Factors affecting broom regeneration in Australia and their management implications

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Summary

Broom regeneration following disturbance, with and without vertebrate herbivores, was studied at three contrasting sites with differing abundances of native plant species in the Shoalhaven River system in southern New South Wales. This study was part of a larger experiment replicated across four countries in both the native and exotic range of broom. In Australia broom seedbanks of 6000 to 20 000 seeds m^{-2} had a natural decay rate of 36% per annum. The proportion of the seedbank that germinated each year was highly variable, but sufficient to be the major cause of seedbank decline. Seedling survival and broom height after three years were similar for all cohorts germinating during the first three years of this study. Seedling survival was higher following cultivation, with grazing and in immature broom stands versus mature broom stands, but lower in sites with a higher native component to the grassland. Broom height after three years was greater when broom was cut and/or the ground cultivated and in immature broom stands, but was unaffected by grazing. The age when broom first flowered varied from three to five years across sites and treatments and was influenced by competition within the grassland and by grazing. These preliminary results are compared with similar data from the native range of the weed. Implications of these results for broom management are also discussed.

Introduction

In its native range broom (*Cytisus scoparius* (L.) Link) is a common leguminous shrub typical of heaths and other acid soils in areas of temperate climate (Tutin *et al.* 1968). Following introduction to Australia for its many historic, cultural and horticultural uses (Hosking *et al.* 1998, Smith 2000), broom has spread, usually from homesteads or small (often mining) hamlets near native bushland, to invade a number of montane parks, forests and river systems in temperate Australia. In these systems, broom poses the most significant threats as, not only does it reduce ground flora diversity in invaded ecosystems and generate a false understorey, but it also harbours feral pigs which perpetuate the disturbance cycle. Many of these suitable habitats are still broom-free in Australia, but are at great risk given the wide distribution of at least isolated broom plants in Australia and the invasion history of this species worldwide (Hosking *et al.* 1998). To address the threat of invasion and problems caused by broom in the 200 000 ha already invaded in Australia, it is vital to understand why this species is able to invade and persist in Australian ecosystems. Such understanding will be the key to developing effective management strategies, both to prevent invasion and suppress dominance of broom. One way to refine broom management is to compare ecological characteristics of broom between areas where it has become a dominant weed and areas where it is not considered a problem despite a long history of presence (Noble 1989). The latter state for many such exotic weeds usually only occurs within the native range.

As part of a multi-national broom biological control program, comparable experiments were set up to study factors affecting broom regeneration through recruitment in France and the UK where it is native and rarely considered a weed (Rousseau and Loiseau 1982, Thompson 1988) and in Australia and New Zealand where it is a highly invasive exotic weed (Hosking *et al.* 1998). Additional aims of these studies were: (a) to complete understanding of whether insects regulate European broom populations (Paynter *et al.* 2000) taking into account a previous study that measured impact of insects on broom survival and fecundity (Waloff and Richards 1977); (b) to help understand which insects may have the greatest impact on exotic broom infestations; (c) to understand why broom is such an invasive weed in its exotic range; and (d) to obtain reliable data for key broom population parameters to allow further development of a population model for broom management (Rees and Paynter 1997). The first experiment was set up in the UK in 1991 and the last in Australia in 1993 (Memmott *et al.* 1993, Fowler *et al.* 1996). Seedlings were followed through to seed production in all countries; data from the two European countries have been published (Memmott *et al.* 1993, Paynter *et al.* 1996, 1998, 2000). This paper describes the Australian experiment and summarizes the first preliminary data from either of the two invaded countries. The results are briefly discussed in relation to conclusions drawn about factors affecting broom recruitment from the two European countries.

Methods

Sites and design of recruitment experiment

The experiment used a series of 5 × 15 m plots set up in (a) broom at least 15 m into mature stands and (b) areas of immature (pre-flowering) broom along the expanding stand edge. Two locations were used, 50 km apart along the Shoalhaven River system in the Southern Tablelands of New South Wales. The experiment commenced in spring (November) 1993.

