Ten year post-fire response of a native ecosystem in the presence of high or low densities of the invasive weed, *Asparagus asparagoides*

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Summary
Bridal creeper, *Asparagus asparagoides* (L.) Druce, is a major environmental weed in southern Australia. Being a geophyte, it has annual shoot growth with a large tuberous root mat belowground. It is capable of displacing native vegetation and has been targeted for control in Australia, especially using biological control. Previous studies on the impact of this environmental weed have suggested that without further restoration, invaded areas could take many years to recover. As fire can be used as a restoration tool, given it can stimulate the regeneration of some native Australian plants, this study aimed to determine the response of a native plant community for the first ten years following a fire, with and without the presence of bridal creeper.

Following a wildfire in March 1996, plots were established in a mallee remnant in South Australia. In October 1996, bridal creeper was controlled in half the plots using glyphosate. In 2006, there was still a significant difference in the density of bridal creeper, with 33.4 ± 5.0 (mean ± SE) emerging shoots m^{-2} in the untreated plots compared to 9.1 ± 1.2 shoots m^{-2} in the controlled plots. However at the same time, there was no significant difference in the native plant assemblages or with the number of native plant species between plots with high or low density of bridal creeper, except for small shrubs, creepers and climbers which had higher cover in the untreated plots. A difference in soil nutrients was also evident. The soil where bridal creeper was not controlled had significantly higher ammonium, potassium and organic carbon, compared to where bridal creeper was controlled. This study site, in the early stages of post-fire succession, appears to be resilient to the impacts of bridal creeper and other weed species, with acacias and other native trees and shrubs dominating the site. It is therefore concluded that fire can be an important restoration tool to stimulate the regeneration of some native Australian plants and speed up the recovery of bridal creeper-invaded ecosystems, provided that bridal creeper and other weeds are kept at a low post-fire density, naturally or through targeted control.

Key words: bridal creeper, environmental weeds, soil nutrients, succession, weed impacts.

Introduction
In Australia, bridal creeper is a Weed of National Significance (WoNS) (Thorp and Lynch 2000). A garden escapee, this geophyte is able to invade undisturbed native ecosystems (Hobbs 1991, Raymond 1995) and impacts or threatens many native plant species (see Fox 1984, Sorensen and Jusaitis 1995, Willis *et al.* 2003, Willis *et al.* 2004, Downey 2006). For example, bridal creeper is the primary threat to the largest remaining population of the endangered shrub, *Pimelea spicata* R.Br. in the south-west of Sydney (Willis *et al.* 2003). Community impacts are also evident, with plant assemblages in areas invaded by bridal creeper in south west Australia containing 52% fewer native plant species compared to nearby native reference areas, which contained little or no bridal creeper (Turner *et al.* in press). In an eight year removal experiment, Turner and Virtue (2006) established that bridal creeper could reduce biomass and abundance of native plants. However within this eight year timeframe, there was no significant change detected in native plant species richness following bridal creeper control and only one saltbush, *Enchylaena tomentosa* R.Br., and native grasses showed significant increases in cover.

Luken (1997) recommended that management activities aimed at removing exotic plant species should involve the manipulation of both exotic and native species. Turner and Virtue (2006) suggested that the minimal recovery of native species in their study could relate to a lack of suitable environmental conditions for germination and establishment of native species. Turner *et al.* (in press) also suggested that recovery of invaded sites may not occur after bridal creeper control. They established that the readily germinable seed bank below bridal creeper in south west Australia contained very few native species compared to exotic species. Further studies were recommended to investigate the role of fire as a restoration tool following bridal creeper control; given that fire has an important role in the regeneration of some Australian native communities (Shea *et al.* 1979, Bell *et al.* 1993, Fisher 1999). For example, seeds of a large number of native leguminous shrubs, such as acacias, require heat before germination occurs (Shea *et al.* 1979, Bell *et al.* 1993, McCaw 1998) and these species would not have been recorded in the readily germinable seed bank measured by Turner *et al.* (in press). The use of fire as a restoration tool could help increase the germination rate of native species and may help tip the balance back towards native species, by increasing the ratio of native to exotic germinations (Turner *et al.* in press).

