New insights into the biological and chemical control of English broom (*Cytisus scoparius*) in the Victorian Alps

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Summary Parks Victoria has led a program to control English broom *Cytisus scoparius* (L.) Link in the Alpine National Park for 25 years. Two elements of this program have been the introduction of biological control agents and the establishment of an adaptive experimental management program (AEMP) to assess different herbicide treatments.

Four biocontrol agents (3 insects; 1 mite) were released from 1995–2011 and a rust self-established by 2005. Assessments of agent establishment, abundance, dispersal and impacts have enabled an evaluation of their potential to contribute to the suppression of broom infestations. The broom seed-feeding beetle, broom gall mite and broom rust were all found to be well established and beginning to reduce plant vigour and/or seed production.

The AEMP compared broom control effectiveness, and outcomes for grasses and sedges (graminoids), for three herbicides applied in two seasons. After seven years the mean broom cover was reduced to <5% in the majority of plots. The trajectories for reduction, however, varied. Broom cover returned to initial levels in plots which missed treatment for two successive years. The results indicate that, once cover is reduced to a sufficiently low level, non-treatment for one year may not affect effectiveness, but non-treatment for two successive years will. Graminoid cover varied with herbicide treatment.

Keywords English broom, *Cytisus scoparius*, biocontrol, adaptive experimental management, herbicide, Victorian Alps.

INTRODUCTION

Introduced in the nineteenth century (Hosking *et al*. 1996), English broom (henceforth broom) is now widespread in Victoria's eastern alps, including the Alpine National Park (ANP). It is a Weed of National Significance in Australia due to its invasiveness, potential for spread and severe impacts on Australia's environment and primary industry (Australian Weeds Committee 2012).

Parks Victoria has implemented an integrated management program to control the spread of broom and limit its impacts on the ANP and adjacent land since around 1990 (Allan *et al*. 2004).

Biological control of broom commenced in the eastern alps in 1995 with the release of the twig-mining moth *Leucoptera spartifoliella* (Hübner). This was followed by releases of the broom seed-feeding beetle *Bruchidius villosus* Fabricius in 1998, the broom psyllid *Arytainilla spartiophila* (Förster) in 2000, and the broom gall mite *Aceria genistae* (Nalepa) in 2008 (Australis Biological 2013). The self-established broom rust *Uromyces pisi-sativi* (Pers.) Liro was first detected in the eastern alps in 2005 (Morin *et al*. 2006).

Extensive bushfires in 2003 burnt a large proportion of broom infestations in the eastern alps, including all of the biocontrol sites established to that time (Allan *et al*. 2005). The fires killed most existing broom plants and produced extensive areas of regrowth (Allan *et al.* 2004). In response, Parks Victoria initiated the AEMP in 2004 to compare broom control efficacy and outcomes for grasses and sedges among six herbicide treatments.

Here, we report on highlights from recent evaluations of the AEMP and biocontrol program.

MATERIALS AND METHODS

Biocontrol Records of releases of biocontrol agents within a ~3750 km^2 area between Omeo and Mitta Mitta were collated from agency sources (Australis Biological 2013). Release sites with sufficient location information documented were mapped and assessments undertaken at all accessible sites that still contained broom between February and April, 2013. At each site assessed (n = 57) broom plants were surveyed for agents along a linear transect. Mature plants were visually searched for agent activity and abundance recorded. Broom rust was identified by lesion characteristics. Impacts were scored as negligible, weak, moderate or severe. Beating samples were collected from plants at the completion of visual searches.

Subsequent assessments focused on distribution and impact of the broom seed-feeding beetle in the Mitta Mitta Valley, between Omeo and Lake Dartmouth. Broom plants at each of 13 sites were sampled in early December 2013 by beating, and the number of beetles collected recorded. The frequency of egg-laying and the density of eggs on green pods were measured at each site. Fifty immature pods were haphazardly collected from each of around 30 plants and pooled. Thirty pods were randomly selected from each pool and the numbers of seed-feeding beetle eggs, larval entrance holes and fertile ovules counted. Potential seed destruction was calculated as: number of eggs + entrance holes/number of ovules (as a percentage). Where the number of eggs + entrance holes exceeded the number of ovules a value of 100% was assigned.

