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Broom management

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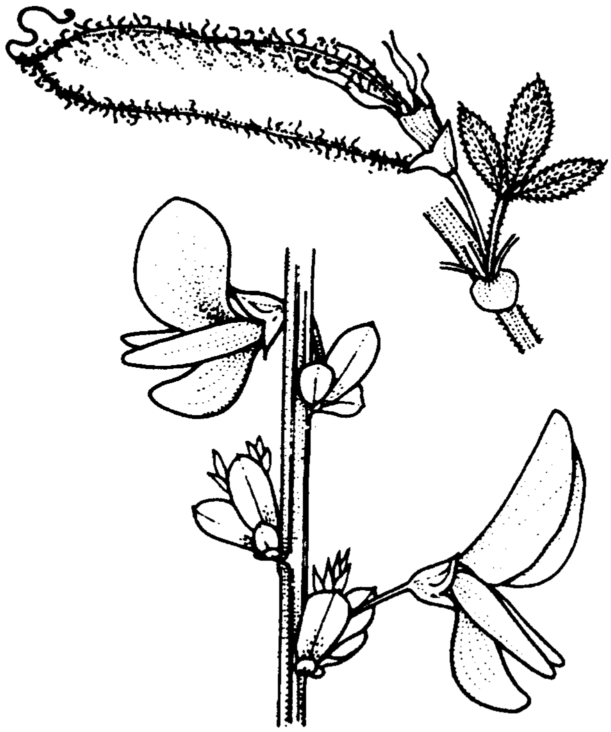
Proceedings of a workshop held at Ellerston and Moonan on 16–17 November 1998

This is part of a series of workshops sponsored by the Co-operative Research Centre for Weed Management Systems

Editors: A.W. Sheppard and J.R. Hosking



CRC Weed management systems

Co-operative Research Centre for Weed Management Systems

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MISSION STATEMENT

The CRC is committed to increasing the sustainability of agriculture and protecting the natural environment by developing ecologically sound, cost effective weed management systems.

OBJECTIVES

- To reduce the impact of weeds on farm productivity and profitability by developing sustainable management programs that optimize the integration of chemical, biological and ecological approaches for annual crop and pasture systems in the cropping zone of southern Australia.
- To develop practical integrated weed management systems that reduce weed infestation, protect the environment and enhance sustainability and productivity of Australian temperate perennial pasture ecosystems.
- To develop integrated strategies for the sustainable management of weeds invading natural ecosystems in temperate Australia, in order to maintain biological diversity of native flora and fauna and to prevent further degradation of natural habitats.
- To implement a suite of weed science and weed management education programs which, for the first time in Australia, offers a coordinated approach to educating undergraduates, postgraduates, professional land and natural resource managers, and the community.
- To interact with researchers and land managers to communicate the results of weed research and foster the adoption of resulting weed management strategies.

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Cover illustration of *Cytisus scoparius* (L.) Link, reproduced with the permission of the Royal Botanic Gardens, Sydney

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Editors: A.W. Sheppard and J.R. Hosking

Broom (*Cytisus scoparius* (L.) Link) population management strategies

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Summary

In November 1998 a broom management workshop was held with this title. The workshop aimed to review the status of broom as a weed, from biogeographic, ecological and economic perspectives, assess the efficacy of available control options, and to start the development of integrated strategies for broom control under a range of situations. Following formal presentations a workshopping session was conducted aimed at developing best-bet management strategies for broom in a range of typical situations where broom needs to be managed. This was followed by a general discussion. The contexts of this workshop, the developed 'best bet' strategies and outcomes of this workshop session are outlined in this paper (see Table 3).

Introduction

Broom (*Cytisus scoparius* (L.) Link) is an exotic weed in five continents. Even within its native range, temperate Europe and eastern Asia, broom can reach an abundance that requires management, particularly within forestry and grazing systems (Hosking *et al.* 1998). In November 1998, the Cooperative Research Centre for Weed Management Systems and the Ellerston Pastoral Company sponsored a broom management workshop, to discuss and develop integrated management strategies for this weed. Thirty-two delegates attended the workshop, including two from New Zealand and one from the USA. Two of the participants had been responsible for most of the research carried out in the international biological control program on broom in Europe since 1988. Workshop participants had expertise in broom ecology, biological control, and management of broom on farms, in commercial forests and national parks. Also present were extension officers, and local and regional council representatives as well as representatives of community and Landcare groups, and the nursery industry.

The aim of the workshop was to review the status of broom as a weed, from biogeographic, ecological and economic perspectives, assess the efficacy of available control options, and to start the development of integrated strategies for broom control under a range of situations. Expected outcomes from the perspective of the participants at the commencement of the workshop are listed in Table 1.

