

Mitigating impacts of weeds and kangaroo grazing following prescribed fire in a Banksia woodland

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Summary Banksia woodlands are renowned for their flammability and prescribed fire is increasingly employed to reduce the risk of wildfire and to protect life and property, particularly where these woodlands occur on the urban interface. Prescribed fire is also employed as a tool for protecting biodiversity assets but can have adverse impacts on native plant communities. We investigated changes in species richness and cover in native and introduced flora following autumn prescribed fire in a 700-hectare Banksia/Tuart (*Eucalyptus gomphocephala*) woodland that had not burnt for more than 30 years. Effectiveness of management techniques at reducing weed cover and the impacts of grazing by Western Grey Kangaroo (*Macropus fuliginosus*) postfire were also investigated. Thirty plots were established across a designated burn boundary immediately before a prescribed fire in May 2011, and species richness and cover were measured 3 years after the fire, in spring of 2013. Fencing treatments were established immediately following the fire, and weed management treatments were applied annually in winter over the subsequent 3 years. Our results indicate that autumn prescribed fire can facilitate increases in weed cover, but management techniques can limit the establishment of targeted weeds postfire. Postfire grazing was found to have significant adverse impacts on native species cover and vegetation structure, but it also limited establishment of some serious weeds including Pigface (*Carpobrotus edulis*). Manipulating herbivores in time and space following prescribed fire could be an important and cost-effective way of maintaining biodiversity values.

Key words: Banksia woodland, Kangaroo grazing, prescribed fire, restoration, weed management.

Introduction

The Southwest Australian Floristic Region is significant internationally as Australia's sole biodiversity hot spot. The region supports a remarkable biodiversity including many species found nowhere else which are under increasing threat (Myers *et al.* 2000). Banksia/eucalypt woodlands on deep quaternary sands are the dominant vegetation of the Perth region. Originally covering 280,000 ha, more than half have been cleared for urban development (Government of Western Australia 2010). Those that remain are highly fragmented and under threat from weed invasion, loss of landscape connectivity, loss of hydrological processes and altered fire regimes.

Banksia woodlands are renowned for their flammability and are fire prone for much of the year (Burrows & McCaw 1990). Prescribed burning is widely employed to reduce intensity of wildfires (Fernandes & Botelho 2003) to reduce the risk to human life and to infrastructure

as well as to protect biodiversity assets (Parsons & Gosper 2011). Prescribed fire is also an important tool for restoring appropriate fire regimes for target species and communities (Valentine *et al.* 2012; Gosper *et al.* 2013).

While prescribed fire can be a useful tool for protecting and restoring biodiversity assets, it can also lead to adverse impacts on native plant communities including recruitment of invasive species particularly in fragmented landscapes (Milberg & Lamont 1995; Fisher *et al.* 2009; Keeley & Brennan 2012). At the same time, prescribed fire can provide an opportunity for control of invasive species by killing adults, by providing physical access to sites for manual or herbicide control and by depleting the soil seed bank (Brown & Brooks 2003; Melland & Preston 2008).

In southern Australia, intense grazing postfire by marsupial herbivores can lead to adverse impacts on biodiversity through limiting native species recruitment and vegetation recovery, particularly

across smaller scale burns in fragmented landscapes and on offshore Islands (McArthur 1996; Meers & Adams 2003; Rippey & Hobbs 2003). While there is evidence that native herbivores can limit establishment and spread of invasive species (D'Antonio *et al.* 1993; Maron & Vila 2001), the role they play in limiting establishment and spread of invasive species in the postfire environment is not well understood.

Land managers need a better understanding of management implications of prescribed fire in Banksia woodlands including techniques that can limit establishment of invasive species and promote recovery of native vegetation in the postfire environment. Paganoni Reserve, a remnant of Banksia/Tuart (*Eucalyptus gomphocephala*) woodland on the southern Swan Coastal Plain, had been unburnt for more than 30 years when an autumn prescribed burn was undertaken to part of the reserve by the Department of Parks and Wildlife. We established field experiments immediately prior to the fire in

about-to-be-burnt and unburnt vegetation and 3 years postfire measured change in species richness and cover, quantified the impacts of marsupial herbivore exclusion on vegetation recovery and monitored the effectiveness of postfire weed management. Specifically, we asked the following questions:

- 1 How do native and weed species richness and cover change in Banksia/Tuart woodland following an autumn prescribed burn?
- 2 How do plant life form spectra change in Banksia/Tuart woodland following an autumn prescribed burn?
- 3 Does an autumn prescribed burn in Banksia/Tuart woodland facilitate weed invasion?
- 4 Can established weed management techniques protect Banksia/Tuart woodland from increasing weed dominance in the postfire environment?
- 5 What are the impacts of excluding grazing by Western Grey Kangaroo on native vegetation cover and on establishment of invasive species postfire?