The level of seed destruction in mature pods was measured on pods collected at 15 sites in mid-January 2014. At each site, 25 mature pods were haphazardly harvested from each of 30–50 plants and pooled for each site. Twenty-five pods from each pool were randomly selected and split open to reveal all ovules. The total number of ovules was recorded as well as the number of eggs on the pod exterior and the number of seeds containing, or destroyed by, seed-feeding beetle larvae.

AEMP Methods are described in Allan *et al*. (2004, 2006). Three herbicides were applied at label rates in two seasons to plots (~1 ha) at three sites (Table 1). Each plot was treated annually from 2004, except for Spring 2009 and Autumn 2010. Four plots missed a second treatment: all t+p aut spr plots in Spring 2010 and t+p aut plot at site 2 in Autumn 2011 (See Table 1 for codes). Hence, these plots missed treatment for two consecutive years. Baseline monitoring occurred in 2004, prior to treatments. Live broom was then monitored annually in spring from 2005 to 2008 and 2011, while graminoids were monitored in spring 2006, 2008 and 2011.

AEMP data were analysed on a site-by-site basis due to significant inter-site variability. Comparison of initial broom cover between autumn-established and spring-established plots for each site was carried out using two-sample t-tests. Analysis of covariance, adjusting for baseline graminoid cover, was employed to compare graminoid cover among treatments at each site at years four and seven.

RESULTS

Biocontrol Ninety-four biocontrol sites were identified from release records, 69 of which were located in the field and 57 still contained broom. The occurrence and abundance of biocontrol agents at these sites is summarised in Table 2.

Table 1. Experimental design showing treatments applied at each of three AEMP sites.

Herbicide	Timing in first year (2004)	Timing in subsequent years	Treatment code
Glyphosate 360 g L^{-1}	autumn	autumn	gly aut
	spring	spring	gly spr
Triclopyr 300 g L^{-1} + picloram 100 g L^{-1}	autumn	autumn	t+p aut
	autumn and spring	spring	t+p aut spr
	spring	spring	t+p spr
Triclopyr 600 g L^{-1}	spring	spring	tri spr
Nil	na	na	control

Table 2. Summary of English broom biocontrol agent establishment at 57 release sites assessed in the Victorian East Alps, February–April, 2013.

Agent	No of sites occupied	Abundance at occupied sites
Broom twig-mining moth	3 (5%)	1–20 cocoons per plant
Broom psyllid	0	nil
Broom seed-feeding beetle	10 (18%)	1–7 beetles per beating tray
Broom gall mite	13 (23%)	1–2000 galls per plant
Broom rust	34 (58%)	Highly variable

In December, when immature broom pods contained developing and immature ovules, broom seed-feeding beetles were abundant at the 13 sites sampled. Oviposition was recorded on 76–100% of pods examined at each site, with 1–48 eggs on each infested pod. Hatched beetle larvae were first instars and were located in pod walls, pod loculi or within developing ovules. The number of fertile ovules in pods averaged 10.9 (range: 3–18) and the mean (±S.E.) calculated level of potential seed destruction was 57.7% (±5.2). Mean actual seed destruction in January in mature pods at 15 sites by seed-feeding beetle larvae averaged 30.6% (±6.4).

AEMP The cover of live broom increased over time in the three untreated controls. In 2004 (year 0) the mean broom cover at sites 1, 2 and 3 was 10%, 26% and 32%, respectively; after seven years, this had increased to 74%, 80% and 93%, respectively (Figure 1). The initial mean cover of broom in plots treated in autumn 2004 was significantly lower than in plots first treated in spring 2004 (Figure 1, P <0.02 for all sites).