Previous workshops on broom have been held in 1986 (at Barrington Tops) and in 1997 (at Tumut). The recommendations from the 1986 workshop (Atchison 1986) are outlined in Table 2, and many of them have been implemented. Although no proceedings are available from the 1997 workshop, one of its outcomes was that the Alpine Liaison Committee allocated resources towards Victorian releases of broom biological control agents already released in New South Wales.

On arrival at the workshop, participants were allocated to one of six groups relating to their area of expertise and provided with a realistic broom management problem, a suggested budget and a task list. The aim was to develop a management strategy for the given problem (see below), before the end of the workshop. The first day of the workshop consisted of formal presentations to set the stage under the following session headings:

- Broom problem in Australia and overseas
- Conflicts of interest
- Why is broom a weed?
- Practical management options
- Industries affected and current control strategies
- Evaluation

Table 1. Expected outcomes from this broom workshop as defined by the participants at the start of the workshop.

	Outcome	Number. of respondents for each outcome
1.	To meet and establish links with researchers and others doing broom control	4
2.	To gain a broader perspective of the broom problem in Australia	3
3.	To identify knowledge gaps and prioritize areas for future research	3
4.	Develop integrated strategies to contain and eradicate broom in natural ecosystems	3
5.	Refine control techniques and best practice guidelines	3
6.	Become conversant with current best practice for broom control	1
7.	Obtain information on the best native species to re-vegetate broom infested areas	1
8.	Learn of the impacts of broom on pastures	1
9.	Understand the realistic potential for effective biological control	1
10.	Coordinate biocontrol agent redistribution and monitoring of releases and prioritize where/when further releases are to be made	1
11.	Understand further biological control research needs and to prioritize this research	1
12.	Secure releases of biological control agents in north western Tasmania	1
13.	To identify any scope for the use of native predators for biological control	1
14.	Discuss need for research on genetic variation in broom	1
15.	Develop collaborative research projects	1

Table 2. Outcomes of National Park Advisory Committee Broom workshop held at the Barrington Tops in February 1986 (adapted from Atchison 1986).

	Required further research	Status
1.	Develop greater contact and collaboration with the New Zealand broom biological control group and consider taking advantage of CSIRO's infrastructure to commence an Australian biological control program for broom	*Ongoing*
2.	Monitor the extent of broom infestations and distribution on the Tops	*Ongoing*
3.	Encourage the collection of background information about broom and the interactions with the rest of the landscape (particularly by Jeremy Smith at University of New England, Armidale)	*Ongoing*
4.	Support research into the impact of broom on catchment hydrology	*Not done*
5.	Support research into broom physiology and the impact of broom on modifying soil nitrogen levels	*Pilot study*
Required control measures		
6.	Manage track access to prevent further spread of broom south into the National Park	*Ongoing*
7.	Clean National Parks and Wildlife Service vehicles likely to have become contaminated with broom seeds	*Ongoing*
8.	Filter infected rivers and streams from the park with mesh that will prevent seed spread	*Impractical*
9.	Control feral pigs	*Ongoing*
Required extension		
10.	Increase public awareness of the threats of broom to the public good via media and mobile exhibitions	*Ongoing*

The majority of these presentations has been edited (these proceedings). After meeting socially in the evening to discuss the aim, the six workshop groups were allocated a two-hour intensive session in the morning of the second day to hammer out their respective management strategies. A plenary discussion session took place for the last hour of the workshop. This discussion focused on relevant control options for different situations where broom is causing problems. Finally a field trip was organized to allow participants to see first hand the extent and severity of broom infestations in the Barrington Tops area.

A summary of specific weed problems presented to each group is given below, together with the management goal, management strategies and evaluation procedures each group developed. This is followed by the outcomes of the final discussion.

A National Park

A 10 000 ha broom infestation in a forested National Park, with limited vehicle access, is still spreading with small satellite infestations building up from the edges. The infestation supports a large feral pig population. The aim of control includes a focus on broom control along roadsides and in public camping areas to ensure some sensitivity towards how the public perceives the park is managing its broom problem. Control budget $150 000 per annum.

Management goal: (a) Maintain the biodiversity of invaded habitats with high conservation value and (b) contain broom spread and presence in areas used by the public.

Management strategy: (a) Identify and map biodiversity 'hot spots' for local control of broom ($20 000 in the first year). (b) Pull and spray broom at these sites in first year and then monitor and control broom in these sites in subsequent years ($20 000 per annum). Management should include protecting/encouraging the existing native flora. (c) Map extent of broom distribution in the park and monitor spread ($10 000 per annum). (d) Contain spread of broom by strategically spraying (Garlon® at 2 mL L^{-1}) around the perimeter of the infestation and satellite populations, along roads and tracks, and at campsites ($80 000 in the first year then $100 000 per annum). Delimit main infestations and control the main disturbance agent, i.e. by trapping pigs within these areas ($20 000 per annum). This would limit the amount of broom regeneration. Old broom stands contain more native species and are thus less dense and therefore less undesirable than young stands. (e) Support biological control initiatives as the main control option for the main infestations.