Methods

The study was conducted on the Swan Coastal Plain, 100 km south of Perth, Western Australia, in a 700-ha remnant of Banksia/eucalypt woodland in very good condition. The overstorey species in the woodlands at our study site were predominantly Firewood Banksia (*Banksia menziesii*) with scattered Tuart. The understorey was dominated by shrubs including Yellow Buttercups (*Hibbertia hypericoides*) and Hairy Yellow Pea (*Gompholobium tomentosum*) with a rich herbaceous flora. Plant nomenclature follows Western Australian Herbarium (1998). In 2008, following a major freeway extension on the western boundary, the reserve was fenced in on three sides. For the resident population of Western Grey Kangaroo, connectivity to the surrounding landscape was significantly reduced. While not quantified, this appears to have resulted in increased population densities within the reserve since that time.

Experimental design

Five paired replicate sites were established in the Banksia/Tuart woodland across the designated burn boundary in unburnt and about-to-be-burnt vegetation. These were established prior to the prescribed burn to ensure homogeneity across sites. Within each paired replicate (burnt and unburnt) site, there were three different 5 m x 5 m treatment plots established; herbivore exclusion (fenced), weed management, and control (no treatment). The prescribed burn took place in late May 2011 (Fig. 1).

Following the prescribed burn 1.2 m high chicken wire fencing was erected around the herbivore exclusion sites. In the weed management plots control measures were restricted to the transformative species that we have the technology and the resources to selectively control. Annual grasses including Annual Veldt Grass (*Ehrharta longiflora*), Great Brome (*Bromus diandrus*), Blowfly Grass (*Briza maxima*) and Wildoats (*Avena fatua*) were controlled with the grass-selective herbicide Fusilade Forte® (128 g/L Fluazifop-P), 3 mL/L, in June 2011, 2012 and 2013, while they were still at the 3-leaf stage. Pigface (*Carpobrotus edulis*) was manually removed before flowering each

year. The annual herb, Pretty Betsy (*Centranthus macrosiphon*), was spot-sprayed each year with Brush-off® (600 g/kg Met-sulfuron-methyl) 0.1 g/15 L, before flowering. Dune Onion Weed (*Trachyandra divaricata*) was sprayed with Glean® (750 g/kg Chlorsulfuron) 0.4 g/10 L, in July each year.

Data collection took place in spring (October) 2013, 2 years and 5 months after the prescribed burn. The point intercept method (Elzinga *et al.* 2001) was used to measure cover of all native and introduced species that occurred in each 5 x 5 m plot. An 8-mm-diameter fibreglass rod was dropped perpendicular to a tape every 10 cm along five transects in each plot, a total of 250 points in each plot. Each species (live leaves, stems or inflorescence) intercepted by the rod at each point was recorded and reported as percentage overlapping cover.

Statistical analysis

Changes in vegetation were investigated using both univariate and multivariate analyses. Initially changes in species richness and total overlapping cover of native versus introduced taxa were compared across burn contrasts and treatments (control, weed management and fencing).