Turner and Virtue (2006) also observed that dead bridal creeper tubers remained in the experimental plots eight years after the weed had been killed with herbicide, and this may have also impacted on native species recovery. Turner *et al.* (2006) established that this belowground biomass, with its slow decomposition, may pose a problem for many years after control. As a way to deplete this root system, Willis *et al.* (2003) recommended that fire could be used to destroy the new season's foliage in autumn, followed by treating the re-growth with herbicide. However, Carr (1996) suggested that fire was not an appropriate management tool for bridal creeper as it stimulated bridal creeper growth and invasion. Fire has also been reported to promote the spread and density of a number of other exotic plant species (Adams and Simmons 1991, Milberg and Lamont 1995, Briese 1996, Duggin and Gentle 1998). In addition, when smoke water was used to promote the germination of the seed bank collected from bridal creeper sites in the study by Turner *et al.* (in press), it assisted in the germination of both native and exotic species. Therefore, the use of fire in bridal creeper management needed to be investigated given that it could promote further weed invasions.

The biology of bridal creeper has recently been described (see Morin *et al.* 2006a). In its native range in southern Africa, it mainly occurs as an understorey species and is usually found scrambling or climbing up other plants (Kleinjan and Edwards 1999). Within Australia, bridal creeper has the potential to dominate native vegetation both above and belowground, with climbing annual shoots and extensive belowground storage tubers (Raymond 1996). However, simply reducing the presence of bridal creeper may not guarantee successful restoration of invaded areas and additional restoration efforts may be needed to ensure the protection of native vegetation (Turner *et al.* in press).

This paper reports on a complementary study to that of Turner and Virtue (2006) which determined the impact by bridal creeper, by measuring the response of vegetation following the removal of bridal creeper. Similarly, the aim of this study was to measure the impact by bridal creeper on plant species and to measure their response to bridal creeper removal. However unlike Turner and Virtue (2006), this study was conducted following a wildfire. Therefore, the study reported here aimed to investigate the successionary pathway that occurred over the first ten years post-fire within a mallee community, with or without the presence of bridal creeper. As nutrient availability in the soil increases following fire (Hobbs and Huenneke 1992, Handreck 1997), this study also measured the impact of bridal creeper and of the fire on the soil nutrient status.

Materials and methods

Study area

The study was undertaken in Meningie Hill Reserve, a mallee remnant community, south-east of Adelaide near the township of Meningie, South Australia 35°41′S, 139°21′E. The study site has calcareous, sandy soil with a south-westerly aspect. Native vegetation within the reserve is dominated by an overstorey of *Eucalyptus diversifolia* Bonpl. and *E. incrassata* Labill., with large shrubs being mainly *Acacia* spp. and *Melaleuca lanceolata* Otto. In March 1996, a wildfire occurred in part of the reserve, burning most of the aboveground vegetation (including bridal creeper) except for woody trunks of the mallee eucalypts.

Methods followed here were similar to Turner and Virtue (2006), who undertook an eight year bridal creeper removal study near Owen, north of Adelaide. In August 1996 at Meningie Hill, 30 (3 m × 3 m) plots were chosen where the fire had burnt five months previously and where there was also an even coverage of bridal creeper. Bridal creeper had re-sprouted from the belowground root system following the fire. Bridal creeper was then controlled in half the plots in October 1996, using 33% Roundup® (360 g L^{-1} glyphosate) with 2% Pulse Penetrant® (1020 g L^{-1} polyether modified polysiloxane), applied by hand with a sponge to minimize off-target contact with native plants. These 15 plots were labelled as 'removal plots' and the untreated 15 plots were labelled as 'bridal creeper plots'. Between August 1996 and May 2006, vegetation was periodically sampled within the plots. In August 1996, the number of shoots of bridal creeper was recorded. This was repeated in November 1998 and May 2006. From April 1997, as native plants began to recover (re-sprouting and germinating) after the fire, the presence of all other plant species within the plots was recorded as well as the percentage aerial shoot cover of each species. This was repeated in May 2002 and May 2006. At the end of the experiment in May 2006, the biological control agent, the bridal creeper rust (*Puccinia myrsiphylli* (Thuem.) Wint.) was observed to be at an early stage of establishment at the study site.

Soil measurements were also taken in May 2006. From the centre of each of the 30 plots, soil cores were taken from below the bridal creeper tuber mats. Soil cores 5 cm deep and 5 cm in diameter were taken 5 cm below the litter layer. Cores from three proximal plots of the same treatment were bulked and any large organic matter was removed, such as tubers and other roots. Five samples per treatment were then forwarded in airtight containers to CSBP Laboratories (WA) for chemical analysis. Nitrogen (NO_3^- and NH_4^+), extractable phosphorus, potassium, organic carbon and pH were measured.