Evaluation procedure: (a) determine whether biodiversity at specific sites is maintained, (b) monitor broom spread in the short and long-term through successive mapping and (c) assess success of pig control through trapping frequency and on-ground assessment of disturbance levels.

The group considered that if further funds were available, these should be used to conduct studies within the main infestations on the management value of fire trialing both pre- and post-fire treatments of slashing and herbicide. Funds would need to be ensured, however, for subsequent long-term biennial clean up and monitoring of cleared areas.

Catchment management

Broom is scattered along a 10 km stretch of a watercourse at the head end of a catchment in native bush within c. 20 m of the bank except at the source of the infestation in an old homestead. A key risk is that the broom will spread downstream into the whole river system, which includes a World Heritage Area (WHA). The aim of control includes a focus on protecting as much as possible the native riverine plant community, thereby minimizing risk of spread downstream. Given that broom seed is known to be able to live for several years on the riverbed. Control budget c. $20 000 per annum.

Management goal: (a) to map broom presence and monitor spread, (b) to remove from, and control broom in, new and peripheral locations and where overhanging a water course, (c) contain and, where possible, reduce existing established infestations around homestead and along access roads, (d) educate local landholders, local land management staff, machinery workers and the general public and encourage their assistance in the control program.

Management strategy: (a) Survey the distribution and general age-class of broom using both aerial and ground surveying by professionals and volunteers. (b) Identify stakeholders including the overcoming of 'grey' areas of accountability between land management agencies, but also understand the State/Regional/Local planning contexts for weed management. (c) Define various management zones such as the homestead, road corridors, river and WHA downstream. (d) Develop management prescriptions, calculate control costs and prioritize action by zone: (i) WHA – high conservation asset risk – annual surveys at flowering time down the catchment to detect broom spread, removing all broom physically as encountered (opportunistic control) – low cost so highest priority. (ii) River – high conservation asset risk, high potential for 'jump dispersal', some risk of weed recurrence – use 'cut-and-paint' method with a suitable ratio of professionals and volunteers targeting reproductively mature specimens at flowering. Start with overhanging plants working upstream from limit of infestation before treating plants up the bank. Mark significant treated infestations (e.g. >4 m^2) for future monitoring of recruitment – high cost, but high priority. (iii) Homestead – low conservation asset risk, high visibility – high volume spraying, mulching and bulldozing could be employed depending on resources, containing the edge of the infestation before working inwards. Containment a high priority, complete removal a low priority. (iv) Road corridors – if known flora suggests low conservation asset risk, survey and control broom using high volume spraying, marking significant infestations for future monitoring of recruitment. Containment a high priority, complete removal a low priority. (e) Causal factor remediation – encourage staff to remove broom seeds from machinery and to control feral animals. (f) Education and community awareness: (i) Machinery operators need to understand the threats of broom and the importance of good machinery and excavation spoil hygiene. (ii) Land management agencies – organize pre- and post-program implementation meetings to follow State/Regional/Local plans. (iii) Homestead users and adjacent landowners – provide information leaflets and advertising of program implementation in local print media. (iv) WHA users – provide information leaflets, weed identification guides, and articles in bush walking newsletters. (g) Revegetation may have a role to play in the Homestead area.

Evaluation procedure: (a) use successive mapping to monitor short and long-term spread of broom downstream and along access roads, (b) monitor controlled and marked infestations for broom regeneration and treat as necessary, (c) assess the recovery of native riparian vegetation, (d) quantify the area of broom controlled in relation to area mapped.

Infested township

Broom is infesting 1000 ha within and surrounding a township in a high-rainfall zone. The infestation covers both private and public land including a golf course, but generally occurs over previously managed grassland of introduced species, i.e. the underlying flora is of little conservation interest. Vehicle access is good and the area is not used for grazing. The infested area has large, medium and small patches of broom in a mixture of growth stages (seedlings, immature plants and mature plants). This infestation is integrally associated with village activities with potentially many willing helpers to assist with control. The aim of control includes improving the natural setting of the village and gaining a collective responsibility by the community to remove and control the broom. Control budget c. $50 000 per annum.

Management goal: (a) prevent spread, (b) improve the aesthetic value of the town with respect to the weed, (c) transfer ownership of the management program to the local community and d) reduce the amount of broom in the long-term to maintain local enthusiasm/ involvement in the management process.