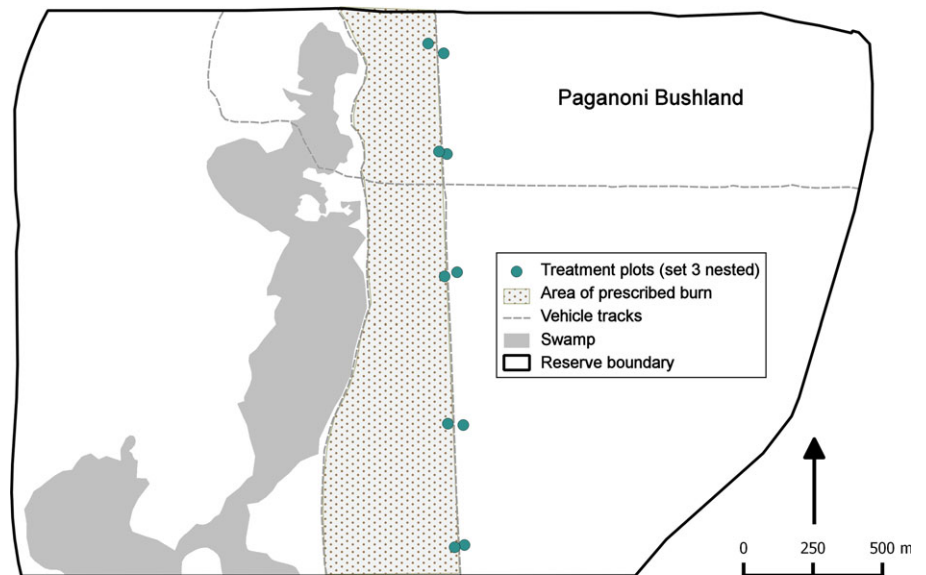


Figure 1. Location of prescribed burn and treatment plots, Paganoni Reserve.

These analyses were repeated using six life form classes. A multivariate analysis was also undertaken to examine changes in species composition and cover based on the site-by-species cover matrix.

The same analysis of variance model was used in for all data sets. For multivariate site-by-species data sets, a common approach is to partition an appropriate dissimilarity matrix (Anderson 2001). Univariate data can also be analysed using this approach using the Euclidian Distance measure, this gives exactly the same result as a conventional analysis of variance (Anderson 2001). For simplicity we adopted this approach.

The plots was analysed using a strip paired design (Table S1). In this design the five blocks treated were treated as random, the two fire contrasts (unburnt and burnt) were treated as fixed and the three treatments (control, fenced and weed management) were also treated as fixed. This design allowed for control of the block effect and to tests difference between factor levels to determine what factors were associated with changes in species richness, cover or composition and if there were any significant interaction between factors.

For multivariate data set, the Bray–Curtis dissimilarity measure was used, while Euclidian distance was used for all univariate analyses. The analyses were undertaken using permutation based non-parametric analysis of variance (PERMANOVA). As these analyses are known to be sensitive to differences in multivariate dispersion between groups, homogeneity was tested (PERMDISP) and data were transformed as required (Table S2). Where homogeneity could not be achieved, no analysis was possible. All analyses were undertaken in PERMANOVA+ (ver 1.0.6) in the Primer package (Anderson *et al.* 2008).

Results

Univariate analysis

Species richness

All data sets had homogenous dispersion between burnt and unburnt plots and

between the three treatments, so no data transformations were required (Table S2). Average species richness of native taxa was significantly richer in the burnt plots (32.3) compared with the unburnt plots (26.2, $P = 0.023$) with no significant differences found between treatments, and there were no significant interactions. No significant differences were found for weed species richness (Table S3).

Average richness by life form showed no significant difference between burnt and unburnt plots. Shrubs showed a significant difference between the three treatments (control 4.8, weed management 5.5, fencing 7.2; $P = 0.05$), but pairwise test failed to show any significant difference. No significant interactions were found (Table S4).

Species cover

Average native species cover was 92.4% in both the burnt and unburnt but with highly heterogeneous dispersion (Table S5). Homogenous dispersion was found across treatments and average native species cover was significantly higher in the fenced plots (132.7%) compared with the control

and weed management plots (74.6 and 70.0%, respectively, $P = 0.001$; Fig. 2, Table S6). Again no significant interaction was found.

Average cover of weeds across burnt plots was 40.8%, significantly higher (pseudo- $F = 24.76$; $P = 0.007$) than in unburnt plots at 23.3% (Fig. 2). Treatment effect was not significant neither was there a significant fire x treatment interaction, and dispersion was homogenous (Table S6). The species that made the highest contribution to the increased cover in the burnt sites were Smooth Cat-sear, Ursinia and Annual Veldt Grass (Table 1). Pigface (*Carpobrotus edulis*), a transformer species (i.e. one that is likely to have significant ecosystem impacts; Richardson *et al.* 2000), was present in 60% of burnt sites and was totally absent from unburnt sites.