Also in May 2006, the soil sampling was repeated in a third treatment, an unburnt area adjacent to the burnt plots that had a similar pre-fire coverage of bridal creeper. Five additional soil samples were taken from this unburnt area. Ten 1 m × 1 m quadrats were selected in the unburnt section of the reserve, based on an even and dense cover of bridal creeper. The number of shoots of bridal creeper was recorded and two soil cores were taken from each quadrat and bulked. Soil samples from two quadrats were further bulked and a total of five samples from this unburnt area were also forwarded to CSBP Laboratories for analysis. Except for the number of shoots of bridal creeper, no other vegetation was measured within this unburnt area.

Statistical analysis was carried out using GenStat (2003). Transformations were applied when appropriate, via a $\log_{10}$ transformation, to meet the assumption of homogeneity of variances. If significant differences were found in the above soil analyses, it was followed by a pair wise Tukey comparison test (GenStat 2003). Multivariate analysis was also used to compare the plant assemblages sampled in May 2006, to compare differences between removal (herbicide treated in the burnt area) plots and bridal creeper plots (untreated in the burnt area) (Primer 6, Clarke and Warwick 2001). A Bray-Curtis similarity index on square-root transformed percentage cover of all plant species (excluding bridal creeper) was calculated to construct a rank-similarity matrix (see Clarke 1993, Clarke and Warwick 2001). ANOSIM (Analysis of Similarity) was used to determine differences in community composition between the removal and bridal creeper plots within the burnt area.

Results

Before treatments were applied, the number of bridal creeper shoots was not different between bridal creeper plots and removal plots in the burnt area ($F = 0.75$; d.f. 1,28; $P = 0.395$). In August 1996, the bridal creeper (untreated) plots had 29.7 ± 3.9 shoots m^{-2} (mean ± SE), while the removal plots had 25.5 ± 3.0 shoots m^{-2} prior to being treated with herbicide (Figure 1). Following the treatment and ten years later in 2006, there was a significant difference in the density of bridal creeper ($F = 26.28$; d.f. 1,28; $P < 0.001$), with 33.4 ± 5.0 emerging shoots m^{-2} in the bridal creeper (untreated) plots compared to 9.1 ± 1.2 shoots m^{-2} in the removal (herbicide treated) plots. The maximum number of bridal creeper shoots in a bridal creeper plot was 77.9 ± 12.4 shoots m^{-2}.

Six months after the herbicide treatment was applied, in April 1997, the mean cover of native plant species was similar between bridal creeper plots and removal plots (Figure 2). In May 2006, there was no significant difference in the number of native plant species between treatments (Table 1). There were also no significant differences in cover of individual groups of native or exotic plant species, except for native small shrubs and native climbers and creepers, where their cover was higher in the bridal creeper (untreated) plots (Table 1 and Figure 2). In contrast, the year immediately following the application of glyphosate (1997) there was no significant difference in the cover of these native small shrubs ($F = 0.17$; d.f. 1,28; $P = 0.684$, Figure 2) and the cover of these native climbers and creepers (log10 transformed; $F = 0.45$; d.f. 1,28; $P = 0.509$, Figure 2) between bridal creeper plots and the removal plots. In 1997, native small shrubs averaged 1.02% ± 0.30 in the bridal creeper plots and 0.84% ± 0.30 in the treated removal plots, while native climbers and creepers averaged 2.47% ± 1.36 in the bridal creeper plots and 1.34% ± 0.41 in the removal plots.

In May 2006, there was no significant difference in the native plant assemblages between treatments (ANOSIM $R = 0.017$; $P = 0.274$, Figure 3). Acacias and large shrubs and trees dominated both treatments in 2006. Combined cover of these large woody native plants within the bridal creeper plots averaged 46.5%, while in the removal plots this averaged 55.0%; yet there was no significant difference between treatments (Table 1).

