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Summary

The effective control of highly invasive weeds in Australia is an important conservation management action. In this study we monitored the outcome of herbicide control on high threat weeds in the wet forests of the Central Highlands of Victoria. Twenty-two control (no weed control) and 32 treatment (weed control) plots were surveyed annually over 24 months. Initial results show that weed cover and frequency decreased substantially in response to weed control; however, it is too early to determine the response of native species. We recommend that herbicide control and the associated monitoring program be continued, and depending on the outcomes, data should be used to develop a more integrated management strategy.

Keywords

Biodiversity conservation, disturbance, habitat restoration, pest plants, roadside habitats, weeds and weed control

Introduction

The control of invasive plant species is considered a critical activity for native vegetation restoration, requiring multiple years of treatment until the desired vegetation state is established. Biological control agents, including pathogens are sometimes used to control weeds but can be time consuming and controversial (Seastedt 2015). Therefore, the application of herbicides is usually the most cost-effective method of control, and experimentally testing the timing and success of control can help refine ongoing weed management.

The Central Highlands region of Victoria supports significant biodiversity values, including extensive stands of Wet Forest dominated by Mountain Ash (*Eucalyptus regnans*). A major threat to biodiversity in the region is the proliferation of 'high threat' weeds such as Blackberry (*Rubus fruticosus* spp. agg.), Himalaya Honeysuckle (*Leycesteria formosa*) and Montbretia (*Crocasmia X crocosmiiflora*), which actively outcompete many native plant species. High threat weeds such as these are commonly dispersed by birds or human activity and machinery, and frequently invade track margins and riparian areas but may also infiltrate more widely into the native forest and plantation matrix (Lindenmayer and McCarthy 2001).

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In 2012, the Central Highlands Eden (CHE) Project was initiated by the Victorian Department of Environment and Primary Industries (DEPI) as a long-term, landscape-scale weed monitoring and management program. A monitoring strategy was developed for the project (Duncan, *et al.* 2012) and is now being implemented to determine the effectiveness of weed control works. The main objectives of the monitoring program were to examine the effect of weed control works on: (i) native lower strata vegetation; (ii) 'high threat' weed species; and (iii) non-target native species in the monitoring plots (Duncan, *et al.* 2012). This study reports the results of the first three years of the trial, including baseline data collection and the results of two treatments over a 24 month period.

Methods

The section of the CHE project area surveyed for this study covers 1,600 km² of State Forest, State Park and National Park between Healesville, Marysville, Noojee and Gembrook, c. 60 km east of Melbourne. Most of the forest has been harvested for timber in recent decades and is now regenerating. The project area incorporated five asset areas identified as having significant biodiversity values: Ada River, Basan Corner, Britannia Creek, Limberlost and Maroondah (Duncan, *et al.* 2012). A total of 22 Control (i.e. no weed control) and 32 Treatment (control of high threat weeds) plots were sampled across a mixture of Wet Forest (Ecological Vegetation Class (EVC) 30), Damp Forest (EVC 29) and Cool Temperate Rainforest (EVC 31). No records exist of weed control prior to initiation of the project, although some informal work may have been undertaken at a low level in the past. Each plot was 40 x 5 m, situated parallel with track margins, with the edge closest to the track located 3-15 m from the track margin and avoiding the slashed verge. Locations of plots were selected on the presence of high threat weed infestations.

The 32 treatment plots were sprayed by contractors in summer to early autumn 2013 after the initial round of monitoring and again in summer to early autumn 2014 after the Year 1 monitoring. The spraying regime consisted of herbicide with active constituent triclopyr used at on label rates, e.g. Garlon[®] at 170 ml per 100 L water for all broad leaved species. In addition, glyphosate (360) applied as Roundup Biactive[®] (undiluted) was used to cut and paint woody species in the vicinity of waterways. While Blackberry accounted for approximately 85% of the weed cover, the weed control program focused on weeds defined by DEPI as possessing a high threat potential, in terms of their ability to actively invade and outcompete native species (Appendix 1).