Average cover of shrubs, perennial grasses and geophytes all showed fencing treatment to have significantly higher values than the control and weed management treatments (Fig. 3). Annual grasses showed the same pattern, but treatment variance was highly heterogeneous and could not be normalized with

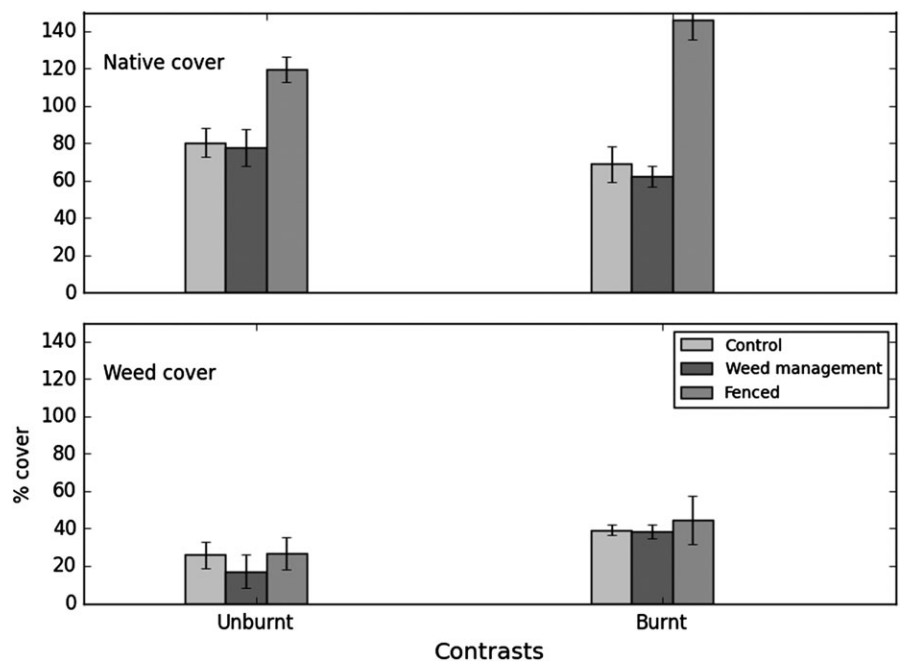


Figure 2. Comparison of average overlapping cover across three treatments (control, weed management and fencing) in the burnt and unburnt sites with standard error bars.

Table 1. The eleven species showing the largest average (> 2%) cover changes between unburnt and burnt plots. Percentage change is difference between unburnt and burnt plots

Weed	Common name	Scientific name	Unburnt Average % Cover	Burnt Average % Cover	% Change
*	Yellow Buttercups	Hibbertia hypericoides	51.3	33.9	-17.5
	Smooth Catsear	Hypochaeris glabra	7.4	18.1	10.7
	Hairy Yellow Pea	Gompholobium tomentosum	1.1	8.4	7.3
*	Blowfly Grass	Briza maxima	9.7	4.8	-4.9
	Rose Banjine	Pimelea rosea	0	4.8	4.8
	Pale Grass-lily	Caesia micrantha	6.6	2.6	-4.0
*	Ursinia	Ursinia anthemoides	1.8	5.6	3.8
	Blue Squill	Chamaescilla corymbosa	6.2	2.8	-3.4
*	Annual Veldt Grass	Ehrharta longiflora	0.6	3.8	3.2
	Native Wisteria	Hardenbergia comptoniana	0.1	3.0	3.0
	Dichopogon	Dichopogon capillipes	2.3	4.6	2.3

*Indicates weed species.