Even though no differences were detected in the native plant assemblages (Figure 3), the soil in the burnt area beneath the untreated plots (bridal creeper

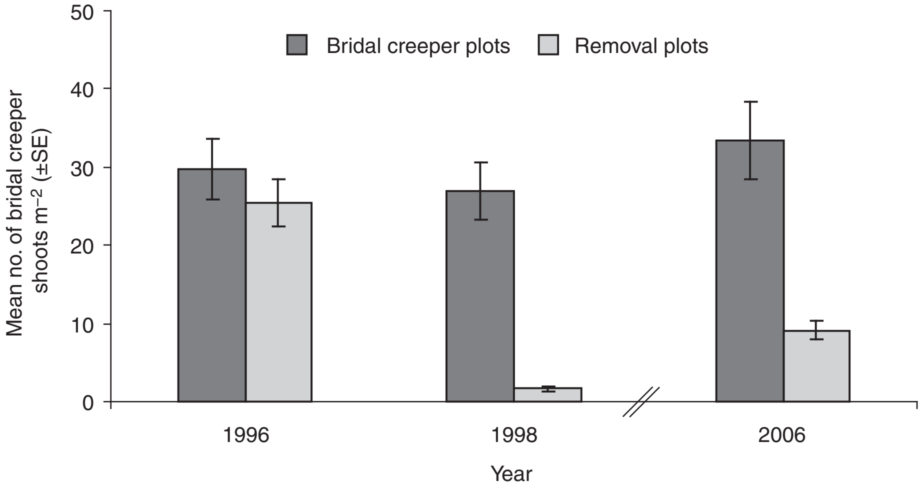

Figure 1. The abundance of bridal creeper across the period of the study. The bridal creeper plots (not treated with herbicide) and the removal plots (herbicide treated) were all located within the burnt area of the study site. The removal plots were treated with glyphosate two months following the 1996 measurements. Bridal creeper abundance was not recorded in the years not shown. In 2006, there was a significant difference in the density of bridal creeper between bridal creeper plots and removal plots ($F = 26.28$; d.f. 1,28; $P < 0.001$).

Table 1. Differences in number of native species per plot (mean ± SE) and plant cover (%) between treatments in May 2006[A].

Variable	Bridal creeper (untreated) plots	Removal (herbicide treated) plots	F	P
No. of native species	11.20 ± 0.62	10.33 ± 0.41	1.36	0.253
Cover of:				
Native small shrubs[C]	3.73 ± 1.08	1.68 ± 0.61	5.46	0.027[B]
Native creepers and climbers	3.16 ± 0.47	1.82 ± 0.28	7.16	0.012[B]
Native monocots	3.65 ± 1.70	2.95 ± 1.50	0.19	0.668
Native acacias	19.75 ± 4.59	19.89 ± 5.79	0.67	0.419
Other native trees and large shrubs	26.70 ± 2.97	35.14 ± 4.03	2.84	0.103
Exotic grasses and bulbs[D]	3.45 ± 1.20	1.45 ± 0.27	3.06	0.091

[A] All plots were within the burnt area. The analysis of variance models with treatment ($n = 15$) as the only factor. A $\log_{10}$ transformation was applied to all variables, except no. of native species and native trees and large shrubs before the analysis.
[B] Statistically significant ($P < 0.05$).
[C] See Figure 2 for description of native groups.
[D] Exotic grasses and bulbs were dominated by veldt grass (*Ehrharta calycina* Sm.) and *Freesia* sp.

plots) had significantly more ammonium, potassium and organic carbon compared to the burnt, removal (herbicide treated) plots, ten years after the fire (Table 2). The additional plots sampled in the unburnt area, which contained bridal creeper, had a significantly higher pH but lower organic carbon and ammonium in comparison to the burnt bridal creeper plots. The areas where the soil was sampled had different abundances of bridal creeper, with the burnt bridal creeper and unburnt plots having approximately eight and twenty times the number of shoots found in the burnt removal plots respectively (Table 2). In the burnt area, the bridal creeper centre sub-plot (1 m × 1 m) had 38.2 ± 7.2 shoots m^{-2} (mean ± SE); the removal centre sub-plot had 4.8 ± 1.0 shoots m^{-2}; while in the unburnt area, the ten additional quadrats averaged 94.0 ± 9.4 shoots m^{-2}.

Discussion

Originally the aim of this experiment was to investigate the successionary pathway that occurred ten years post-fire in a mallee community, with or without the presence of bridal creeper. However, bridal creeper had begun to recover in the removal (herbicide treated) plots, to a density of 9.1 ± 1.2 shoots m^{-2} in 2006. This was still significantly lower than in the untreated plots, therefore this study measured the response of the plant community following a fire in the presence of high and low densities of bridal creeper. However, neither density of this invasive weed influenced the post-fire response of vegetation within this mallee ecosystem, with acacias and other native trees and shrubs dominating the burnt area of site 10 years post-fire.