At Krawarree, altitude *c.* 600 m above sea level (35°48'S 149°40'E), broom had formed a 5 ha solid stand across the unfenced border of a cattle property and the Deua National Park. It had been fenced off from cattle and left 15 years prior to the experiment, but the whole stand had open access to numerous macropods, wombats and rabbits from the adjacent national park. At this locality, site 1 (Krawarree 'improved') was set up as two pairs of plots, one in mature and the other in immature young broom on the 'improved' pasture side of the broom stand otherwise dominated by the introduced perennial grass, *Phalaris aquatica* L. (Table 1). One plot in each pair was fenced to keep out animals from the size of rabbits to cattle. Fencing material consisted of mesh (mesh size approx 5 cm) with large corner fence posts to a height of 1.5 m and depth of 0.5 m in the soil. Site 2 (Krawarree 'native') consisted of two unfenced plots set up on the national park side of the broom stand in infested native grassland dominated by *Poa labillardieri* Steud., *Microlaena stipoides* (Labill.) R.Br. and *Themeda australis* (R.Br.) Stapf; one in mature and other in immature broom (Table 1).

The third site, named 'Waterboard' after the utility responsible for the area, was a cattle and sheep grazed paddock altitude *c.* 500 m (35°17'S 149°48'E), on the west bank of the Shoalhaven River. Here the broom formed a 30 m wide solid strip parallel to the river and separated from it by an equivalent strip of blackberry (*Rubus discolor* Weihe & Nees). The broom stand was of mixed aged with some senescence amongst the largest individuals and was growing in riversand-based soil. The

Table 1. Conditions at the start of experiments set up at Krawarree and Waterboard sites. The cover of native species excluded broom cover and was from data collected at the first census on 6 December 1993 in undisturbed plots. Densities of broom and the broom seedbank are back-transformed means ± SE.

Site	Krawarree 'improved'	Krawarree 'native'	Waterboard
% cover native species in herb layer	5%	71%	14%
Density of mature broom (m^{-2})	3.4 ± 1.4	10.0 ± 7.4	1.1 ± 0.8
Maximum age (years) of broom (by growth rings)	15	8–10	20–21
Height of mature broom (cm)	249 ± 11	191 ± 8	238 ± 57
Broom seeds under mature broom (m^{-2})	18524 ± 3162	3036 ± 1977	15675 ± 3756
Broom seeds under immature broom (m^{-2})	2360 ± 1233	1500 ± 524	1569 ± 601
Broom seeds 5 m from broom stand (m^{-2})	No plot used	No plot used	39 ± 26

infested grassland was dominated by natives (mainly *P. labillardieri*, *Carex gaudichaudiana* Kunth and *M. stipoides*) and mixed introduced perennial and annual grasses. Three pairs of plots were also used in (a) mature broom, (b) immature broom and (c) 5 m out from the edge of the broom stand on the pasture side of the strip (Table 1). One plot in each pair was fenced as at Krawarree to keep out livestock as well as resident rabbit, wombat and pig populations.

Disturbance treatments

The following disturbance treatments were randomly allocated to the three 5 × 5 m subplots within each plot. In two subplots all broom growing in or overhanging the subplot was clipped or sawed to ground level and the age of five of the largest individuals was assessed from growth rings.

(a) In one subplot the stumps were painted with Grazon® (active ingredients triclopyr and picloram), otherwise leaving the herb-layer undisturbed as might occur following natural stand senescence ('cut' treatment).

(b) In the other subplot all broom stumps were removed and the ground manually cultivated to 10 cm depth to resemble disturbance caused by pigs and wombats ('cultivation' treatment).

(c) The third subplot was left untouched as a control.

These treatments were identical in the experiments in France and New Zealand, with only treatment (a) being left out of the UK experiment (Paynter *et al.* 2000).

Before allocating disturbance treatments, the number and heights of mature broom plants in each subplot were measured and ten soil cores, 3.2 cm diameter and 10 cm depth, were taken from each subplot (during November 1993). The cores were sieved, hand-sorted and the number of seeds with fresh white endosperm per core recorded. Soil cores were then taken yearly at the annual maximum, that is after seed fall and before autumn germination, except on two occasions at the start of the experiment in November 1993 and in November 1996. This sampling allowed assessment of the proportion of the autumn seedbank germinating each autumn-spring.

Detailed sampling of broom plots in southern Australia was done in a comparable manner to experiments at the other sites and conducted in two ways:

(a) Five random quadrats (0.5 × 0.5 m) were used in each of the experimental subplots. For each quadrat the number of broom seedlings (with no woody parts), saplings (woody and 1+ year old), the approximate percentage cover of broom, native species, other exotic species, litter and bare ground were recorded. Quadrats were re-randomized for each sampling date to give statistically independent samples across dates.

