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High macropod populations at Look At Me Now Headland, North Coast NSW: implications for endangered *Themeda triandra*-grasslands on coastal headlands

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Abstract: High grazing pressure from over-abundant macropods (kangaroos) is perceived to have a detrimental impact on biodiversity. Studies have shown potential changes in state and retardation of degraded vegetation recovery while other investigations have shown correlations with increased floristic diversity. The responses of grasslands to high impact macropod grazing may not be universal. Endangered *Themeda triandra*-dominated grasslands, on coastal headlands of New South Wales (NSW) and the associated threatened flora are thought to be negatively affected by high macropod grazing.

We assess these assumptions via a comparative investigation across 46 headlands (467 plots) on the North Coast of NSW, and a BACI (Before and After Control Incident) design grazing exclusion experiment at a particularly significant site. We compare floristic richness, species density, evenness, Shannon H, Whittaker Beta Diversity, occurrence of listed threatened flora, average sward height and macropod density.

Look At Me Now Headland (LAMN), between Coffs Harbour and Woolgoolga has one of the highest recorded population densities of macropods. Here 16 permanent plots were placed with grazing exclusion cages erected around half. Sampling occurred annually (October-November) for four consecutive years (2015-2018). Under high macropod grazing pressure LAMN Headland was found to have the highest scores for total richness, species density, species diversity and moderate to high values for species evenness and beta diversity. Within grazing exclusion plots the sward height increased significantly and was associated with a significant decrease in species density, beta and alpha diversity.

Our results indicate that macropod grazing, even at the highest intensities, may be beneficial to floristic species diversity within the endangered *Themeda*-grasslands of coastal headlands and seacliffs within the North Coast Bioregion of NSW; our broader comparative study would suggest that this may also be the case on other headlands.

Key words: grazing management, monitoring, threatened community, threatened species, sward height, species diversity, richness, BACI.

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Introduction

Uncontrolled high numbers of grazing macropods (kangaroo) are thought to cause substantial changes in vegetated communities often leading to cascading changes in state (Flemming et al., 2012; Morgan et al., 2017). High densities of macropods have been known to cause detrimental impacts on soil health, fauna habitat, the recovery from fire and recovery of degraded vegetation (Meeers & Adams, 2003; McIntyre & Tongway, 2010; McIntyre et al., 2010; Howland et al. 2014). Overabundant macropods are viewed as generally posing a threat to the conservation and restoration of native vegetation remnants (Read; https://www.esa2019.org.au/symposia-at-esa19/). While negative impacts on flora have been shown in some instances, these impacts may not be universal and evidence suggests that different outcomes may occur within different vegetative systems (Hunter & Hunter 2017a). If differences in impact exist it is important that these are looked at, so that more nuanced and targeted management actions are made appropriate to each system.

Themeda-dominated assemblages on coastal headlands in New South Wales (NSW) are currently listed as an Endangered Ecological Community- *Themeda*-grasslands of coastal headlands and seacliffs within the North Coast Bioregion of NSW (NSW *Biodiversity Conservation* Act 2016; http://ww.environment.nsw.gov.au/determinations/ThemedaGrasslandSeacliffsEndSpListing.htm). These communities exist on island-like rocky headlands primarily on basalt substrates, but they are not restricted to this rock type. A total of 108 ha of the community is thought to be extant within NSW of which 72% (78 ha) occurs within conservation reserves (J.T.Hunter *unpublished mapping* 17/03/2019). Though described as grasslands, most occurrences are a mosaic of co-dominant *Themeda triandra* and a variety of prostrate shrubs sometimes referred to as grassy prostrate heaths (Hunter & Hunter 2017a). *Themeda*-assemblages on headlands and seacliffs are thought to be endangered by encroachment of taller shrubs (native and non-native), invasive weeds, inappropriate fire regimes, inappropriate plantings, agriculture, foot traffic and grazing by native and non-native herbivores (Adam et al., 1989; Kenney, 2012; Lunt et al., 2010). Many of these threats have been proposed without any research to corroborate how much these factors may negatively impact on the grasslands. Recent research suggests that a more nuanced understanding may be required and that some suggested threatening processes may have benefits to the grassland, at least under specific scenarios, and that a blanket cessation of certain threats may be more detrimental (Hunter & Hunter, 2017ab; Hunter, 2018).