An invader may have a large effect in one habitat, but a negligible effect in another habitat (Byers *et al.* 2002). In portions of the adjacent unburnt area, bridal creeper density was relatively high, similar to that observed at the Owen site in the study by Turner and Virtue (2006), which had an average of 87.8 ± 8.8 shoots m^{-2} in 2004 (mean ± SE, Turner and Virtue unpublished). However, whilst not directly measured, individual shoots were shorter throughout the whole Meningie site compared to Owen, with the former site appearing to have less bridal creeper aboveground biomass and rarely having tall 'curtains' of bridal creeper shoots. The whole study site at Meningie may be less suitable for bridal creeper compared to the Owen site.

Hester and Hobbs (1992) established a strong correlation between soil phosphorus and abundance of exotic species. The Owen site had available soil phosphorus in the range of 10.8–13.8 mg Kg^{-1} (Turner and Virtue 2006), compared to 3.6–6.0 mg Kg^{-1} at the Meningie site (Table 2). Lower soil phosphorus, combined with reduced aboveground biomass, may partly explain the lack of competitive effects of bridal creeper observed in this post-fire experiment. However, in some parts of the unburnt area at this Meningie study site, there were low levels of phosphorus (Table 2) and bridal creeper abundance was relatively high, averaging 94.0 ± 9.4 shoots m^{-2}. Therefore, at this Meningie study site, bridal creeper was still able to achieve a high abundance in some of the unburnt area that had relatively low soil nutrients. Therefore, it is likely that the native vegetation, being the primary post-fire successional species such as acacias, were able to at least partially suppress bridal creeper in the areas that were burnt.

It appears, from the several studies that have investigated the response of plant communities to bridal creeper control, that impacts and the recovery of native vegetation, as well as the response of secondary invaders, are site specific and depend on the history of the site and its current successionary state. At the Owen site in South Australia, Turner and Virtue (2006) reported an increase in biomass of chenopods but overall there was no difference in the number of species following bridal creeper control. There was also an increase in the exotic *Oxalis pes-caprae* L. eight years after this control. Similar to this Meningie study, four sites in a southern Western Australia study showed no overall significant increase in exotic cover following bridal creeper control (Turner *et al.* 2008). In the Western Australia study, in bridal creeper invaded plots, cover of other exotic species (excluding bridal creeper cover) increased from 4.2% in 2004 to 12.8% in 2006 following the biological control of bridal creeper; however this was comparable to the exotic cover in the nearby uninvaded reference plots at the same time in 2006 (Turner *et al.* 2008). Yet, at one of the Western Australia sites, Quell Creek, Turner *et al.* (2008) reported an increase in exotic cover from 0.03% to 23.4% following the biological control of bridal creeper.

In the burnt area of this Meningie study, native small shrubs, creepers and climbers had higher cover in the bridal creeper plots compared to the removal (herbicide treated) plots (Table 1). These species could be responding to the higher nutrients found below bridal creeper. In Western Australia, at the same study site mentioned above, Quell Creek, Turner *et al.* (2008) also reported that native climbers had increased from 0.07% to 5.0% and that this cover of native climbers was higher than the nearby native reference plots at the same time in 2006, being only 0.8% (Turner *et al.* 2008). In this Western Australia study at Quell Creek, the bridal creeper invaded plots had higher soil nutrients than the nearby native reference plots (Turner *et al.* submitted) and, following biological control, native climbers had six times greater cover in the higher nutrient soil (Turner *et al.* 2008). This is also supported by a glasshouse trial that established that a native climber, *Billardiera heterophylla* (Labill.) L.W.Cayzer & Crisp) (bluebell creeper), had increased growth rates with increases in soil fertility (Turner *et al.* submitted).

An alternative hypothesis for the higher cover of native small shrubs, creepers and climbers in the bridal creeper plots compared to the removal (herbicide treated) plots at this Meningie site is that they may have been accidentally killed by the herbicide application in the removal plots during the initial bridal creeper removal in 1996. Whilst due care was taken to only target bridal creeper, there may have been inadvertent contact with some regenerating native species. However, it is assumed that the off-target impacts were minimal given that there was no significant difference in the cover of native small shrubs, creepers and climbers in 1997, a year following the application of glyphosate. Even so, the differences in cover of these native species in 2006 may not be ecologically significant (although statistically significant between treatments), given the differences recorded relate to a difference in cover of only one to two percent between treatments and between 1997 and 2006 (Figure 2).