(b) In each experimental subplot, five permanent quadrats (also 0.5 × 0.5 m) were marked out using random co-ordinates after treatment allocation. Once broom plants were at least one-year-old saplings, each plant was identified by a set of unique co-ordinates. Their heights were measured at each sampling date. When the plants first flowered their age was recorded.

Censusing was performed once in spring (September–November), and autumn (March–June) and after each major rainfall event (>20 mm) in summer (November–March). Censusing was not carried out during droughts, i.e. 12–17 months after the start of the experiment (summer 1994/95), 28–30 months after the start of the experiment (autumn 1996) and 44–54 months after the start of the experiment (the El Niño drought from July 1997 to May 1998).

Grass competition-free plots

To assess the effect of competition from grass cover on broom seedling growth following disturbance treatments, a 'cut' treatment was imposed on two additional fenced 5 × 5 m subplots in mature broom at Krawarree 'improved' in November 1993. After six months grass was clipped to ground level leaving existing broom seedlings intact. The age at first flowering of broom seedlings in these plots was noted and compared to age at first flowering in other cut treatments at the same site.

Statistical analysis

Data were analysed using the GLIM statistical package (McCullagh and Nelder 1983) and followed the same procedure as outlined in Paynter *et al.* (1998). Seedbank data for each core were Log (n+1) transformed to normalize data prior to analysis.

Results

Conditions at the start of the experiment (Table 1) showed that in the immature broom plots no plants had set seed suggesting maximum age would not have exceeded five years. Mature broom density was highest in the Krawarree 'native' site and lowest at the Waterboard site, where the mature broom had started to senesce. Maximum recorded broom age reflected this, the youngest broom being at the Krawarree 'native' site thereby suggesting this was the site that had been invaded by broom most recently. Seedbank density was lowest at the site with the youngest mature broom and highest at the Krawarree 'improved' site (Table 1).

Seedbank dynamics

Change in the seedbank under mature broom at Krawarree 'improved' and 'native', and at Waterboard are given in Figure 1 for the disturbed (cut only and cut and cultivated combined) and undisturbed plots. In undisturbed plots at each site the average seedbank over four years was approximately 20 000 seeds m^{-2} at Krawarree 'improved' where the seedbank remained quite steady, 6000 seeds m^{-2} at Krawarree 'native' where the seedbank increased three-fold over the four years and 15 000 seeds m^{-2} in the mixed grassland at Waterboard where the seedbank showed a three-fold decline prior to the last sampling date. The highest annual increment recorded in the seedbank was 5500 seed m^{-2} at the Krawarree 'native' site 28 months after the start of the experiment (summer 1995/96). Seedbanks in disturbed plots (i.e. without seed input) declined steadily during the course of the experiment at all sites giving an overall rate of decline of 36% per year. After four years seedbanks were half to one order of magnitude lower across sites, by which time, regenerated broom was seeding in the plots. These changes did not differ significantly between cut and cultivation treatments.

Recruitment from seed

Emergence of seedlings was observed in all months but appeared to be linked to

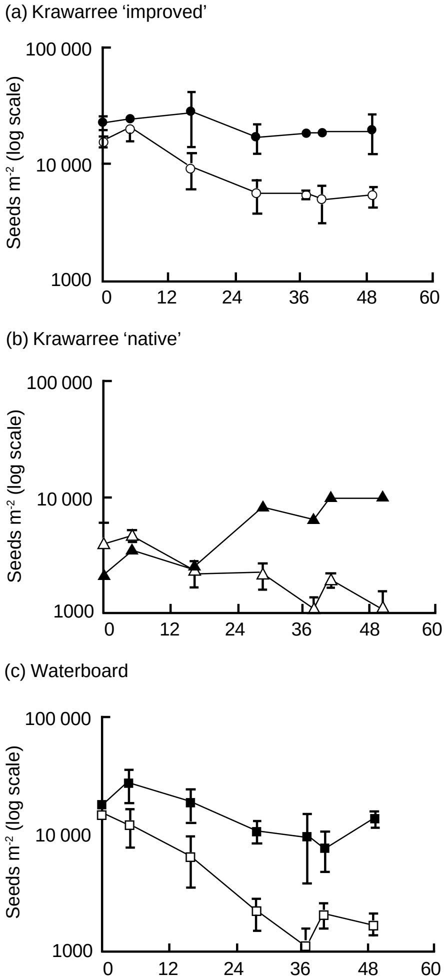

Figure 1. Changes in number of broom seeds in the seedbank over time in undisturbed (●,▲,■) and disturbed (○,△,□) broom plots (mean ± SE).