Management strategy: (a) Map the infested areas. (b) Treat outlier infestations to prevent spread, especially along roads (where visibility will be an issue) either by mulching for medium sized stands ($1000 ha^{-1} for 10 ha) or spot-spraying for isolated plants in patches less than *c.* 25 m^2 ($10 000 per annum). (c) Set up a demonstration site at an aesthetically important point in the town, where several control options are trialed e.g. mulching, slashing, and oversowing with local perennial grasses and/or shrubs native to the region ($10 000 per annum). On private land goats and possibly fire might also be included in a trial. (d) Run a public awareness campaign. Educate the community with regard to the threat posed by broom. Capture community interest to change the way people perceive their town (e.g. contract a landscape architect to plan and show how the town would look with the weed replaced by local native species). Provide incentives to encourage local community/council cooperation, involvement, pride and ownership of the broom control project by targeting local identities and groups (e.g. Rotary, Returned Serviceman's League, etc.) and support other communal activities that make use of the land ($20 000 per annum).

Evaluation procedure: (a) determine the amounts of broom controlled by each method and carefully map and record control efforts, particularly along roads and access tracks, also monitor any further weed spread and (b) assess achievements against milestones set for gaining community involvement (e.g. attendance at display days, number of local people signing up and showing up, level of voluntary participation), and for passing on the management of the project to a locally run committee based on the outcomes of the demonstration trial.

A significant budget would need to be maintained for at least five to ten years to ensure that public involvement becomes self-perpetuating.

Forestry

Broom infests several multiple hectare blocks of plantation trees. The plantations have a felling/replanting cycle of about 20 years at the end of which the whole block is disturbed. During this process windrows of tree stumps are formed at seven row intervals in the plantation where broom may persist through most of the cycle. Broom is a problem in the replanting phase, growing up quickly from seed and smothering planted saplings or reducing productivity by slowing growth of the young plantation. In the last few years before plantation harvesting, the broom itself is shaded out within the stand, but it has laid down a large seedbank. Vehicle access is good and aerial treatment is economic. The infested areas are of similar size, but forestry blocks in between them are susceptible to invasion. The aim of control includes limiting economic losses to the forestry industry, by limiting risk of spread of existing infestations into adjacent blocks and a public responsibility of keeping the noxious weed under control. Control budget limited only by need to minimize control costs.

Management goal: (a) containment of broom within existing infested areas, (b) elimination of broom from access roads and fire tracks, and (c) reduction in broom impact on plantation production.

Management strategy: straightforward with regards to (a) and (b) using mapping, chemical control and long-term monitoring to prevent broom spread and to eliminate it along access roads and fire tracks. To achieve (c), however, an adaptive management strategy should be adopted (Shea *et al.* 1998), i.e. using the management process to improve the strategy itself by actively trying a range of management techniques and control levels to provide internal checks on the process.

A research project to demonstrate the impact of broom on forestry production would be required before any further action is taken (e.g. Barnes and Holz 2000). Following this, novel control options to be tried following harvest could be (a) woodchop and roll timber waste and redistribute rather than using windrows, (b) prepare ground for replanting soon after harvest to allow broom to start to regenerate prior to planting, (c) regenerating broom is then sprayed with the highest recommended rates of glyphosate (e.g. 1350 g a.i. ha^{-1}) and the penetrant Pulse® immediately prior to planting (e.g. Hore 2000). For existing broom infestations in young plantings control options include: (a) slashing broom between rows, (b) cleaning up inter-row areas with shielded (to protect trees) applications of glyphosate, and (c) applying urea-based fertilizer (e.g. 200 kg nitrogen ha^{-1}) to the young trees. (d) biological control, particularly using shoot feeders, may also help depress the growth rate and height of competing broom within the plantation, thereby reducing its impact.

Evaluation procedure: (a) monitoring the success of the containment campaign outside plantations and (b) conduct an economic analysis for each of the combinations of management options trialed.

The group suggested that one way to reduce the pressure of broom on future operations might be to set up a long rotation forestry trial (e.g. 40 years) aimed at sawlog (i.e. plank) production rather than woodchips. Thinning the trees as part of the management program may provide temporary openings in the canopy that would force broom to germinate, before the trees shade it out as they continue to mature. A long-term economic analysis in relation to current practice must also be an important component of such a trial.

Cattle farm

Broom infests a property of several hundred hectares, only 20% of the land has no history *of broom. Some areas have had to be abandoned to broom due to poor access and low productivity of the pasture or along water courses, most of the infested productive areas have a broom seedbank that keeps sending up young broom plants every year following attempts to control them. Broom is all down the valley so broom seeds from the property are not likely to infest previously uninfested areas. Only cattle are run on the property, but there are also rabbits, kangaroos and wombats. The local council is threatening to impose a fine if broom is not controlled on the property. Vehicle access is good to most of the property. The aim of control includes limiting loss of pasture to broom, pacifying neighbouring landholders, and convincing the council that you are conducting control as efficiently as your budget allows. A typical annual budget for broom control would be c. $20 000, and would be very variable between years.*

Management goal: (a) to contain the existing infestations within the first five years, and (b) start reducing the size of the infested area between year five and ten.