Eastern Grey Kangaroos (*Macropus giganteus*) are common and abundant within peri-urban communities of coastal NSW and are often found in high numbers on some grassy headlands. The northern beaches of Coffs Harbour, and in particular the Emerald Beach area, has been designated as a kangaroo hotspot (Henderson et al., 2017). One of the reasons for such high numbers include the upgrade of the highway which has precluded movement of macropods out of the coastal areas and into the hinterlands; however, other explanations are also likely. Henderson et al. (2017) investigated the population sizes of kangaroos in the northern beaches area of Coffs Harbour and found that Emerald Beach area (between Coffs Harbour and Woolgoolga) which includes Look At Me Now Headland (LAMN) and Dammerels Headland had kangaroo populations more than twice as high as any other location in the region (4.87 individuals ha^{-1}). Similar kangaroo densities (5 individuals ha^{-1}) in Goorooyarroo and Mulligans Flat Nature Reserves (in the Australian Capital Territory) have been considered to have had detrimental impacts to soil health, fauna habitat and recovery of degraded vegetation (McIntyre et al., 2010; ACT DTMS & ACT PCL, 2010). Of the Coffs Harbour headlands WIRES et al. (2016) suggested that the population densities were detrimentally effecting biodiversity values, specifically that macropods, through direct consumption and trampling were a medium to high threat impacting negatively on threatened flora species and the threatened *Themeda*-dominated coastal headland assemblages. In spite of these claims no actual data existed to substantiate the negative impacts on the endangered *Themeda*-dominated grassland or the threatened species on these headlands.

In contrast, correlative studies have indicated that events that reduce *Themeda triandra* sward height and dominance may lead to increased floristic diversity at the local and landscape scale, and retention of threatened flora species populations on coastal headlands (Hunter, 2016; Hunter & Hunter, 2017ab; Hunter 2018). In particular, analyses by Hunter and Hunter (2017a) indicated that increased grazing pressure from macropods, even at the highest densities, was associated with increased floristic species and trait diversity within *Themeda*-dominated assemblages of the Coffs Harbour region.

LAMN Headland is a major location for the conservation of the endangered *Themeda*-grasslands on coastal headlands and designated Saving Our Species site for the conservation of the grasslands, the threatened shrubs *Zieria prostrata* J.A. Armstrong and *Pultenaea maritima* de Kok and a known site for *Senecio spathulatus* A.Rich. and *Thesium australe* R.Br. (http://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/saving-our-species-program; Cohn, 2004; Hunter, 2016; Hunter & Hunter, 2017ab). LAMN Headland provides an interesting case study of a headland with a long history of high macropod abundance on a location that is a key area for the conservation of endangered grassland and listed threatened flora species.

Here we test the effects high macropod grazing pressure on the floristic diversity of *Themeda*-dominated assemblages at LAMN Headland. Firstly, we compare biodiversity measurements (richness, rarity, species density, species diversity) obtained from occurrences of *Themeda*-dominated assemblages on headlands. Secondly, we more directly investigate the effects of grazing by tracking the changes across a grazing exclusion experiment using a Before and After Incident (BACI) design over a four-year period.

Methods

Study area

Themeda-dominated assemblages on coastal headlands in eastern Australia form an intricate mosaic of grass and prostrate heath and is best described as grassy prostrate heath (Hunter & Hunter, 2017a). Vegetation data was collected from headlands with *Themeda*-dominated assemblages in the North Coast Bioregion of NSW, Australia, the broader study area covering approximately a 530 km stretch of coastline from Byron Bay south to Gosford (-28.5469° to -32.6638°). The climate of the region is sub-tropical with mean annual rainfall of 1345-1737 mm, mean maximum annual temperatures from 23.4-27.6° C and mean minimum of 9-14.0° C. LAMN Headland at Emerald Beach, between Coffs Harbour and Woolgoolga and the adjacent Dammerels Headland were chosen for a BACI (Before and After Control Incident) design grazing exclusion experiment (both headlands are now referred to collectively as LAMN).

Vegetation and plot data

On 46 coastal headlands we collected data from 467 vascular floristic survey plots, each 2 x 2 m dimension placed randomly within *Themeda*-dominated assemblages (http://www.givd.info/ID/AU-AU-003). The survey was conducted over spring and early summer (November to February) from 2015-2018. Species nomenclature follows PlantNET (http://plantnet.rbgsyd.nsw.gov.au/; accessed January 2017). Vascular plant taxa were scored using overlapping percent cover and frequency. Frequency was determined by dividing the plot into 16 subplots (50 x 50 cm) where the rooted presence and absence of each species was scored in each subplot. A drop plate 10 cm in diameter was attached to a metal ruler and used to record the height of standing biomass of the ground layer vegetation at five random locations within each plot.

During the general survey, the intensity of macropod grazing was assessed via visual observation of live animals, and observed amount and age of macropod dung on headlands. A score from none (no observed animals or dung), **low** (1 piece of macropod dung within a 2 m radius), **moderate** (2-5 pieces of dung within a 2 m radius), **high** (more than 5-10 pieces of dung within a 2 m radius and residential animals seen), **very high** (large resident colonies seen with 10-30 pieces of dung) and **extreme** being more than 30 pieces was allocated to each plot.

