaired to determine if plants protected from browsing native fauna might recover.

Comparisons between plants inside and outside the predator proof fence were made using ANOVA with Tukey’s pairwise comparisons. A probability value of 0.05 or less was considered to indicate a significant difference. Some areas of Templetonia outside the predator proof fence were burnt between April and August 2019; these burnt plants were excluded from the analysis.

Figure 10a. Photograph from a Reconyx PC900 camera-trap showing a boodie browsing a *Templetonia egena* with a browsing score of 3-4.

Figure 10b. Base of a Templetonia plant showing teeth marks, believed to be Boodies.

Table 6. Quantitative scale created to assess the amount of browsing occurring on Templetonia egena.

Browsing score	Description
0	No sign of browsing, Figure 11a.
1	Very light browsing; some browsed leaves but no broken stems, Figure 11b.
2	Light browsing, few broken stems, Figure 11c.
3	Moderate browsing, <50% dead but many broken stems, Figure 11d.
4	≥50% dead with many broken branches and signs of browsing, Figure 11e.
5	Dead with many broken stems due to browsing, Figure 11f.

Figure 11a. No browsing, score 0.0

Figure 11b. Light browsing, score 1.5

Figure 11c. Light to moderate browsing, score 2.0

Figure 11d. Moderate browsing, score 3.0

Figure 11e. Severe browsing, score 4.0

Figure 11f. Very severe browsing, score 4.8

2.2.1 Results of Templetonia assessment

We assessed the browsing score for 61 individual Templetonia plants in and around the predator-free pen at Matuwa (11 fenced, 30 unfenced, and 20 outside). Twenty-six plants were assessed in both April and August 2019.

There was a significant difference between mean browsing score for Templetonia plants inside and outside the predator proof enclosure (Table 7, Figure 12). Browsing impact significantly increased between April to August (p = 0.002). Browsing impact was not significantly reduced by the presence of a browsing exclosure fence, but this is expected given that digging fauna were breaching the exclosure and 44 new digs were counted in the exclosure in August 2019 (Figure 8 and 9; LG-BIS-B1-F). Templetonia present outside the predator-free pen were significantly less browsed that either fenced or unfenced Templetonia inside the pen (Table 7, Figure 12).

Examination of the browsed plants indicated the animals were eating the leaves (phyllodes) and bark of the plants (Fig 10b). Boodie scats were common around browsed plants and Reconyx PC900 motion activated cameras have also captured multiple photos of boodies browsing and climbing Templetonia plants (Figure 10a-b) suggesting that boodies are the main consumers of Templetonia. On-going research using genetic techniques is being used to confirm which herbivorous species (mala or boodies) are consuming Templetonia and other species within the predator-free enclosure.

The browsing score for Templetonia plants did significantly increase between April and August 2019. Given that we only have two survey periods, the difference may attributable to observer variation, season, or browsing. We cannot attribute a cause to the change in browsing score without further surveys. The rapid change in browsing score does however suggest that *Templetonia egena* may be a suitable indicator species for the impact of browsing species on native vegetation at Matuwa.

Table 7. Comparison of browsing score for Templetonia egena in and around the predator-free pen at Matuwa.

ANOVA: Browsing score~Treatment+Month					
	Df	Sum Sq	Mean Sq	F value	P value
Month	1	7.98	7.98	10.02	***0.002
Treatment	2	178.64	89.32	112.08	***<2.00^{-16}
Residuals	83	66.14	0.80		

Tukey multiple comparison of means				
	Difference	lower	upper	Adjusted p-value
Outside – Fenced	-2.95	-3.56	-2.35	***0.00
Unfenced – Fenced	0.18	-0.39	0.75	0.75
Unfenced - Outside	3.13	2.59	3.66	***0.00
August - April	0.61	-0.12	1.34	0.002