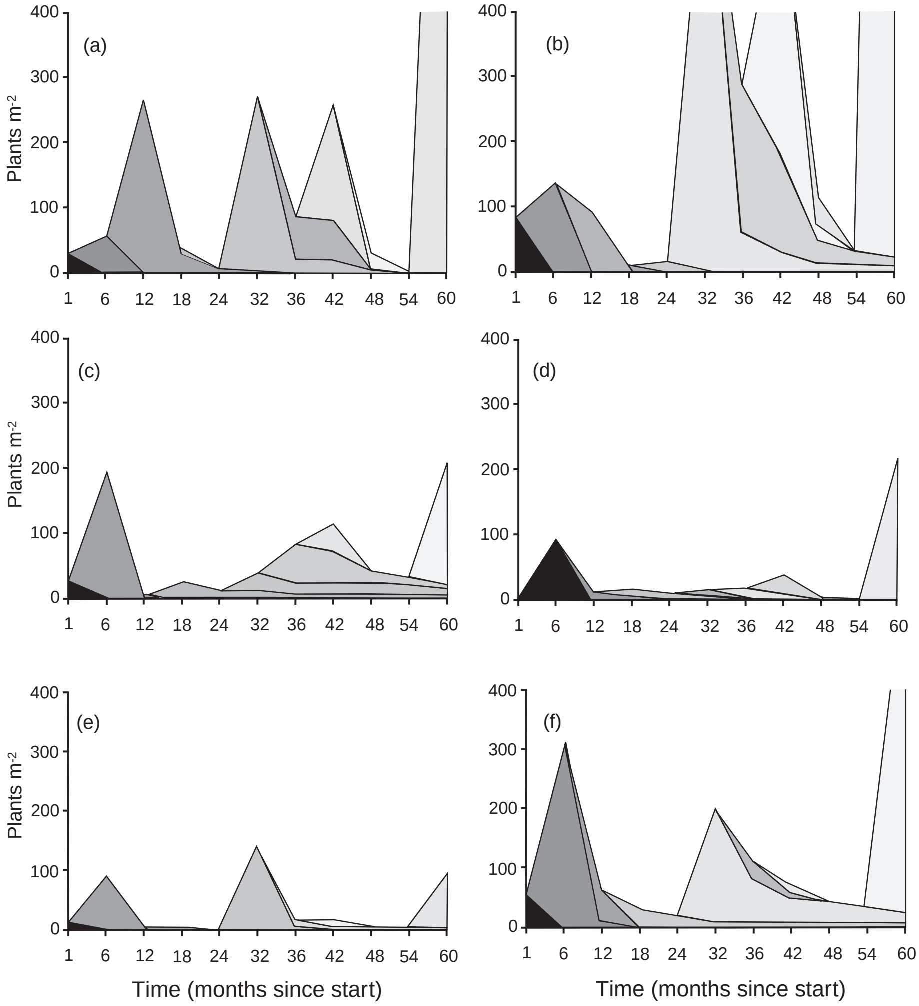

Figure 2. Population curves for broom plants at Waterboard in broom plots for (a) fenced undisturbed, (b) unfenced undisturbed, (c) fenced cultivated, (d) unfenced cultivated, (e) fenced cut and (f) unfenced cut subplots. Different shades are different cohorts.

significant rainfall and daytime temperatures of at least 15°C. Flushes of germination followed dry periods, particularly droughts. For example, a 10 month drought period in 1997/1998 (44–54 months after the start of the experiment) followed by rain led to the greatest flush (Figure 2) at all sites where seedling densities reached 2500 m^{-2}. The chance that a seed in the seedbank became a seedling also varied greatly between sites and years (0.1% to 69%). This was not a function of whether broom overstorey was removed and/or soil was cultivated. The chance that a seed in the seedbank became a seedling was highest during the fourth year at all sites (Figure 3), the year after the drought, suggesting that this proportion was related to seasonal factors rather than local conditions. The exception to this was grazing which tended to increase the chance a seed germinated into a seedling (Figure 3).