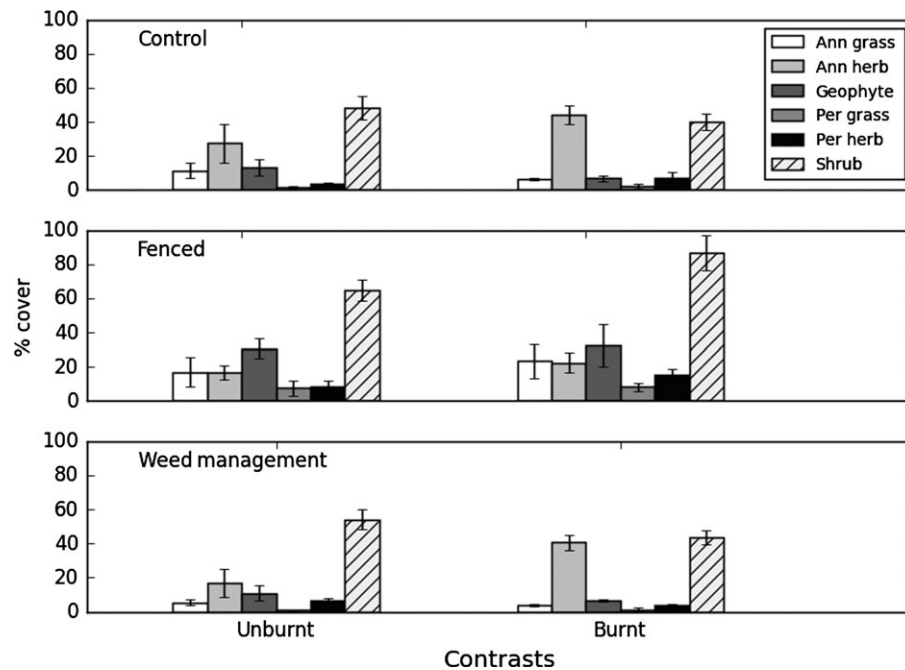


Figure 3. Comparison of average overlapping cover for each life form across three treatments (control, weed management and fencing) in the burnt and unburnt sites with standard error bars.

transformation (Table S5). Perennial herbs also showed the same pattern, but only the weed management and fencing treatments were significantly different. Annual herbs showed the reverse pattern with higher average cover in the control and weed management treatments compared to the fenced treatment; however, only the control and fenced were significantly different (Table S7). No significant interactions were found, and only annual grasses had heterogeneous dispersion.

Multivariate analysis

For the full site × species matrix, analysis of multivariate dispersion showed no significant difference between the burnt and unburnt plots or between the three treatments (Table S8).

The PERMANOVA showed there was a significant fire effect on species composition and cover (pseudo-*F* = 4.58, *P* = 0.021). These differences result from changes in the cover of both native and

introduced taxa (Table 1, Table S9). Among native flora, the largest changes were seen in the shrubs and geophytes. Yellow Buttercups showed a 17% decrease in the burnt plots, while the shrub Rose Banjine (*Pimelea rosea*) only occurred in burnt sites and two other shrubs, Hairy Yellow Pea and Native Wisteria (*Hardenbergia comptoniana*) were much more abundant in the burnt sites. Among the geophytes, Blue Squill (*Chamaescilla corymbosa*) and Pale Grass-lily (*Caesia micrantha*) had lower cover in burnt sites, while Dichopogon (*Dichopogon capillipes*) was higher (Table 1). The annual herbs that largely contributed to the change were weeds; Smooth Catsear (*Hypochaeris glabra*) and Ursinia (*Ursinia anthemoides*) both had higher cover in burnt sites as did Annual Veldt Grass. Blowfly Grass had lower cover in burnt sites.

The PERMANOVA also indicated a highly significant treatment effect (control, fencing, weed management; pseudo-*F* = 3.23, *P* = 0.001; Table S9) with no significant fire × treatment interaction. Pairwise comparisons between the treatments showed significant differences between the fenced and control (*t* = 2.00, *P* = 0.007) and between the fenced and weed management (*t* = 2.02, *P* = 0.003) but no significance difference between the weed management and control treatments.

Discussion

Our study highlighted contrasting patterns in native species richness and cover post-fire. Overall native richness increased, but overall native cover did not change. However, the multivariate analyses revealed changing cover of individual species was a major contributor to significant change postfire. The dominant resprouting shrub, Yellow Buttercups, decreased while a number of re-seeders including Yellow Hairy Pea, Rose Banjine and Native Wisteria increased. The decline of Yellow Buttercups following the burn is most likely temporary. Adult plants were not killed by fire, and over time, resprouting shrubs should return prefire cover. The re-seeding shrubs were either absent or

in very low cover in unburnt sites, and all require fire to regenerate from soil-stored seed. Other studies have found diversity of re-seeder shrubs is highest in these systems 2–5 years after fire (Hobbs & Atkins 1990) and their cover would then be expected to decrease with time since fire.