The survey of all 54 plots was undertaken annually over a 24 month period, from January to March (mid-late summer) 2013 in Year 0 (just prior to the first treatment in late summer-early autumn 2013) (Practical Ecology 2013), November to December 2013 (early-mid summer) (Year 1) just prior to second treatment (Practical Ecology 2014) and November to December 2014 (early-mid summer) (Year 2) (this survey). At each 40 x 5 m plot, general landscape and site disturbance characteristics were recorded comprising; aspect, slope and Ecological Vegetation Class. Within the plot a complete vascular flora species list, including cover abundance for each taxon was recorded. Cover abundance was scored using the Domin cover scale: + (single plant, no measurable cover); 1 (few individuals, <1% cover); 2 (many individuals, <1% cover); 3 (1-5%), 4 (5-10%), 5 (10-25%), 6 (25-33%), 7 (33-50%), 8 (50-75%), 9 (75-90%) and 10 (90-100%). Species frequency, based on 10 randomly placed 1

m² quadrats within the plot, was also recorded as was leaf litter, bare ground, total weed and native cover estimates using the Domin scale within these 10 subplots. Plant nomenclature follows the Victorian Biodiversity Atlas (Version 3.0.7) (DELWP 2014).

We examined variation in 16 habitat, vegetation and life form variables, using repeated measures analysis of variance (ANOVA). We tested within treatment effects (i.e. variation between sites within control and treatment plots respectively) and the two-way effect between control and treatment sites, and time period. All analyses were undertaken using STATISTICA version 12 (StatSoft Inc. 2015).

Results

Total native and weed cover changed over time within control and treatment plots (Table 1, Fig. 1). While native cover decreased in controls, it remained high in treatment plots. Conversely, weed cover increased in controls over time to $43.7 \pm 5.3\%$ in Year 2, but decreased substantially in treatments from $33.1 \pm 4.5\%$ in Year 0 to $10.7 \pm 1.7\%$ in Year 2 (Fig. 1).

Cover of high threat weeds mirrored that of total weed cover, indicating that the majority of weed cover comprised high threat weeds (Fig. 1). The difference in high threat weed cover between control and treatment plots prior to weed control was 8.1%, while the variation following spraying in treatments was 33.6%, indicating that weed control significantly reduced high threat weed cover (Fig. 1).

Native cover was separated into life-form categories (trees, tree ferns, shrubs, ground ferns, graminoids, forbs); however, none of these functional groups displayed a significant treatment effect over time (Table 1). Bare ground differed significantly within control and treatment plots and over time (Table 1, Fig. 1). Bare ground increased in treatment plots from $12.1 \pm 1.8\%$ in Year 0 to $23.5 \pm 2.2\%$ in Year 1 following the initial weed control; it then recovered to pre-weed control levels in Year 2. Litter cover in treatment plots increased over time when compared to controls (Table 1, Fig. 1) mainly due to the increased input from dead Blackberry leaves.

The mean frequency of high threat weeds displayed a similar trend to that of weed cover and high threat weed cover (Fig. 1). While the frequency of occurrence in 1 m² control quadrats increased marginally over time from $79 \pm 4\%$ (Year 0) to $83 \pm 9\%$ (Year 2), frequency decreased in response to weed control in treatment plots from $73 \pm 6\%$ (Year 0) to $52 \pm 8\%$ (Year 2). Despite a decrease over two years (reduction in cover by 21%), high threat weeds remained in over half of treatment plots. Mean native species richness displayed significant variation over time *within* control and treatment plots, while native richness also differed *between* control and treatment plots over time (Table 1). It appears as if native richness gradually increased over time in controls and treated plots. While a significant within treatment effect was detected for introduced richness, there was no difference between controls and treatments over time.

Discussion

This study expectedly demonstrated that weed control after two years substantially reduced overall weed cover, high threat weed cover and frequency, and introduced species richness in treatment

plots, against a backdrop of gradually increasing introduced species cover, frequency and richness in control plots. Early indications suggest that native ground layer life-forms are starting to respond positively in treatment plots although it is currently too early for statistical evidence. In a review of ecosystem response following management of Weeds of National Significance in Australia, Reid *et al.* (2009) found that native species did not always naturally recover after weed management, and other weed species often replaced the high threat species. Consequently, if natural recovery is the goal, follow up weed management and monitoring is critical during the first few years of treatment when weed species are most affected and bare ground is relatively high.