Accurate assessment of macropod population sizes was beyond the scope of this project and we acknowledge a number of issues relating to the short-term nature of our macropod observations, and the use of dung which can decay at different rates depending on weather (Johnson & Jarman, 1987). We also acknowledge that observations were only made on a one-time basis; the results can only be of a generalised nature.

Within the LAMN headlands sixteen plots were chosen with eight randomly allocated total grazing exclusion cages. Surveys were conducted in the manner discussed above in November 2015, October 2016, November 2017 and November 2018. Grazing exclusion fencing was placed around and over the top of exclusion plots in December of 2015 after the first survey (Fig. 1). Exclusion cages were designed to minimise the visual impact for local residents and tourists.

Fig. 1. Example of grazing exclusion cage on Look At Me Now Headland near Coffs Harbour in the NSW North Coast Bioregion.

Statistical analysis

For each spatial and temporal plot placed on LAMN the sward height of the groundlayer, floristic species density (species per plot), Shannon H diversity and summed frequency scores were calculated. Total species richness for each treatment within *Themeda*-dominated assemblages was also collated. Shannon H, species evenness, turnover, total frequency and statistical comparisons between biomass height were calculated within PAST version 3 (Hammer et al., 2003).

The relative interaction index (RII) of Armas et al. (2004) was used to compare the frequency of individual species (out of 16) in plots before erection of exclusion cages and the same plots three years after the erection cages. RII was calculated using $RII = N_{after}-N_{before}/N_{after}+N_{before}$, N equals the frequency score of individuals (out of 16) found in plots before erection of exclusion cages and against plots after caging. The RII score ranges from -1 to 1 with positive scores indicating a positive effect on the frequency of species by grazing exclusion. Before calculation of RII species with only one observation were removed from the dataset. Similarity percentage analysis (SIMPER) identifies the species driving differences between selected types. SIMPER using the Bray–Curtis similarity measure (Hammer et al., 2003) was used to identify taxa contributing most to the Bray-Curtis separation of exclosure and control plots at the final year of sampling (2018).

PERMANOVA (permutational MANOVA) within PRIMER-e (version 7.0.13; Quest Research Limited; Ivybridge, Devon, UK) was performed on data averaged over year and treatment (both considered fixed variables with treatment nested within year). Permutations were conducted with 9999 iterations after square root transformation of the data and Bray-Curtis transformation. Interactions between year and treatment were assessed.

Results

Comparison between headlands

Across the 46 headlands the LAMN headlands were found to have the highest observed macropods densities and highest observed grazing intensities, which corresponded with the lowest average recorded groundlayer sward height (Table 1). The highest flora species richness for *Themeda*-dominated communities was recorded at LAMN (Table 1). The highest number of recorded threatened flora species, highest species density, highest average plot richness and highest average Shannon H diversity score all were obtained at LAMN (Table 1). The highest evenness score occurred at Diggers Point with LAMN had an average score for evenness (Table 1). The highest score for beta diversity occurred at Minnie Waters. LAMN had a higher than average score for Whittakers beta diversity (Table 1).

Table 1. Select floristic attributes for *Themeda*-dominated assemblages within the NSW North Coast Bioregion with macropod grazing. Headlands ordered by Macropod density. Highest scores are highlighted along with the lowest average sward height.