After seven years plots which had missed only one treatment had mean broom cover of <5% with the exception of gly aut (17.4%) and gly spr (8.5%) at site 3. For plots in which treatment commenced in spring, the reduction in broom cover was slower in gly spr and tri spr plots than in t+p spr plots (Figure 1). In the four plots which missed two consecutive annual treatments in later years (all t+p aut spr plots and the t+p aut plot at site 2), broom cover increased back to its initial level by year seven (Figure 1).

In the t+p and tri plots, graminoid cover tended to increase over time. After four years, the estimated mean graminoid cover in each of these plots was higher than in controls, although not significantly (P <0.05) for two plots: t+p aut (site 1) and tri spr (site 2). Comparisons after seven years were similar, despite missed treatments in later years. In contrast, graminoid cover in the glyphosate plots, tended to decrease over time (Figure 2). Estimated mean graminoid cover after four years was lower in the gly plots than in controls, except for gly aut at site 3. However, this difference was only significant (P <0.05) for gly aut (site 1) and gly spr (sites 1 and 2).

DISCUSSION

Biocontrol Assessments at broom twig-mining moths release sites in Victoria's eastern alps prior to the 2003 bushfires indicated that moths had become widely established and were beginning to have visible impacts on host plants (McArthur 2003). However, by 2008 there had been no increase in moth density or impact (DPI 2008) and by 2013 they had disappeared from most sites at which they had been released. Establishment of the broom psyllid in the eastern alps also appears to have been unsuccessful.

In 2013, the broom seed-feeding beetle was widespread between Omeo and Lake Dartmouth, but rare or absent elsewhere. No records of releases of seed-feeding beetles in the Omeo Valley could be located and it appears likely that beetles have dispersed there from at least 10 km away. The abundance of the beetle 16 years after it was released in the eastern alps

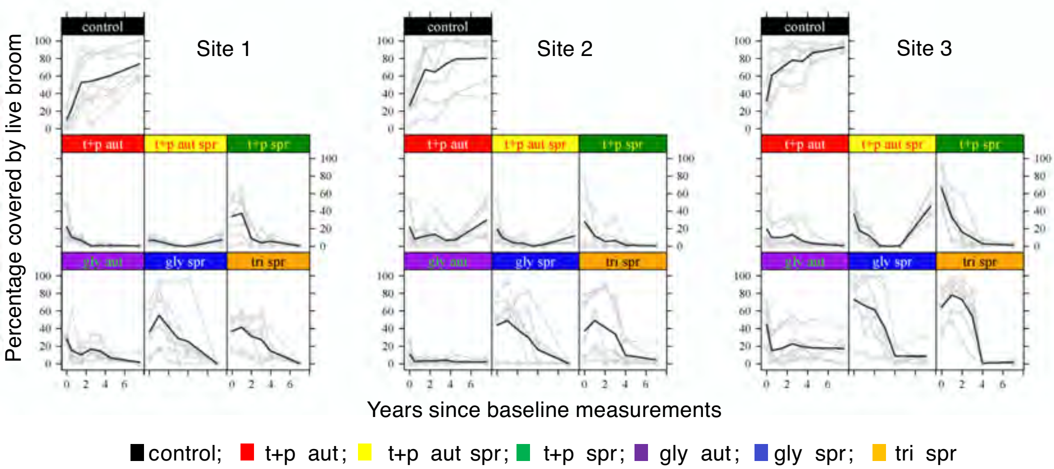

Figure 1. Changes in cover of live broom in each plot at each site. Black lines show mean cover. Grey lines (seven per plot) show individual transects and within-plot variability.