Survival

Seedlings were divided into cohorts based on the date of first census. Patterns of survival of different seedling cohorts in the different treatments, in six mature broom subplots at Waterboard are given in Figure 2. The patterns observed at this site were typical of all sites except for fenced disturbed plots at Krawarree 'improved' which was the only site where rapid grass growth led to decreasing success of later cohorts (data not shown). Waterboard (Figure 2) was also the most natural broom regeneration site of the three as the existing mature broom stand was already starting to senesce when the experiment was set up. Broom saplings survived under mature broom for up to three years. For the first five cohorts there was no significant effect of cohort number on survival of seedlings to three-year-old saplings (Figure 4). Season of germination may not be important in seedling survival as these five cohorts started in both summer and autumn. Cohorts that geminated in later seasons are also showing similar survival levels (data not presented). Rainfall is fairly aseasonal in the Shoalhaven valley and may help explain seedling survival.

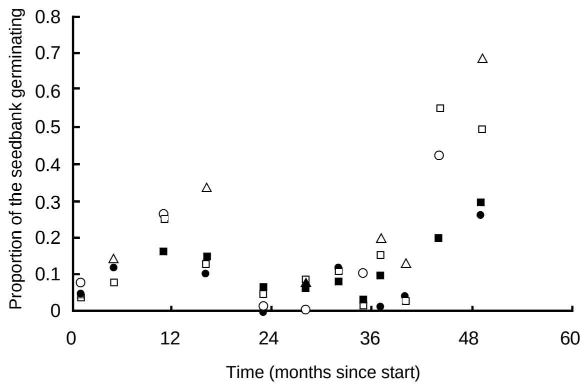

Figure 3. Probability of seed in the seedbank becoming a seedling against time at (a) Krawarree 'improved' (○,●), (b) Krawarree 'native (△,▲) and (c) Waterboard (□,■) both with (○,△,□) and without (●,▲,■) grazing.

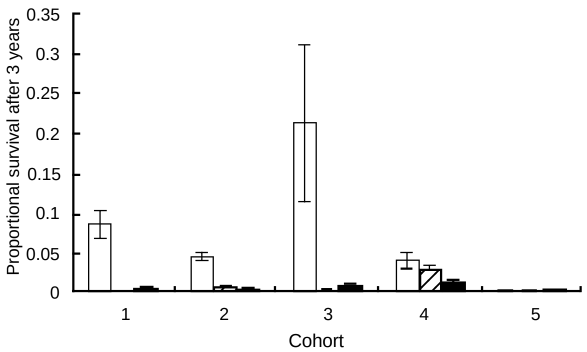

Figure 4. Survival of the first five cohorts of broom seedlings (dates varied between sites), for the first three years after germination, following application of disturbance treatments (back transformed from arcsine transformed data) for the three sites; Krawarree 'improved' (white bars), Krawarree 'native' (striped bars) and Waterboard (black bars) ± SE.