Headland	Macropod density	Average sward height cm	Native richness	Threatened Species no	Species density (Average)	Shannon H Average	Evenness Average	Whittaker Beta
Look At Me Now	**Extreme**	**4.2***	**70***	**4***	**8-24 (15)***	**2.41***	0.76	2.74
Dammerels Headland	Very High	8.1	41	3	5-19 (12)	2.16	0.73	2.08
Boambe Headland	High	26.5	43	2	6-14 (10)	1.94	0.71	3.27
Boomerang Point	High	15.4	25	1	12-16 (14)	2.17	0.63	0.79
Diggers Camp	High	15.0	24	1	4-15 (7)	1.50	0.67	2.25
Hat Head	High	10.9	30	1	11-17 (13)	2.25	0.74	1.13
Kemps Corner	High	9.8	32	0	11-18 (14)	2.33	0.73	1.15
Macauleys Headland	High	32.5	46	2	5-14 (8)	1.74	0.76	**4.41***
Woolgoolga Headland	High	19.5	22	1	8-15 (11)	2.00	0.70	1.00
Bare Bluff	Moderate	16.4	42	2	5-20 (11)	2.29	0.69	1.77
Charlotte Head	Moderate	14.4	14	0	7-8 (8)	1.54	0.63	0.87
Darkum Rocks	Moderate	16.3	18	1	7-10 (9)	1.88	0.73	1.00
Arrawarra Headland	Low	21.5	32	2	7-19 (11)	1.96	0.71	1.73
Big Hill Point	Low	14.1	15	0	3-11 (8)	1.62	0.71	0.80
Bonville Headland	Low	12.4	16	2	4-11 (8)	1.62	0.70	1.09
Booti Hill	Low	30.5	14	0	6-12 (9)	1.84	0.75	0.56
Bunker Headland	Low	24.7	13	0	4-8 (10)	1.53	0.76	1.05
Camden Head	Low	14.6	30	0	5-18 (12)	2.05	0.76	1.61
Cape Hawke	Low	50.5	9	0	6-8 (7)	1.68	0.78	0.29
Corumbirra Point	Low	16.9	29	2	7-14 (11)	1.93	0.66	1.70
Crescent Head	Low	16.0	23	1	12-16 (14)	2.31	0.72	0.64
Diggers Headland	Low	21.7	11	1	7-8 (8)	1.81	0.77	0.38
Diggers Point	Low	17.2	22	3	7-18 (11)	2.13	**0.81***	0.77
Elephant Head	Low	17.7	13	0	4-11 (9)	1.69	0.69	0.96
Grants Head	Low	21.3	20	0	6-18 (12)	2.02	0.73	0.67
Grassy Head	Low	27.9	23	1	5-9 (7)	1.67	0.76	2.20
Green Bluff	Low	17.0	18	1	4-13 (8)	1.76	0.76	1.22
Lennox Headland	Low	20.2	9	0	2-7 (4)	1.06	0.75	1.61
Middle Head	Low	46.8	16	0	13 (13)	2.16	0.67	0.23
Minnie Waters	Low	34.7	18	1	5-12 (9)	1.70	0.65	1.00
Mullaway Headland	Low	22.7	60	1	5-20 (11)	1.93	0.67	3.46
Ocean View Headland	Low	17.9	68	1	5-18 (11)	1.97	0.67	3.24
Point Plummer	Low	13.3	20	0	10-12 (10)	1.97	0.68	0.78
Queens Head	Low	13.8	20	0	15-15 (15)	2.37	0.72	0.27
Racecourse Head	Low	19.4	23	0	8-15 (12)	2.17	0.73	0.87
Red Rock	Low	7.2	15	1	3-9 (6)	1.44	0.73	1.40
Scotts Head	Low	20.1	17	0	3-13 (7)	1.53	0.69	0.94
Seal Rocks	Low	24.3	11	0	7-10 (9)	1.73	0.67	0.53
Treachery Headland	Low	19.5	13	0	3-8 (5)	1.44	0.73	1.40
Yagon Gibber	Low	19.9	10	0	6-7 (7)	1.57	0.75	0.54
Bald Head	None	12.4	16	0	7-14 (11)	2.10	0.80	0.50
Broughton Island	None	42.9	21	0	5-11 (9)	1.87	0.75	1.36
Crowdy Head	None	22.4	11	0	3-8 (6)	1.73	0.67	0.53
Diamond Head	None	21.7	31	1	13-20 (16)	2.42	0.70	0.90
Flat Top	None	18.9	15	0	12-13 (13)	2.31	0.80	0.20
Forster	None	17.9	11	0	8-9 (9)	1.73	0.67	0.53

BACI grazing exclusion

A total of 86 taxa were found within plots over the course of the investigation of which 66 were found within control and 50 within exclusion plots in the final year of sampling (2018). The sward height increased significantly from an average of 4.2 cm across all plots before erection of cages to 28 cm after three years of grazing exclusion (Fig. 2; Fig. 3). Initially there was no statistical difference between species density scores within treatments at the start of the experiment but in each subsequent observation after exclusion plots were erected species density decreased significantly in exclusion plots (Fig. 4). In contrast control plots remained statistically stable before increasing significantly in 2018 (Fig. 4). Average species density (richness within plots) declined by more than half within grazing exclosures over the observation period. The total number of species recorded across each treatment was found to vary over the observation years but in general was found to decline within exclosure plots and remain comparatively stable within control treatments (Fig. 5). As with species density, Shannon H was not significantly different between treatments in 2015 but decreased significantly each year since fencing, while control plots remained stable before an increase in the final year (Fig. 6). The summed frequency of all species recorded within plots was again not statistically significantly different between treatments in 2015 but was found to decrease significantly yearly in the exclosure plots and overall remain relatively stable within control plots (Fig. 7). The frequency of recorded *Themeda triandra* observations was found to remain relatively stable within control plots and was found to remain stable across years until the final observation in exclosures whereby the overall frequency of *Themeda triandra* was found to increase (Fig. 8). Whittaker's beta diversity within the final year of observation was found be higher within grazed plots (0.7341) compared to ungrazed plots (0.66957). The number of new species found colonising plots over the four years of observations was greater within grazed treatments (Fig. 9).

PERMANOVA results indicated that there was no significant floristic difference between treatments prior to cages being erected (2015 $p = 0.8368$) or one year after their erection (2016 $p = 0.5704$). Two years after cages were erected a near significant difference between treatments was found (2017 $p = 0.0688$) with a highly significant difference between treatments being found three years after erection of cages (2018 $p = 0.0033$).