Management strategy: To satisfy neighbours and local council in year one (a) spray fence lines and tracks using Grazon 1.7 L per 100 L ($4000), and (b) set up a small fenced demonstration area involving a herd of 50–60 dairy goats ($3000 goats, $6000 electric fencing), then (c) carry out wombat and rabbit control ($800). In years two to five: (d) continue to spray fence lines and spot-spray flowering broom every two years ($4000), (e) fence to restrict cattle movement and prevent seed distribution as budget allows, dividing the property progressively into 20 ha paddocks (*c.* $10 000 in a good year), (f) over-sow low to medium infestations with appropriate perennial grasses for the region and add organic fertilizer e.g. processed sewage or ash ($200), (g) build windbreaks of trees (e.g. pine) on windward fence-line of each goat paddock between goat fence on inside and cattle fence on outside ($1500 per annum over four years), (h) mulch around previously sprayed fence lines ($1500), (i) invite Landcare and other interested community groups in years 4 or 5 to learn about goat use.

Evaluation procedure: Estimate the area of broom infestation that has been returned to production each year in relation to the total area infested each year. This should directly involve local council representatives to obtain an independent assessment of success of the management strategy and alleviate their concerns.

Other control strategies could include flaming large broom plants to improve accessibility to goats. Stocking rates should be carefully monitored to prevent overgrazing as this will allow broom to regenerate in cleared paddocks. The estimated required budget in the first year was *c.* $20 000 for a 200 ha property. While start-up costs such as for the goat demonstration paddock and initial fence-line and track spraying would decline with time, continued expenditure would be required for spot-spraying, setting up wind breaks, mulching, vertebrate pest control, and the cattle fencing to divide the property into 20 ha paddocks. This last item might be optional depending on variation in funds between years.

Threat to rare plant

At present, a rare orchid is only known to grow in a broom-infested area of a National Park. The above ground parts of the plant are annual and leaves and flowers are present in January and February. Almost nothing else is known about the biology of the plant. Part of the known orchid population is now under the edge of the broom infestation. The location of the plant is not to be made public because of the risk of orchid enthusiasts collecting known plants. Control budget up to $15 000 per annum.

Management goal: (a) protect the existing threatened plant population by immediately controlling the invading broom infestation in a manner posing minimal risk to the threatened plant and (b) survey for other populations of the threatened plant in similar habitats while starting ecological studies to better understand the plant.

Management strategy: (a) immediate broom control to 10 m beyond the edge of the threatened plant population irrespective of broom stand age, this control would consist of cutting broom and treating stumps with glyphosate to prevent resprouting (*c.* $1000 per annum) and (b) $9000 would be allocated to surveys of the threatened plant and studies on its ecology, using contracted researchers, students or local enthusiasts.

Evaluation procedure: Annual monitoring of the size of the threatened plant population.

Additional actions included: (a) contribute to feral pig control within the threatened habitat, (b) study the role of fire on the ecology of the threatened plant (if possible without further threatening remaining populations), and (c) consider the likely horticultural value of the threatened plant as a way of sponsoring management efforts. Control budget required was considered to be *c.* $10 000 in the first year, with reduced amounts in subsequent years when the nearby broom infestation has been removed and the surveys completed.

General discussion

Biological control was the first focus of extensive discussion. It is still the only option for the bulk of large infestations in Australia – any other method was prohibitively expensive – despite a risk that biological control will not work and a long time frame for implementation.

To date, the biological control program in Australia has resulted in the release and establishment of three biological control agents. Two further agents are in quarantine and two more are still under investigation in the native range. The first agent to be released in Australia, the twig mining moth, was released in 1993 (Syrett *et al.* 1999). None of the agents are yet in large enough numbers to be causing much damage in Australia. While this is disappointing, as each insect species has only one generation a year, it is not unexpected. The likely long-term damage caused by three of these potential agents in New Zealand and Oregon is high (S. Fowler and D. Isaacson personal communication), although for some species it may take anything from 5 to 30 years to have a significant impact. Nonetheless, the evidence to date does not support any idea that an effective suite of agents has already been introduced anywhere in the world to combat broom. For this reason the collaboration between Australia, New Zealand and the Oregon Department of Agriculture continues to support screening and evaluation of new agents. The most promising of these are currently a gall mite (*Aceria genistae* Nalepa), which can kill plants and greatly reduces the growth rate of the weed, and the gall fly (*Hexomyza sarothamni* (Hendel)), which is known to be extremely specific and, without a large complement of parasites, may restrict broom growth.