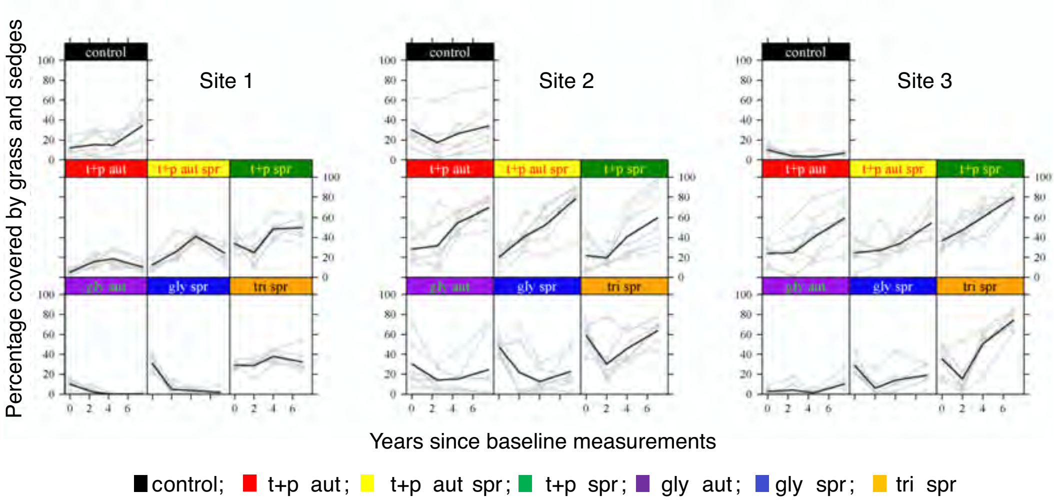

Figure 2. Changes in cover of graminoids in each plot at each site. Black lines show mean cover. Grey lines (seven per plot) show individual transects and within-plot variability.

is very encouraging. It is clearly showing evidence of persistence, dispersal and substantial impacts on broom seed production.

Although only introduced in 2010, the broom gall mite is also establishing well. Gall abundances at established sites ranged from only a few to thousands, spread over several hectares, with evidence of dispersal over at least 800 m. Where gall densities were high, the health and reproductive capacity of broom was clearly reduced. Pod production on heavily galled plants was much less than on ungalled or lightly galled plants.

At locations where broom rust was present it was readily detected from infection pustules on foliage and stems. Rust infection levels varied considerably; most plants supported light infection levels that appeared to have little impact on host fitness. However, in several scattered locations infection levels were high to severe and were clearly having a debilitating effect on the host.

The successful establishment of three biocontrol agents in the eastern alps, all with demonstrated capacity to weaken the health and/or reproductive capacity of broom plants, bodes well for biocontrol to make a useful contribution to the control of this challenging weed. Continued redistribution of gall mites and seed-feeding beetles will be undertaken to accelerate their dispersal. Monitoring of establishment, impacts and interactions among the agents will also be undertaken.

AEMP Without herbicide control, broom quickly dominates sites after fire. The initial cover in plots first treated in spring 2004 tended to be higher than in plots first treated in autumn 2004. Commencing treatment sooner after fire appears to prevent broom cover increasing. Beginning treatment in the first spring after fire may help keep broom cover even lower. Despite the majority of treated plots reaching low levels of broom cover, the slow decline in cover in the gly spr and tri spr plots indicates that these treatments may be less effective at reducing management requirements than the other treatments, as they may retain a greater capacity for seed production and replenishment of the soil seed bank. Given the longevity of broom seed (Hosking *et al*. 1996) this could imply a requirement for longer-term management.

Missing a single treatment year did not result in an increase in broom cover. However, missing two years in succession did, with cover rapidly returning to pre-treatment levels (Figure 1). This has potential implications for management, as it may be possible to miss a year occasionally, or even to only treat every second year, once broom cover has been reduced to a low level. This is being investigated in Stage II of the AEMP.

The tendency for graminoid cover to decrease in the glyphosate plots raises concerns in relation to lack of cover for soil stability. Apart from post-fire recovery, the increase of graminoid cover in t+p and tri plots over time could also be due to herbicide use as the majority of plots had significantly higher mean cover than controls after four and seven years.

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