Of the 46 species within the exclusion plots, 31 were found to have decreased in abundance by November 2018 with only 15 species found to increase over this time (Table 2). *Themeda triandra* was found to have the smallest increase in frequency (RII score 0.085) (Table 2). Of these 15 species that increased in the exclosure plots, 11 did not contribute to SIMPER separation of the treatments; the remaining four had a slightly higher overall frequency within control plots largely due to these species being in low frequency and being new colonisers rather than increasers which also were found within the control plots. One introduced species was found to have increased while one rare species and four introduced species declined in exclosure plots

Table 2. List of plant species found within grazing exclusion plots on LAMN Headland and relative interaction index (RII) score. RII varies from -1 to 1 with negative scores indicating a reduction in frequency after the implementation of three years of grazing exclusion (2018). Introduced species are indicated by '*'. Listed threatened species are indicated by '[R]'.

Species	Score
Brunoniella australis	1
Dianella revoluta	1
Einadia hastata	1
Gonocarpus hirtus	1
Goodenia bellidifolia	1
Hydrocotyle hirta	1
Lomandra multiflora	1
Paspalidium constrictum	1
*Paspalum urvillei**	1
Thysanotus tuberosus	1
Tricoryne anceps	0.75
Hybanthus stellarioides	0.615385
Themeda triandra	0.084746
Podolobium scandens	0
Pimelea linifolia	-0.02941
Lobelia anceps	-0.17647
Cynodon dactylon	-0.25
Poranthera microphylla	-0.25926
Polymeria calycina	-0.30233
Pratia purpurascens	-0.33333
Oxalis perennans	-0.35714
Senecio spathulatus[R]	-0.38462
Zoysia macrantha	-0.46269
Hibbertia vestita	-0.5
Viola banksii	-0.51724
Goodenia rotundifolia	-0.6
Mitrasacme paludosa	-0.63636
Schoenus apogon	-0.74468
Hypochaeris radicata	-0.91667
Carex breviculmis	-0.93103
*Anagallis arvensis**	-1
Centipeda minima	-1
Dichondra repens	-1
*Eragrostis interrupta**	-1
Gonocarpus humilis	-1
Hydrocotyle laxiflora	-1
Isolepis cernua	-1
Lachnagrostis filiformis	-1
Lomandra longifolia	-1
Ottochloa gracillima	-1
*Paspalum dilatatum**	-1
Samolus repens	-1
Schoenus nitens	-1
Spiranthes australis	-1
Stackhousia viminea	-1
*Taraxacum officinale**	-1

(Table 1). *Themeda triandra* was not found within SIMPER outputs indicating that this dominant species had no impact on the significant separation of the treatments within the final year of observations. All threatened species (*Senecio spathulatus, Zieria prostrata, Pultenaea maritima*) except *Thesium australe* (which was not visible at the final survey) had a higher relative frequency within control plots and contributed small percentages to the Bray-Curtis separation of the treatments (Table 2). Three introduced taxa also made contributions to the Bray-Curtis difference in treatments (in decreasing order: *Hypochaeris radicata, Lysimachia arvensis, Conyza bonariensis*) with higher frequency within control plots, although *Paspalum mandiocanum* was more prevalent in exclusion plots (Table 2).

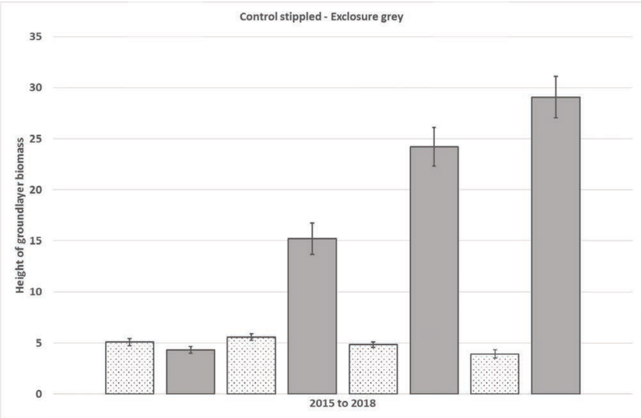

Fig. 2: Bar chart showing height of ground layer vegetation and standard error comparison for control and exclusions plots before erection of cages (2015) and for three years of grazing exclusion (2016-2018).

Fig. 3. Photographs of exclusion plots and biomass changes after two years of grazing exclusion.