New funding sources are required, however, as the core sponsors over the last nine years (NSW National Parks and Wildlife Service, Ellerston Pastoral Company and State Forests of NSW) will not be able to maintain the same level of support for the program. A number of other organizations represented at the workshop expressed interest in contributing to the biological control program. A key outcome of the workshop was the recommendation that the future management of the broom biological control program moves from being NSW-based to a National program managed by the CRC for Weed Management Systems.

For national park and state forest areas on the Barrington Tops plateau, funds are still needed for chemical control of broom in priority areas: roads and access tracks, high visitation areas, and threatened species habitats. Such a management approach is expensive and is not sustainable in the long-term, but essential to contain broom infestations while biological control is given a chance to work.

There are more options for broom control on-farm. Discussion revisited information presented in the talks pointing towards the benefit of fencing broom areas into small paddocks and grazing these areas with Boer and milking goats. These goats have been domesticated for many years and have shorter legs than feral or Angora goats. As such, they are more easily contained and they browse broom and shrubs in preference to grasses and legumes. Similarly the benefits of mulching broom and using the mulch to delay regeneration were also discussed (Talbot 2000), especially if combined with oversowing of perennial grasses, although the cost of mulching at *c.* \$1000 ha^{-1} was too high for most agricultural situations.

Use of fire to control broom was also discussed. It appeared that more research was needed before this became a recommended management tool. A concern with the use of fire was the observation that rate of linear spread from an existing infestation can double following fire (P. Downey personal communication). In farming situations it has a use to remove the bulk of the broom and encourage germination of broom seed prior to use of chemicals or goats. Discussions on chemical control supported information from the presentations that this is effective in the short term, but remains expensive and needs to be followed up for many years until the seedbank has been depleted. Nobody treating areas where plants had seeded for a number of years had managed to reach the stage where seed no longer germinated. This was despite control being carried out continuously for over 20 years or more (Smith 2000). There are also significant risks of herbicide damage to non-target species growing amongst broom. Such species need to be encouraged as replacement vegetation.

A major concern with landholders was that broom control on private properties was required by law and imposed by local councils. The councils, however, still expect control measures applied by landholders to be immediate, thus favouring short-term effective, but long-term ineffective control options such as greater use of herbicides. The risk of prosecution is driving this. There was a perceived need by many present to educate local authorities in the need for long-term management practices. Assistance from these authorities and an understanding of what can be achieved on individual properties would also aid long-term control. Arranging field days to demonstrate the effectiveness of long-term integrated strategies over short term, quick-fix strategies is a perceived need in the farming community and is outlined as a recommendation of this workshop.

The workshop provided participants with information about methods that others had used to manage broom. The workshop also provided contacts for future exchange of information on control techniques. The outcomes of this workshop are summarized in Table 3. The proceedings provides a permanent record of most of these discussions.

Table 3. Outcomes and recommendations from the workshop.

	Outcomes and recommendations
1.	A series of 'best bet' management strategies were developed to manage broom infestations in 6 realistic situations where it causes problems in Australia: (a) a National Park, (b) in a catchment, (c) an infested township, (d) in commercial forestry, (e) on a cattle farm, (f) as a threat to rare plants (see text for details).
2.	It was recommended that efforts to complete a biological control program be continued with a shift in funding and priorities from a state-based to a National program under the auspices of a national body e.g. the CRC for Weed Management Systems, which includes all the state and federal research organizations involved in broom biological control research and extension work.
3.	Further research was required for the development of situation-focused broom management strategies involving existing knowledge on the effectiveness of herbicides, mechanical removal, fire, goats and revegetation.
4.	Arranging field days to demonstrate the effectiveness of long-term integrated strategies over short term, quick-fix strategies to educate local authorities in the need for long-term management practices. Assistance from these authorities and an understanding of what can be achieved on individual properties would also aid long-term control.

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References

Atchison, C.J. (1986). Broom workshop proceedings. Barrington Tops State Forest and National Park, 22–23 February 1986. Unpublished report. New South Wales National Parks and Wildlife Service.

Barnes, C.D. and Holz, G.K. (2000). Broom (*Cytisus scoparius* (L.) Link) competition and management in eucalypt tree farms. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 163-5.

Hore C. (2000). Herbicides for broom (*Cytisus scoparius* (L.) Link): testing alternatives to Grazon®. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 167-8.

Hosking, J.R., Smith, J.M.B. and Sheppard, A.W. (1998). *Cytisus scoparius* (L.) Link ssp. *scoparius*. *In* 'The biology of Australian weeds' Volume 2, eds F.D. Panetta, R.H.Groves and R.C.H. Shepherd, pp. 77-88. (R.G. and F.J. Richardson, Melbourne).