Nutrient availability in the soil is usually only increased for a short time following fire (Hobbs and Huenneke 1992, Handreck

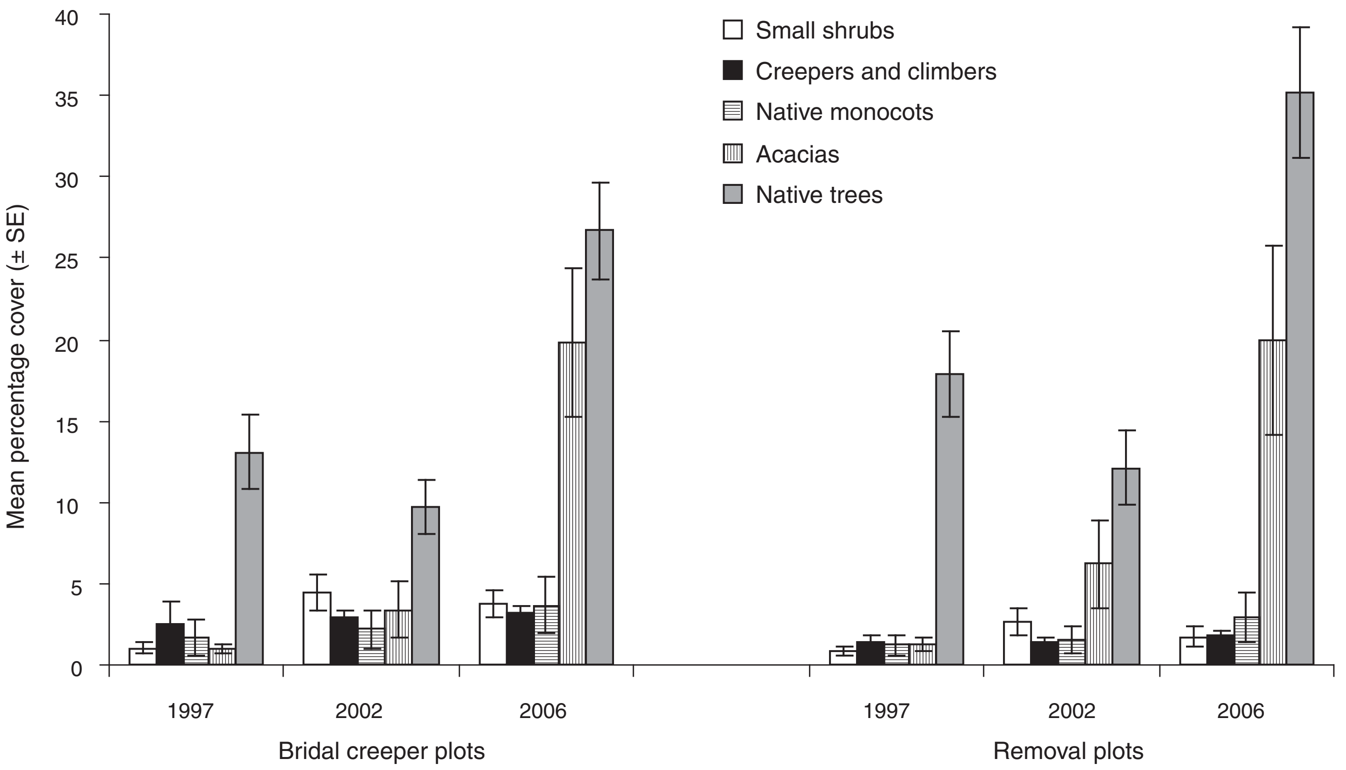

Figure 2. Percentage cover of native species in 1997, just after the herbicide treatment was applied, and in 2002 and 2006. Both bridal creeper and removal plots were burnt. Bridal creeper plots were not treated with herbicide. Native trees are a combination of *Eucalyptus diversifolia* Bonpl., *E. incrassata* Labill. and *Melaleuca lanceolata* Otto. Acacias are a combination of *Acacia paradoxa* DC. (primarily), *A. pycnantha* Benth. and *A. longifolia* (Andrews) Willd. Native monocots are mainly a combination of *Dianella revoluta* R.Br., *Xanthorrhoea caespitosa* D.J.Bedford and orchids. Creepers and climbers were dominated by *Billardiera cymosa* F.Muell. and *Carpobrotus modestus* S.T.Blake. Small shrubs were dominated by *Thomasia petalocalyx* F.Muell., with fewer *Rhagodia* sp., *Dampiera* sp. and *Hibbertia* sp.