There appears to be minimal, if any, further reduction in weed cover in Year 2, which may indicate variability in the spraying regime, i.e. large, easy to observe infestations were treated intensely from Year 0 to 1, while spraying effort may have reduced from Year 1-2, due to the perceived reduction in infestation size. This observation is reinforced by the frequency data, which indicate that despite a 21% decrease in high threat weed frequency over two years, high threat weeds were still present in over half the treatment plots, albeit at a lower cover. This suggests that without weed control, the frequency (and by inference, cover) of high threat weeds will increase over time. Currently, high threat weeds are largely confined to a relatively narrow band in the vicinity of track margins, possibly due to decreasing light availability in the surrounding forest matrix. The risk is that these infestations may begin to encroach further into the forest over time, rather than being restricted to narrow bands along tracks (Lindenmayer and McCarthy 2001). The presence of weed seedbanks and the interactions between the remaining cover and extent of bare soil and weed growth, can also affect the success of herbicide treatments on high threat weeds (Chauhan, *et al.* 2012).

This project reinforces the importance of monitoring the effect of weed control not only on weed species (to determine efficacy of treatments) but also on native species cover, frequency and richness (to determine if natives respond positively to weed management). If natural recovery is to be successful in the wet forests of the Central Highlands, then continued weed control is essential to allow native species to recolonise the space previously occupied by high threat weeds; otherwise, high threat weed cover will quickly rebound to pre-treatment levels. In cases such as these, integrated weed control is often the best option for long term weed management (Chalak and Pannell 2015) and additional methods such as mechanical removal, can assist the success of these programs. However, intensive weed control at landscape scales is expensive and studies such as these can be helpful to determine where and how to prioritise funding so that the most cost-effective approach is implemented. The optimal management strategies will be context specific; however, continued monitoring of the outcome of herbicide treatments is vitally important to develop the best approach, and then adapt the management and monitoring practices where necessary.

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Table 1. The repeated measures ANOVA results for vegetation and habitat variables. F is the test statistic. P level is the significance level, indicated by * (P<0.05), ** (P<0.01), *** (P<0.001). ns indicates not significant.

Variable	Within control effect			Within treatment effect			Year x Treatment effect		
	F	P value	P level	F	P value	P level	F	P value	P level
Native cover	7.7	0.001	**	4.8	0.010	*	3.6	0.019	*
Weed cover	7.7	0.001	**	23.5	0.000	***	15.4	0.000	***
High threat weed cover	5.3	0.009	**	19.0	0.000	***	19.4	0.000	***
Blackberry live adult cover	2.4	0.105	ns	8.7	0.000	***	19.0	0.000	***
Native tree cover	0.8	0.437	ns	13.9	0.000	***	2.3	0.084	ns
Native tree fern cover	3.7	0.032	*	11.4	0.000	***	0.5	0.663	ns
Native shrub cover	0.1	0.886	ns	1.6	0.216	ns	0.5	0.668	ns
Native ground fern cover	1.5	0.229	ns	1.1	0.336	ns	0.5	0.715	ns
Native graminoid cover	0.3	0.753	ns	0.0	0.990	ns	0.8	0.499	ns
Native forb cover	3.3	0.048	*	3.4	0.036	*	1.3	0.272	ns
Introduced forb cover	0.6	0.552	ns	3.0	0.055	ns	0.1	0.958	ns
Litter cover	5.6	0.007	**	0.7	0.509	ns	4.3	0.009	**
Bare ground cover	10.7	0.000	***	19.7	0.000	***	4.3	0.009	**
High threat weed frequency	0.9	0.425	ns	9.6	0.000	***	6.2	0.001	**
Native richness	11.0	0.000	***	17.1	0.000	***	3.3	0.028	*
Introduced richness	3.1	0.053	ns	4.7	0.011	*	1.3	0.288	ns

Figure 1. Mean ($\pm$ SE) cover scores for the three years of sampling: (a) total native cover, (b) introduced species cover, (c) high threat weed cover, (d) bare ground, (e) litter, (f) frequency of high threat weeds in 1 m² quadrats, (g) Mean native species richness over time, (h) Mean introduced species richness over time

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