Shea, K., Amarasekare, P., Mangel, M, Moore, J., Murdoch, W.W., Noonburg, E., Parma, A., Pascual, M.A., Possingham, H.P., Wilcox, W. and Yu, D. (1998). Management of populations in conservation, harvesting and control. *Trends in Ecology and Evolution* 13, 371-5.

Smith, J.M.B. (2000). An introduction to the biogeography and ecology of broom (*Cytisus scoparius*) in Australia. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 140-4.

Syrett, P., Fowler, S.V., Coombs, E.M., Hosking, J.R., Markin, G.P., Paynter, Q.E., and Sheppard, A.W. (1999). The potential for biological control of Scotch broom (*Cytisus scoparius* (L.) Link) and related weedy species. *Biocontrol News and Information* 20, 17-34.

Talbot E. (2000). Cutting and mulching broom (*Cytisus scoparius* (L.) Link): a Tasmanian perspective. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 183-5.

Raising awareness of the broom (*Cytisus scoparius* (L.) Link) problem on the Barrington Tops, New South Wales

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Summary
Awareness of broom as a problem on the Barrington Tops increased following action of the Barrington Tops Advisory Committee and the Barrington Tops Broom Council. This paper describes how publicity and public pressure generated by these groups led to the commencement of a biological control program for broom and illustrates how support can be generated for the management of environmental weeds.

Introduction
When the Barrington Tops National Park in New South Wales (NSW) was established in 1969 there were many hectares of broom, *Cytisus scoparius* (L.) Link, established within its boundaries. The New South Wales National Parks and Wildlife Service (NPWS) surveyed the extent of the problem and sought help from the New South Wales Department of Agriculture and chemical companies. For the next ten years there followed a period of trial and error. However in 1980 and 1981 the use of 2,4,5-T (active ingredient 2,4,5-trichlorophenoxy acetic acid) to spray broom was suspended because of high levels of 2,4,5-T in urine of park workers and damage to native plants caused by the spray. The broom control program had always been limited by the season and the weather. The Forestry Commission also had a major broom problem and used Garlon® (active ingredient triclopyr) on areas close to water and walking trails and 2,4,5-T elsewhere. The Forestry Commission also tried slash, burn and spray but the regrowth was considerable.

Barrington Tops Advisory Committee
The Barrington Tops Advisory Committee for the national park was formed in about 1972. Advisory committees, which initially comprised of community representatives, are appointed by the New South Wales government through the Minister for Planning and the Environment. These Committees advise the Minister via the departmental head who runs the NPWS.

By November 1983 the Barrington Tops Advisory Committee was being told that funding for the broom program is 'something of a lucky dip' and $10 000 was put up in the budget and for the first time in eight years this was refused and not included in the NPWS estimates to Treasury. The Regional Director of NPWS then reintroduced the broom item during the allocation of Capital Works Grants and hoped for Ministerial approval. That $10 000 had already been put up as collateral for a Commonwealth Employment Program grant and as this was a four to one allocation it was well worth the gamble. The NPWS would either have $50 000, or nothing, to spend on broom control. At this time control measures were hit and mainly miss. Fortunately the money came through that year.

By 1985 the Barrington Tops Advisory Committee decided that the broom problem was becoming serious on the plateau and more reports were coming in of broom colonizing waterways leading off the plateau. These plants at lower altitude appeared to be able to set viable seed. The Committee suggested to NPWS that some of the broom funding be diverted to holding a Broom Workshop to which we would invite as many experienced people as we could from the academic world, neighbouring landholders and local weed control bodies. On 22–23 February 1986, some 27 people came together to camp at Little Murray and put their collective thoughts forward. To those people we are all indebted.

The Broom Council
From that workshop the Committee decided that: (a) there be a regional body formed called The Broom Council, (b) the Council would restrict its charter to the study of broom, (c) membership of the Council would include one person from each of the organizations initially invited to the Broom Workshop, with the power to co-opt extra relevant people (d) the Council be an autonomous advisory and coordinating body, however each member organization must retain responsibility for broom control on its own lands, and (e) the Council would work towards long term biological control of broom.

With NPWS agreement the first meeting of the Broom Council was held at Gloucester on the 24 March 1987, and the following attended:

- Barrington Tops Advisory Committee *Bev Adams, Margaret Mason*
- Scone Shire Council *Doug Collison*
- Upper Hunter Pasture Protection Board *Ken England*
- Hunter Pastoral Company (HPC) *Tony Clark*
- Dungog Shire Council *Eric Pasenow, Des Hopson*
- Gloucester Shire Council *Bruce Redman*
- Gloucester Pasture Protection Board *Bill Carter*
- NSW Department of Agriculture (Gloucester) *John Britton*
- NSW Forestry Department (Gloucester) *Tony Yates, John Freeman*
- NSW Soil Conservation Service *Mike Fletcher*
- Hunter Valley Conservation Trust *Ian Furner*
- Hunter District Water Board *Col McKenzie*
- NPWS *Carl Atchinson, John Trudgeon, Peter van Herk*
- Flick and Company *Peter Edlick*

Those elected to form the executive were Tony Clark as chairman, Carl Atchinson as deputy-chairman / secretary and Tony Yates as publicity officer.