The same pattern was evident in the geophytes. Although there was no overall change in cover, two common geophytes Blue Squill and Pale Grass-lily decreased while *Dichopogon* increased postfire. While summer fire stimulates flowering and brings underground storage organs out of dormancy resulting in recruitment and higher cover postfire (Lamont & Downes 2011), this later autumn burn may have impacted geophytes that had already commenced active growth (Pate & Dixon 1982). *Dichopogon*, on the other hand, has a biology that is unusual among geophytes in south-west Australia, as it does not start actively growing until early winter (Pate & Dixon 1982) and it showed an expected increase in cover following the burn. Geophytes are an important component of the flora of these woodlands, and further work is required to gain an understanding of the impacts of prescribed fire on their postfire recruitment and survival.

Fencing or weed management had no effect on native species richness, but fencing did significantly increase native cover including shrubs, geophytes and some native grasses. The shrubs most severely impacted by grazing were postfire re-seeders, Hairy Yellow Pea and Native Wisteria, both almost totally absent outside the enclosures. Postfire grazing also reduced cover of geophytes, particularly *Dichopogon*. These findings are consistent with other studies in southern Australia that have found grazing by marsupial herbivores in fragmented landscapes can significantly impact recovery of native plant communities postfire (Meers & Adams 2003; Rippey & Hobbs 2003). Other studies in disturbed remnant Banksia/Tuart woodland, where herbivores were not present, report that weed management postwildfire increases native species richness (Neasham 2004). The woodland at our study site was relatively undisturbed, and the lack of response of the native vegetation to weed management may be

partly attributable to the high diversity of natives in relation to richness and cover of weeds and also to the impacts of grazing on any native recovery with control sites all unfenced.

Patterns in species richness and cover of weeds postfire was the reverse of natives. While fire facilitated an increase in weed cover postfire there was no change in weed species richness. An increase in weed cover following fire has been reported for other studies in Banksia woodland (Hobbs & Atkins 1990; Milberg & Lamont 1995; Fisher *et al.* 2009) and in other Mediterranean ecosystems (D'Antonio 2000; Keeley & Brennan 2012). In our study weedy annual herb cover, largely Smooth Catsear, greatly increased, predominantly outside fenced plots probably related to the reduced competition from shrubs (Keeley *et al.* 2005; Keeley & Brennan 2012). Introduced annual herb cover tends to decrease in Banksia woodland in the first 5 years following fire as native shrub and tree cover increases (Hobbs & Atkins 1990; Milberg & Lamont 1995; Crosti *et al.* 2007).

The prescribed burn also facilitated establishment of Pigface. D'Antonio *et al.* (1993) found fire could facilitate invasion of Pigface into Californian maritime chaparral but that very hot fire could destroy the soil seed bank. They found postfire conditions enhanced establishment of seedlings germinating from seed brought into burnt areas by herbivores. The autumn prescribed burn at Paganoni was a cool patchy burn and not hot enough to destroy soil-stored seed. By the third year postfire, this species was flowering and setting seed across the 70-hectare prescribed burn area and a manual control programme had to be implemented at considerable cost. Pigface is a transformer species in that it has serious adverse impacts on ecosystem function and biodiversity of Mediterranean shrublands and woodlands across Europe and North America (Molinari *et al.* 2007) and allocation of resources to manage this species postfire should be a high priority for managers of Banksia/Tuart woodlands in south-west Australia.

Contrasting patterns occurred in weedy annual grass recruitment postfire.

Although overall annual grass cover did not increase postfire, an increase in Annual Veldt Grass and a decrease in Blowfly Grass were major contributors to the significant change in species composition and cover postfire. Many studies have found that fire can promote recruitment of introduced annual grasses (D'Antonio 2000; Fisher *et al.* 2009; Keeley & Brennan 2012). But there is some evidence that autumn fire can reduce their soil-stored seed banks (Cox & Allen 2008; Prober *et al.* 2009; Gosper *et al.* 2011). Autumn prescribed fire may have suppressed recruitment of Blowfly Grass at our study site by reducing propagule availability through destroying germinating seedlings or destroying the soil seed bank.

Weed management did not significantly change overall weed cover, but our targeted weed control programme did result in lower cover of weedy annual grasses and of Pigface in treatment sites, a reflection of the effectiveness of grass-selective herbicides and of a targeted manual removal programme. Annual herbs not targeted for control, including Pink Velvet, *Ursinia* and Smooth Catsear, had similar levels of cover in both weed management and control treatments while in the fenced treatments, where shrub cover was high, their cover was significantly lower.