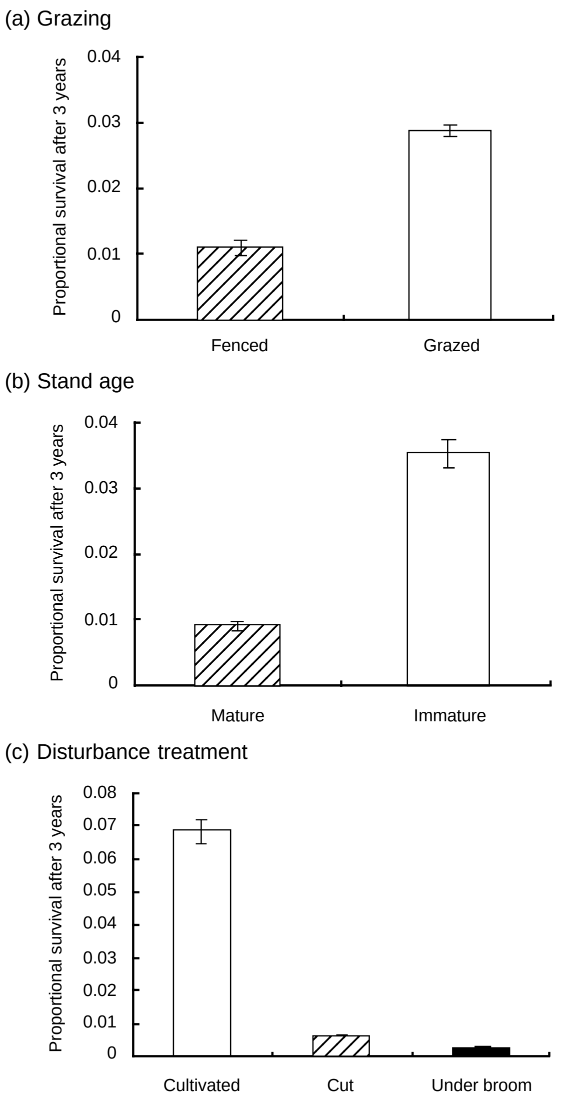

Figure 5. Effect of treatment on survival of the first five cohorts of broom seedlings for the first three years after germination following application of disturbance treatments (back transformed from arcsine transformed data). Mean data for all sites combined ±SE.

There was an effect of site on percentage survival to three years, being higher at Krawarree 'improved' (5.4% ± 2.1 (SE)) than at the other two sites (0.64% ± 0.01; $F_{2,31}$ = 13.3, P<0.01). Cultivation (but not the cut treatment) ($F_{1,31}$ = 6.4, P<0.05), grazing ($F_{1,31}$ = 18.9, P<0.001) and whether the seedlings were in immature broom over mature broom ($F_{1,31}$ = 23.5, P<0.001) increased sapling survival over this time across all sites (Figure 5).

Height and rate of regeneration

Height of three-year-old broom saplings (n = 585) was unaffected by cohort number or grazing although there were significant effects of site ($F_{2,48}$ = 8.15, P<0.01), disturbance treatment ($F_{2,48}$ = 4.69, P<0.05), and whether the plots had mature or immature broom present ($F_{1,47}$ = 5.47, P<0.05; see Table 2). Three-year-old saplings were significantly shorter at the Krawarree 'native' site, significantly taller in immature broom and significantly shorter in the undisturbed control subplots. There were no significant height differences between the cut and cultivated treatments (Table 2).

There were some marked local differences in rate of regeneration between treatments across sites that must have reflected local site conditions. For example, following a broom cut or cultivation at Krawarree 'improved', regeneration without grazing was fastest following cultivation in mature broom subplots, while being fastest on cut subplots in the immature broom plots. Rapid growth of exotic grasses slowed regeneration in the cut plots under mature broom, while broom seedlings were probably already present in the cut subplots under immature broom that could grow quickly following the cut. Outside the fence, grazing tended to nullify these differences. In other mature broom plots at Waterboard and Krawarree 'native', regeneration was fastest in cut plots as removal of vegetation cover either caused the mobile sand to bury the first few cohorts of seedlings (at Waterboard) or exposed a shallow soil that dried too quickly for seedling establishment (at Krawarree 'native').

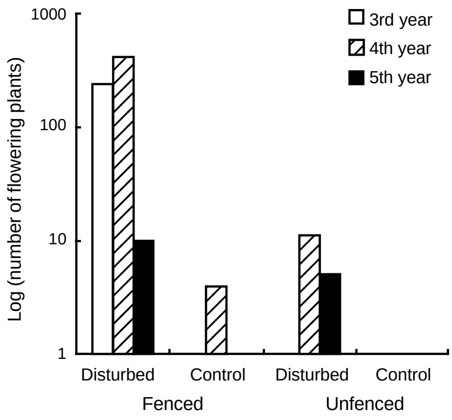

Figure 6. Number of flowering plants in different age classes (third to fifth year) at first flowering in disturbed and control plots inside and outside fenced areas. Data from all sites.

Age at flowering

For broom plants that were followed, the minimum age at which plants first flowered per subplot had a median and peak at four years, but varied between three and five years (Figure 6). Grazing and the presence of grass competition following seedling establishment increased age at flowering by at least a year, while disturbance decreased age at flowering by at least a year.