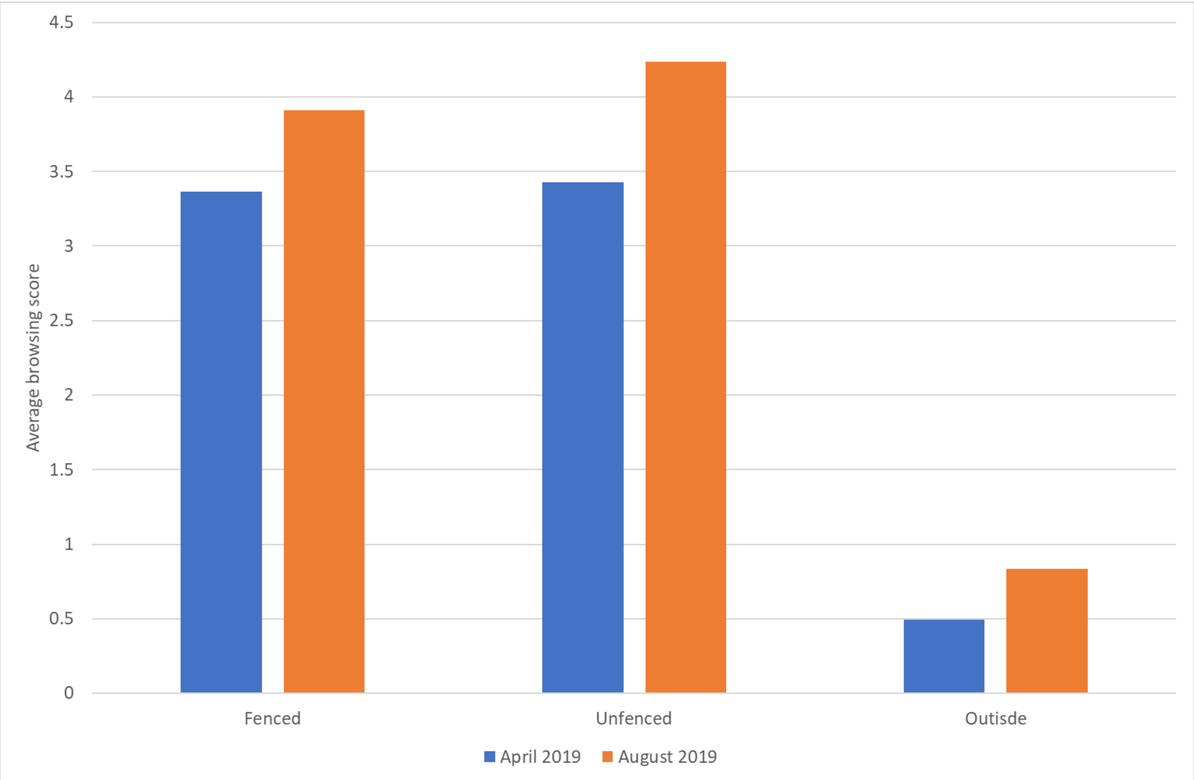

Figure 12. Comparison of browsing score for Templetonia egena in and around the predator-free pen at Matuwa. Lower scores indicate less browsing damage.

3 Discussion

There was a very strong browsing impact on *Templetonia egena* inside the predator-free fence at Matuwa. It is likely that the main browsers are boodies, but this is to be confirmed. In August 2019 it was observed that many Templetonia plants inside the predator-free fence were dead. These plants were generally not assessed during the first assessment (April 2019) because the study was aimed at determining future vegetation changes. Nevertheless, these deaths indicate that browsing pressure is very high and could be considered excessive. It is expected that more Templetonia will die inside the enclosure if this browsing pressure continues. Further research is required to set a threshold of acceptable browsing pressure on Templetonia in the predator-free pen at Matuwa.

Very little effective rainfall fell at Matuwa in 2018 (229.1mm) and 2019 (69.5mm; average annual rainfall = 260.8mm) and this may have exacerbated the browsing pressure on Templetonia. General observations indicate that other plant species have also been heavily browsed inside the enclosure. *Acacia and Ptilous* species, for example, are being gnawed at the roots, *Solanum lasiophyllum* is frequently gnawed to the ground, the fruit, leaves and bark of *Eremophila* species are consumed, and the bark of spreading *Grevillia* species are visibly gnawed.

There is no evidence that small browsing/grazing exclusion plots can alter browsing damage, and these plots would need to be constantly monitored and repaired to prevent breaches. Boodies and golden bandicoots are digging animals and will penetrate under fences if they are not built properly and maintained.

4 Recommendations

- Bi-annual assessment of browsing on *Templetonia egena* plants inside and outside the predator-free pen.
- At least one more survey of abundance, cover and distribution of plants in the vegetation assessment plots (Fenced, unfenced, and outside). Survey to include a count of fauna diggings within each plot.
- Fence several *Templetonia egena* plants inside the predator-free pen to determine a rate of recovery by plants spared from future browsing.

Appendices

Appendix 1 Original vegetation monitoring data fields

CODES				
LIFEFORM			LIFESTYLE	
Code			Code	
H	Herb		Annual	
F	Fern		Perennial	
GP	Geophyte			
GR	Grass			
Z	Sedge		FIRE RESPONSE	
T	Tree		Code	
S	Shrub (over 31 cm)		A1	Seed stored in soil
DS	Dwarf Shrub (1-30 cm)		A2	Seed stored on plant (serotinous)
P	Parasite		A3	No seed on site
V	Vine (climber/runner)		B1	From Epicormics
R	Rush		B2	From woody rootstock/lignotuber
CY	Cycad		B3	From fleshy underground organ (corm, bulb, tuber, rhizome)
X	Xanthorrhoea/Kingia		U	Unknown
U	Unknown			
COVER			ABUNDANCE	
Code			Code	
1	No plants		1	No plant
2	<1% cover		2	1 plant
3	1-5% cover		3	<10 plants
4	5-25% cover		4	10-50 plants
5	25-50% cover		5	50-100 plants
6	50-75% cover		6	100-500 plants
7	75-95% cover		7	>500 plants
8	95-99% cover			
9	100% cover			
DISTRIBUTION			FLOWER FREQUENCY	
Code			Rare	
1	1/4		Occasional	
2	2/4		Frequent	
3	3/4		Buds (Y/N)	
4	4/4		Fruit (Y/N)	

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