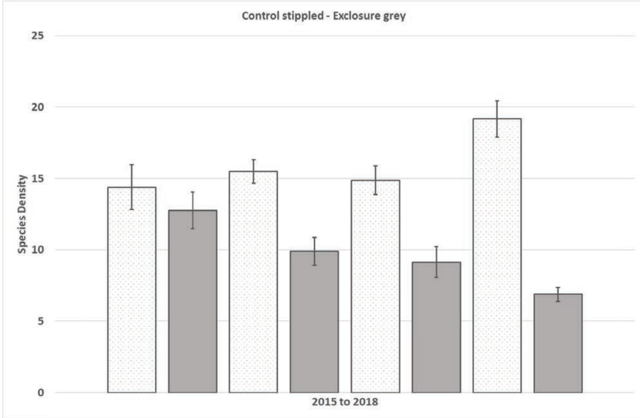

Fig. 4: Bar chart showing height of species density (number of species per plot and standard error comparison for control and exclusions plots before erection of cages (2015) and for three years of grazing exclusion (2016-2018).

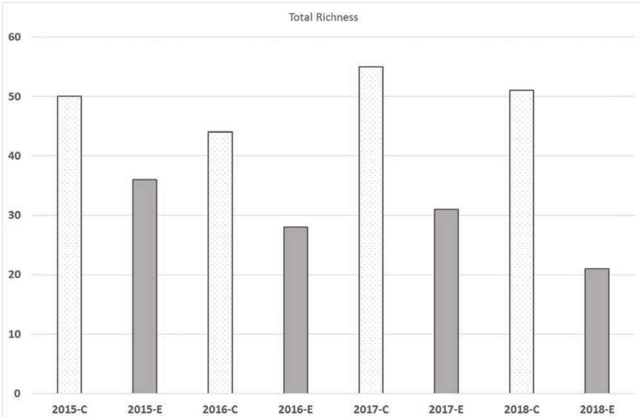

Fig. 5: Bar chart total species count found across all plots within control and exclusion treatments before erection of cages (2015) and for three years of grazing exclusion (2016-2018), Control (C) and Exclusion (E).

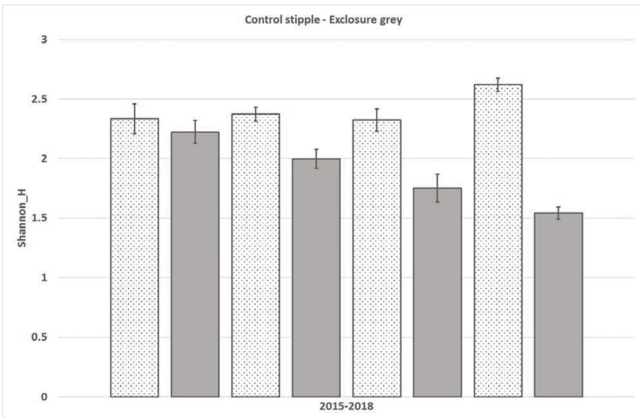

Fig. 6. Bar chart showing species diversity (Shannon H) and standard error comparison for control and exclusions plots before erection of cages (2015) and for three years of grazing exclusion (2016-2018).

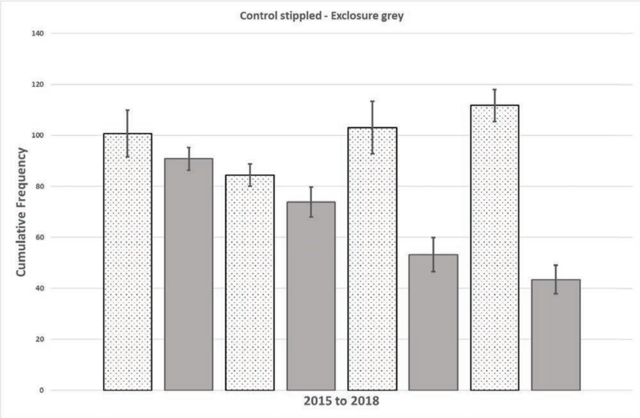

Fig. 7: Bar chart showing summed total frequency of all species found and standard error comparison for control and exclusions plots before erection of exclusion cages (2015) and for three years of grazing exclusion (2016-2018).

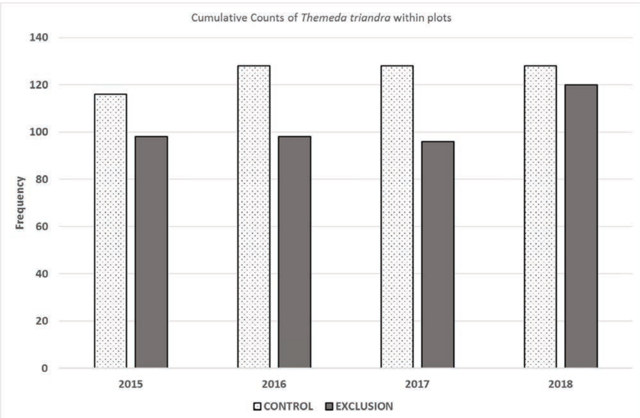

Fig. 8: Cumulative frequency of *Themeda triandra* comparison for control and exclusions plots before erection of cages (2015) and for three years of grazing exclusion (2016-2018).