Discussion

Seedbanks

Changes in the seedbank under undisturbed broom (Figure 1) suggested different stages of stand development across sites and this was supported by age of the oldest plants at each site. An increasing seedbank at Krawarree 'native' during this study suggested that seedbank replenishment outweighed seed losses, while the senescent broom at Waterboard failed to replenish its seedbank. A relatively constant seedbank at Krawarree 'improved' over four years suggests this site had seedbank replenishment matching seedbank losses, thereby indicating a likely maximum to seedbank size. The peak recorded annual increments in the seedbank were of similar magnitude to the inputs recorded in terms of a seed rain of up to 8000 seeds m^{-2} (Hosking *et al.* 1998). Rates of seedbank decline and the final seedbanks after four years in disturbed plots with mature broom overstorey removed were comparable to those from southern France (Paynter *et al.* 1998).

Censusing only three times a year and strategically following rain, detected most peaks in seed germination, although seedlings could have emerged and died undetected between sampling dates. Despite

Table 2. Cohort mean heights (cm) of three-year-old broom saplings across these sites in mature and immature broom in the three disturbance treatments. Means calculated using heights of a total of 585 three-year-old saplings divided into a maximum of five cohorts for each site/treatment combination. See text for statistical analysis.

Site	Krawarree 'improved'		Krawarree 'native'		Waterboard	
Broom maturity	Mature	Immature	Mature	Immature	Mature	Immature
Undisturbed	12 ± 8	37.8	0	5.7 ± 3	12 ± 2	34.5 ± 8
Cut	33.1 ± 12	45.5 ± 10	9.2 ± 1.2	15.7 ± 9	56.2 ± 19	72.5 ± 26
Cultivated	33.4 ± 14	54.2 ± 6	6.6 ± 4	10.9 ± 2	49.1 ± 11	60.5 ± 36

this deficiency the proportion of the seedbank which germinated in peak flushes was high and of comparable magnitude to the annual rate of seedbank decline. This result suggests that most of the seedbank decline observed at sites without seedbank replenishment (Figure 1), was likely to have been due to germination. Post-dispersal seed predation levels observed, at least at Krawarree (Paynter *et al.* 1996), probably account for seed losses prior to entering the seedbank.

Recruitment from seed

Germination was not restricted to particular seasons as in the native range, a result common to many weeds in Australia (Sheppard 2000) and results from aseasonality of rainfall. The proportion of the seedbank that germinates was highly variable across seasons, as observed in France, but was generally higher on average in Australia for any given germination cohort. For example the proportion of the seedbank that germinates averaged about 4% in France for the first three cohorts (data in Paynter *et al.* 1998), but 11% for the first three cohorts in Australia. This proportion represents about one tenth of the seedbank decay rate in France compared to a third of the seedbank decay rate in Australia. While the proportion of the seedbank that germinated was correlated with March rainfall in France, in Australia it appeared to be more related to the time since previous significant rainfall. This proportion did not vary with disturbance treatment in this experiment. This difference contrasts with the results from the UK and France where disturbance promoted germination of seed. An explanation for this result may be that the available competitive herb layer in undisturbed Australian plots was not sufficient to significantly suppress broom germination rates.

Survival and growth

The most significant contrast between broom population dynamics in Australia compared with the native range (Paynter *et al.* 2000) was the survival and growth rates of later cohorts of seedlings. In the native range, only the first cohort survived to flowering and only following disturbance. In Australia cohort age had no effect on survival to three years old or height reached by that age, which is probably equally true for survival to flowering (complete data not yet available). Cultivation increased seedling survival to three-year-old saplings and cultivation or cutting was necessary for survival beyond three years in a mature broom stand, a result comparable to results from France (Paynter *et al.* 1998). Cultivation resets the herb layer to zero cover, thereby allowing broom a greater chance of surviving than when it has to grow through an existing herb layer. Higher seedling survival to three years in grazed plots may have been due to grazing animals (mainly rabbits, kangaroos and cattle) removing much of the competing grass layer and reducing its smothering capacity. Grazing was observed to have a significant negative effect on seedling survival in the UK experiment, but in the Australian experiment grazing did not significantly reduce the height of three-year-old saplings, probably due to lower grazing intensity. In the UK rabbit grazing intensity was considered to be very high (Paynter *et al.* 2000). Site differences within Australia were evident in survival, being lower in sites with soils that appeared more prone to drying (i.e. sandy soil at the Waterboard site and shallow soil at the Krawarree 'native' site) and height attained being lower in largely native grassland. Broom survival and height gains were greatest in immature broom.