One of the outcomes of fencing was a high cover of weedy annual grasses, and it appears Western Grey Kangaroos are suppressing their cover across the study site. While the negative impacts of Perennial Veldt Grass in Banksia woodland are well documented (Crosti *et al.* 2007; Fisher *et al.* 2009), the longer term impacts of annual grass invasion in Banksia woodland are not well understood. Work in other Mediterranean ecosystems suggests invasive annual grasses can have major impacts on biodiversity. They can successfully compete for light water and nutrients in the postfire environment and suppress seed germination and regeneration of native flora (Keeley & Brennan 2012). They can also reduce native diversity and alter ecosystem processes through creating fine fuel loads that increase fire frequency (D'Antonio 2000). Kangaroos preferentially graze grasses

and grass-like plants (Wann & Bell 1997), and the high cover of weedy annual grasses particularly in burnt fenced sites suggests that maintaining a level of grazing by Western Grey Kangaroos could be an effective tool for managing weeds in these woodlands. Herbivory has also been found to limit establishment of Pigface seedlings postfire in Californian shrublands (D'Antonio *et al.* 1993), and this is consistent with the higher rate of establishment of Pigface in our fenced plots.

Response to disturbance such as fire in fragmented landscapes can sometimes differ markedly in accordance with management history (Prober *et al.* 2013). Site-specific information is therefore integral to development of an adaptive management framework (Williams 2011) and to guiding effective management of significant remnant woodlands such as Paganoni Reserve particularly in response to disturbance such as prescribed fire. Importantly though, our results are based on a single fire at a single site and management implications may not necessarily be able to be generalized across all Banksia/Tuart woodland in the region.

Management Implications

- 1 Our study indicates that the most serious changes we are likely to see in species cover in the Banksia/Tuart woodland at Paganoni Reserve after an autumn prescribed burn is an increase in the cover of weeds particularly some introduced annual grasses and herbs and the recruitment of transformer weeds likely to have major impacts biodiversity and ecosystem function such as Pigface.
- 2 While established techniques including an annual control programme using selective herbicides can effectively reduce cover of grass weeds postfire, introduced annual herbs not targeted for control were found to remain very abundant in burnt sites for at least 3 years after a prescribed fire, particularly when grazing reduces competition from shrubs.
- 3 Grazing by Western Grey Kangaroo can have a major adverse impact on vegetation structure postfire particularly on

the establishment of a shrub layer. While fencing out herbivores postfire could be a useful tool for restoring native vegetation, in our study it also reduced grazing pressure on serious weeds including Pigface and some annual grasses.

- 4 Keeping herbivores in the system and manipulating them in time and space could be an important and cost-effective way of maintaining biodiversity values following fire in this previously long unburnt Banksia/Tuart woodland. Further research into combining fencing and weed control appears warranted as it may prove more effective in supporting native recovery than either treatment alone. Temporary fencing postfire, combined with controlling serious weeds inside the fences, could allow shrubs to establish before introducing grazing to maintain low weed abundance.
- 5 Maintaining an appropriate Western Grey Kangaroo population size and grazing regime in the longer term in these isolated remnants will need careful management.

Acknowledgements

We thank the Friends of Paganoni Reserve and The Wildflower Society of Western Australia for outstanding field assistance, Matt Williams for statistical advice and Suzanne Prober for advice on experimental design. Department of Parks and Wildlife (DPAW) Swan Coastal District fire crews organized and conducted the prescribed burn. Comments from two anonymous referees greatly improved the final manuscript.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. PERMANOVA table of the analysis of richness of native species using paired strip design.

Table S2. Tests for homogeneity of dispersion using PERMDISP for species richness data, NS indicates not significant.

Table S3. Mean species richness of both native and weed species by main effects of PERMANOVA model.

Table S4. Mean species richness of the six main lifeforms by main effects of PERMANOVA model.

Table S5. Tests for homogeneity of dispersion using PERMDISP for species cover data, NS indicates not significant.

Table S6. Mean cover of both native and weed species by main effects of PERMANOVA model.

Table S7. Mean cover of the six main lifeforms by main effects of PERMANOVA model.

Table S8. Tests for homogeneity of dispersion using PERMDISP for species composition and cover data (site x species matrix using untransformed cover data), NS indicates not significant.

Table S9. PERMANOVA table of the analysis of composition and cover (of sites x species matrix using untransformed cover data) using paired strip design.