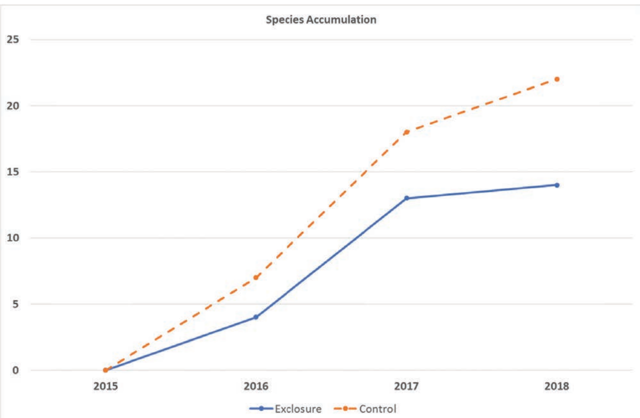

Fig. 9: Number of new species found within exclosure and control plots during the course of four years of monitoring.

Discussion

Our experimental plots confirmed that over the four years, at least for the LAMN headlands (LAMN Headland and nearby Dammerels Head) the longer macropods were excluded, the higher the sward height became at the expense of floristic diversity (alpha, beta and gamma) and numbers of individuals. Plot species richness, species diversity, turnover between plots (Whittakers beta diversity), new species colonisation (species accumulation) and the number of individuals was found to decrease significantly within ungrazed plots and the two treatments diverged to a point that they were statistically different floristic assemblages. Importantly, these changes were not due to any appreciable change in *Themeda triandra* frequency across treatments. *Themeda triandra* remained a dominant entity in both heavily grazed and grazing exclusion sites, in terms of frequency and cover, and was not found to contribute to Bray-Curtis separation of treatments. These results are in agreement with correlative analyses performed by Hunter and Hunter (2017a) who showed macropod grazing was significantly associated with increased floristic and trait diversity. Hunter and Hunter (2017a) and Hunter (2018) also highlighted that interference in *Themeda triandra* overdominance by any means (e.g. grazing, wind shear, competition, interference) was correlated with increases in floristic alpha, beta and gamma diversity.

Eldridge et al. (2003) suggested that 10-20 years was likely to be necessary for ecosystem change to occur as a result of grazing exclusion. However, in our results statistically significant divergence occurred within the treatments by the fourth year. The reasons for this rapid change could be that macropod grazing is not synonymous with grazing by introduced species, or just the inherent differences of this system. It may also be due to the particular defining, and therefore magnitude, of ecosystem change. Within our system heavily grazed and ungrazed were still largely dominated by *Themeda triandra* and in general though the same species occurred across all treatments, the grazing exclusion plots were species poor, and reduced in numbers of individuals. Thus, these changes though significant (p = 0.0033) may not constitute the ecosystem change or trophic modification generally looked for in other investigations (Morgan et al. 2017).

Having headlands with areas that are grazed at various intensities (including ungrazed) is likely to increase the heterogeneity of grassland types on these headlands, thus increasing overall diversity. Our results would suggest that some level of macropod grazing is important within *Themeda*-dominated assemblages on headlands in order to maintain floristic diversity at the local patch, between patches and across the landscape, but importantly, even at the highest macropod pressure, these benefits are maintained. As has been shown by other studies these results are unlikely to be universal within other grassland systems (Meeers & Adams, 2003; McIntyre & Tongway, 2010; McIntyre et al., 2010; Howland et al., 2014). Our study highlights the need to investigate the differences in responses of vegetation assemblages even though they may be dominated by similar species (*Themeda triandra*).

Table 3. SIMPER analysis based on Bray-Curtis similarity using the final 2018 survey data for LAMN Headland. Species are listed in decreasing order of contribution to the Bray-Curtis difference between exclosure and control-grazed plots. Introduced species are indicated by '*'. Listed threatened species are indicated by 'R'