1997). Bridal creeper may be able to permanently capture and retain the nutrients released during the fire by trapping nutrients and organic material with its dense tuberous root mat (Turner *et al.* 2006) and recycling them through its annual senescence. This may explain the differences in nutrient levels between the burnt bridal creeper plots and the burnt removal plots in this study (Table 2). Carr (1996) suggested that fire was not an appropriate management tool for bridal creeper as it stimulated bridal creeper growth and invasion. Given this, fire should not be used as a sole control measure for bridal creeper, as bridal creeper will re-shoot and trap the nutrients released during the fire. This could over time transform the community and move it further away from its restoration goals. Therefore, fire is only suitable if used in conjunction with other restoration and control techniques, such as those recommended by Willis *et al.* (2003).

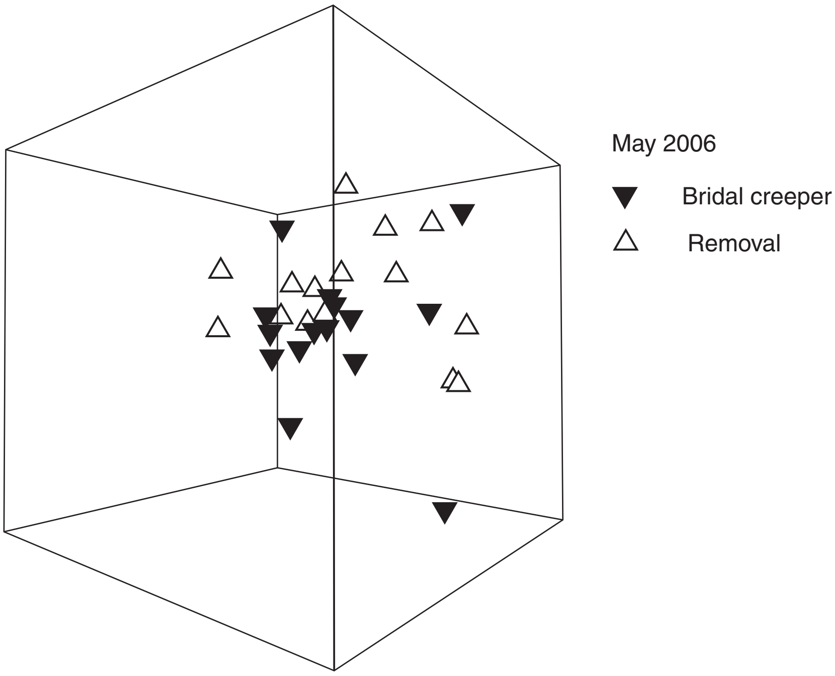

Figure 3. Individual plots shown in a three-dimensional ordination (non-metric multi-dimensional scaling). The relative distance between plots (represented by triangles) represent the degree of dissimilarity of native plant assemblages between burnt plots at the end of the study period in May 2006. Analysis of similarity revealed no significant difference between bridal creeper plots (herbicide untreated) or removal plots (herbicide treated): Sample statistic (Global R): 0.017, P = 0.274.

It seems plausible that the native vegetation was able to suppress bridal creeper and other weeds in the burnt area at Meningie, for the ten years following the single disturbance event, being a wildfire. However, in the absence of future fires, it has been reported that populations of native legume species (including acacias) decline, as adults die at the end of their normal life span of approximately four to 15 years without seedling recruitment (Shea *et al.* 1979, McCaw 1998, Fogarty and Facelli 1999). Therefore this site may become more vulnerable to invasion at a later successional stage. The burnt areas where bridal creeper was not controlled could be more vulnerable to invasion by other weeds or to an increase in the density of bridal creeper, given the differences observed in the soil nutrients (for example see Lake and Leishman 2004 and Turner *et al.* submitted). Following the decline of early post-fire species, such as acacias, areas with the higher nutrient levels may be replaced with those species (native and exotic) that respond more favourably to higher nutrient soils.