Seedling survival to three years appeared to be somewhat lower at our sites compared to the native range. For example average survival following cultivation across sites in Australia ranged from 21.4 to 2.1%, while average survival to three years of broom was *c.* 15 and *c.* 50% in France and the UK respectively (Paynter *et al.* 1998, 2000). Average height at three years was similar however between our sites and the French site at about 40 cm (Paynter *et al.* 1998).

Implications for management

Seedbank survival data collected here suggest that at these sites it will take *c.* 11 years for an average seedbank under mature broom to decay to a level where the chance of regenerating one three-year-old plant per square metre would be less than 1 given the observed average seedling survival rates. This observation broadly agrees with field evidence that at least 25 years of spraying broom in the one location has not been enough to prevent continued broom germination from the seedbank (Smith 2000). To hasten this process control strategies that impact directly on the seedbank, for example fire (see Downey 2000), should be considered for broom management in Australia.

Our study also showed that any of the kinds of disturbance tested enhanced broom survival. Even slashing mature broom should therefore be recommended only when combined with existing or oversown competitive ground cover. At our study sites with moderate exposure to grazing animals and wombats, such exposure also increased the germination rate and survival to three years, without any negative impact on height gains of broom. Although this exposure did slightly increase age at first flowering it did more harm than good and should be avoided during the regeneration phase of broom. For broom management, exposure to grazing may need to be restricted to mature plants (Sheppard *et al.* 2000). The great variation in response to fencing across all sites shows that the type of vertebrate herbivore involved will greatly influence their impact (c.f. Paynter *et al.* 2000). Restriction of access for those vertebrates that are associated with broom stands in Australia, such as pigs and wombats, is likely to be an important component of any overall broom management strategy.

Our study suggests broom may be easier to control on sites with infertile or quick drying soils as at these sites survival to three years was an order of a magnitude lower. Our preliminary observations also suggest that the time from disturbance to a new flowering infestation of broom will also be longer in such soils. Similarity in age at first flowering across the distribution of broom suggests that basic climatic factors such as temperature may have little effect on speed of stand regeneration.

Broom control is likely to be most effective when the seedbank is low and competitive ground-cover high (i.e. when the broom stand is still developing). If there is an even-aged established broom stand already present, more effective control may be achieved if control measures are held back until the stand becomes naturally senescent, as the seedbank may decline naturally during this stage.

Acknowledgments

John Hosking, Jeremy Smith and Richard Groves for critically reviewing this manuscript and John Hosking for assisting with the identification of some native species in the plots. John Lester, Joel Armstrong and Paul Downey for assistance with data collection and Anthony Swirepik and Matthew Smyth who also helped with setting up the fenced and cleared plots.

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Controlling broom (*Cytisus scoparius*) in pasture on the Barrington Tops – a graziers perspective

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Summary

Broom, *Cytisus scoparius*, is a major weed on the property 'Tomalla', part of Ellerston Pastoral Company. Current broom control is by herbicides, fire and grazing. The effectiveness of these techniques at 'Tomalla' is reviewed. Cost of herbicide control of broom on 'Tomalla' is currently around $45 000 per annum. Additional resources have also been invested by the Company as a core partner in a biological control program initiated by the Broom Council. The council was set up to coordinate broom control efforts on the Barrington Tops plateau. To date there has been no impact from biological control agents that have been released on broom on the Barrington Tops.

Introduction

Broom, *Cytisus scoparius* (L.) Link, was reported to have been introduced as a pot plant to the property 'Tomalla' property (1200–1317 m) on the Barrington Tops plateau in the 1840s (Waterhouse 1988). It has spread from 'Tomalla' to be a problem on over 10 000 ha on the Tops. Broom is now estimated to cover about 2000 ha of the 4800 ha grazing property 'Tomalla', part of the larger Ellerston Pastoral Company. Seeds have been spread in several ways on 'Tomalla'. They were carried on tracks of bulldozers during logging operations, on livestock and by water down creeks. Cattle have been observed reducing broom growth in young broom stands by eating seedlings. This paper reviews broom control options that have been tried on the property in recent years and discusses the success of these programs.

Herbicides

On the property, broom is easily killed using the herbicide Garlon® (active ingredient triclopyr, 170 mL to 100 L) when broom is in leaf and flower during the months of October, November and December. In other months diesel has been added to the mixture, but in the long term this ends up being too costly. When