Taxon	Av. dissim	Contrib. %	Cumulative %	Mean Frequency Exclosure	Mean Frequency Control-grazed
Pimelea linifolia	5.429	8.576	8.576	4.14	8.89
Viola banksii	4.636	7.323	15.9	2.57	6.67
Polymeria calycina	4.395	6.943	22.84	5	6.33
Poranthera microphylla	3.944	6.23	29.07	0.143	4.89
Zoysia macrantha	3.906	6.17	35.24	2.43	4.22
Oxalis perennans	3.445	5.442	40.68	0.857	4.44
Goodenia rotundifolia	3.189	5.038	45.72	0	4.11
Schoenus apogon	2.975	4.699	50.42	0.714	3.56
Hybanthus stellarioides	2.397	3.786	54.21	0.714	3.33
*Hypochaeris radicata**	2.197	3.47	57.68	0	3.44
Lobelia anceps	2.067	3.265	60.94	2.57	0.444
Carex breviculmis	1.95	3.081	64.02	0	2.78
Hibbertia vestita	1.866	2.948	66.97	0.571	2.67
*Senecio spathulatus*R	1.858	2.935	69.91	0	2.33
Hydrocotyle hirta	1.802	2.847	72.75	0.143	2.67
Mitrasacme polymorpha	1.732	2.736	75.49	0.286	1.78
Themeda triandra	1.546	2.441	77.93	16	14.2
Cassytha filiformis	1.261	1.992	79.92	0	1.22
Cynodon dactylon	1.123	1.774	81.7	0.143	1.67
Lagenophora stipitata	1.009	1.594	83.29	0	1.33
Lobelia purpurascens	0.9793	1.547	84.84	0.571	0.889
Entolasia stricta	0.8827	1.394	86.23	0	1.11
Gonocarpus hirtus	0.8086	1.277	87.51	0	1
*Lysimachia arvensis**	0.7025	1.11	88.62	0	1.11
Mitrasacme paludosa	0.6729	1.063	89.68	0	0.889
Lomandra multiflora	0.6537	1.033	90.71	0.143	0.556
Phyllanthus virgatus	0.6483	1.024	91.74	0	0.889
*Conyza bonariensis**	0.6121	0.9669	92.71	0	0.889
Podolobium scandens	0.5588	0.8827	93.59	0.714	0
Lachnagrostis filiformis	0.4728	0.7468	94.33	0	0.778
*Zieria prostrata*R	0.4585	0.7243	95.06	0	0.444
Xerochrysum bracteatum	0.4206	0.6643	95.72	0	0.556
Parsonsia straminea	0.3439	0.5433	96.27	0	0.333
Isolepis cernua	0.3365	0.5315	96.8	0	0.444
Stackhousia viminea	0.3354	0.5299	97.33	0.286	0.222
Bacopa monnieri	0.2481	0.392	97.72	0.286	0
Casuarina glauca	0.2431	0.384	98.1	0	0.333
*Paspalum mandiocanum**	0.2375	0.3752	98.48	0.286	0
Desmodium varians	0.2215	0.3499	98.83	0	0.333
Tricoryne anceps	0.1994	0.3149	99.14	0	0.333
Brunonia australis	0.1621	0.256	99.4	0	0.222
Geitonoplesium cymosum	0.1146	0.1811	99.58	0	0.111
*Pultenaea maritima*R	0.1146	0.1811	99.76	0	0.111
Ophioglossum lusitanicum	0.08411	0.1329	99.9	0	0.111
*Paronychia brasiliana**	0.06645	0.105	100	0	0.111

While our results clearly suggest an advantage for floristic diversity from macropod grazing, even at high impact, this should not be equated with other forms of grazing (for example non-native herbivores) without research on impacts. We have not investigated the impacts on other elements of biodiversity such as fauna and faunal habitat requirements, or impacts on soil.

From the larger north coast NSW perspective however, high densities of macropods were only observed on a limited number of headlands (17%) with most headlands having either low or no observable macropods grazing (74%) (Table 1). Little grazed or ungrazed examples of grassy headlands were the norm. While ungrazed examples may contribute to structural (sward height) heterogeneity overall and may form floristically distinct (though species-poor) units, grazing by macropods may be beneficial on other headlands to maintain floristic diversity at all scales (alpha, beta and gamma).

We fully acknowledge the limitations of the current study which include a short observation period (4 years), and more importantly, that the experimental plots were only placed on a single headland. However, we believe the combination of our correlative comparisons, the highly significant results obtained from the single experiment, and the results matching those of other statistically significant correlational analyses within the same system and region (Hunter & Hunter 2017a), are worthy of consideration. Lack of replication across headlands means that it is unclear whether the strength of our results can be readily applicable to all *Themeda*-dominated headlands though we believe the results provide strong incentive for more extensive experimentation. Our results also indicate that high density grazing pressure from macropods may not be universally detrimental to the maintenance of floristic diversity in some grass dominated vegetation types.

Conclusion

Exclusion of macropod grazing pressure over four years was associated with significant and sustained losses of species diversity, relative abundance and lowered species colonisation leading to homogenisation and a distinct but species-poor flora. In agreement with other studies on NSW coastal headlands, macropod grazing, even at high densities and impact, were associated with higher floristic species diversity (alpha, beta and gamma), threatened flora occurrence and individual plant numbers without a notable reduction in the dominance of *Themeda triandra*. High intensity macropods grazing was not associated with degradation or loss of the endangered floristic community or threatened flora species within it but was found to be associated with an increased occurrence of introduced species. In spite of a lack of replication across other headlands the strength of the results and agreement with recent studies would suggest that macropod grazing may be an important feature that helps maintain floristic species diversity within plots, between plots and at the headland scale in *Themeda*-dominated communities on headlands and seacliffs within the North Coast Bioregion of New South Wales.

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