Biological control agents have been released in Australia to control bridal creeper (Morin *et al.* 2006b, Turner *et al.* 2008). Briese (1996) suggested that fire and biological control may not be compatible strategies for weed management in native areas, although a personal observation in a Tuart woodland in Yanchep National Park (north of Perth, 31.533°S, 115.683°E) following a high intensity fire in January 2005, indicate they can be compatible for bridal creeper. The biological control agent, the bridal creeper rust exhausts the fleshy tuberous root system of bridal creeper (Morin *et al.* 2002, Turner *et al.* 2004). At Yanchep National Park, it appeared that the fire, following five years of biological control, was able to burn most of the senesced root system. In addition in November 2005, the biological control

Table 2. Differences in mean (± SE) soil variables between treatments in May 2006[A]. In 2006, the abundance of bridal creeper differed between plots and therefore the abundance is also documented below.

Soil variable	Burnt bridal creeper plots	Burnt removal (herbicide treated) plots	Unburnt bridal creeper area	F	P
Nitrate (mg Kg^{-1})	5.60 ± 1.57	5.20 ± 0.20	2.60 ± 0.60	3.70[B]	0.056
Ammonium (mg Kg^{-1})	5.80 ± 1.46[b]	2.40 ± 0.24[a]	2.60 ± 0.24[a]	5.75[B]	0.018
Phosphorus (mg Kg^{-1})	6.00 ± 1.22	3.80 ± 0.20	3.60 ± 0.40	3.02[B]	0.087
Potassium (mg Kg^{-1})	165.6 ± 28.9[b]	83.8 ± 7.0[a]	101.2 ± 5.8[ab]	6.06	0.015
Organic carbon (%)	4.29 ± 0.43[b]	1.87 ± 0.18[a]	1.64 ± 0.32[a]	20.02	<0.001
pH	6.86 ± 0.24[b]	7.62 ± 0.21[ab]	8.10 ± 0.18[a]	8.75	0.005
Bridal creeper (shoots m^{-2})	38.2 ± 7.2[C]	4.8 ± 1.0[C]	94.0 ± 9.4		

The burnt bridal creeper plots and the unburnt bridal creeper area were not treated with herbicide and the burnt removal plots were treated with herbicide. Different letters after SE relate to significant difference at P = 0.05 based on Tukey multiple comparisons tests.
[A] The analysis of variance models with treatment (n = 5) as the only factor.
[B] Log_{10} transformation applied.
[C] This abundance relates to the centre 1 × 1 m of the plot, where the soil cores were taken.

agents were observed to have re-colonized bridal creeper plants that had survived or germinated since the fire. However, more research into this area is needed, given that fire is a natural occurrence in most Australian ecosystems and weeds that have invaded these native ecosystems are increasingly becoming targets for biological control (McFadyen 1998).

Because fire is a disturbance, it may increase the chances of weed invasion (Fox and Fox 1986, Adams and Simmons 1991, Milberg and Lamont 1995). However, no exotic species benefited following the fire or following the control of bridal creeper during this study at Meningie. Exotics other than bridal creeper only averaged a maximum of 3.45% cover (Table 1) and native species dominated suggesting that fire did not decrease the site's resilience. Weed species present at the site but remaining at low density included *Ehrharta calycina* Sm., *Brassica tournefortii* Gouan and *Freesia* sp. Thomson and Leishman (2005) found that fire did not promote invasion into areas that were non-nutrient enriched. This is supported by Hester and Hobbs' (1992) suggestion that fire does not necessarily increase weed invasion and was a useful management tool in remnant vegetation in Western Australia. However, the Meningie study was undertaken at only one site, and therefore further research is recommended, given that the outcomes may vary across sites depending on timing of fire, fire intensity, pre-fire invasion status and soil quality.

Fire can be an effective tool for weed management, especially when used in conjunction with other control techniques (Willis *et al.* 2003). However, in highly disturbed roadside remnants and those areas that have elevated soil nutrient levels, the use of fire may promote exotic species (for example see Milberg and Lamont 1995, Thomson and Leishman 2005). The degree of weed invasion could change depending on fire frequency and intensity as well as season of the burn, for example a spring versus autumn burn (Hobbs and Huenneke 1992). This study indicates that fire can be an important restoration tool to stimulate the regeneration of native Australian plants and speed up the recovery of bridal creeper invaded ecosystems, provided that bridal creeper and other weeds are kept at a low post-fire density, naturally or through targeted control. Further research is now needed to confirm the suitability of fire across a range of bridal creeper sites throughout southern Australia.

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