The committee decided that the functions of the Broom Council were to:

(a) act as a forum for the co-ordination of control activities, information and research relating to broom,

(b) foster public awareness of broom and to build public support for its long term control, and

(c) work towards this long term control through biological agents.

In general business, the three organizations represented by the executive (HPC, NPWS and NSW Forestry Department) discussed their recent commitment to the destruction of broom, and a round figure of $450 000 was estimated as the overall cost. All agreed that the present methods of control were both costly and inadequate.

Biological control
The Barrington Tops Advisory Committee determined that CSIRO research capacity was needed, however, the thrust of CSIRO research was towards weeds of economic significance, particularly pasture weeds, whereas the invasion of broom was largely of environmental concern. However, if funding was available the research might become a higher priority.

A motion was carried that the Council write to the Chairman of CSIRO, Neville Wran, asking him to review CSIRO Plant Industry work on environmental weeds (by Dr. R. Groves) and requesting that CSIRO reconsider biological control research of broom. The Council also requested that the executive ascertain the costs of producing a single page information leaflet, in colour, which could be circulated to relevant organizations, e.g. 4WD Clubs, National Parks Association and Shires. The Forestry Department subsequently published such a sheet. The

Council met every three months, collected data on the broom distribution and continued a campaign to foster public awareness.

Then came a stroke of luck! The Chairman of CSIRO, Neville Wran, was to be guest speaker at a dinner of my old school, Fort Street, at the beginning of October 1987. This gave me an opportunity for some personal contact with Mr. Wran placing the case for research factually before him. During this discussion it was suggested that Mr. Wran might contact HPC and a helicopter trip was arranged as the best way to see the invasion of the weed was from the air. As a result Mr. Wran inspected the area in November 1987 when broom flowers were at their best.

Then followed publicity of a sort the Broom Council could not generate. Deputy Leader of the National Party in the Federal Parliament, Mr. Bruce Lloyd, accused Mr. Kerry Packer (Proprietor of HPC) and Mr. Wran of cronyism in question time in the Legislative Assembly. The media ran the story for twenty-four hours with the television and the papers *concentrating* on the visit. Suddenly everyone knew about and saw in flower broom on the Barrington Tops. Immediate retractions were demanded and received, so the media publicity continued for another few days.

The Shires of Scone and Gloucester wrote to the Leader of the National Party, Ian Sinclair, to acquaint him with details of the Broom Council and its work. State Member for Scone, Colin Fischer, went on radio and issued a press statement and also wrote to Mr. Wran commending him for his 'genuine attempt to observe at first hand this pernicious and insidious noxious plant'. The Broom Council had now achieved aims (a) and (b) and set about gaining aim (c), a program for biological control, funded by government departments and the HPC.

After a change of government in the NSW State election in 1988, the Broom Council invited the Minister for Agriculture and Rural Affairs (the Honourable Ian Armstrong), the Minister for the Environment (the Honourable T. Moore) and the Minister for Natural Resources (the Honourable Ian Causley) to come to see for themselves the current and potential broom problem on the Barrington Tops. Local members were aware that representatives from the Broom Council had attended National Party Meetings in their electorates and had promulgated the necessity for government action to be taken immediately if the broom infestation was to be contained in the future.

The three ministers and two local members, members of the Broom Council, the Advisory Committee, the NPWS, and the Forestry Department gathered at Polblue half way through 1988 and with the assistance of two helicopters donated by HPC flew on a surveillance tour of the area covered by broom. All costs up to this point in time had been borne by individual members of the Broom Council or the two Departments, NPWS and Forestry.

The Broom Council told the Ministers that the Council's estimated cost of establishing a broom biological control program would be approximately $78 000 in year 1, $174 000 in year 2 and $141 000 in year 3 and subsequent years. CSIRO and HPC had committed themselves and it was hoped the NSW government would do so as well. By 19 October 1988 there was a joint submission from the Ministers for Agriculture and Rural Affairs, the Environment, and Natural Resources for a special allocation to partially fund a research project by NSW Agriculture and CSIRO to develop a broom biological control program. Accordingly it was recommended that special allocations be made over the next three financial years to meet two-thirds of the estimated costs of the research program. This amounted to $38 000 in 1988/89, $125 700 in 1989/90 and $108 500 in 1991/92.

The Broom Council had now completed all three functions that it had set out to achieve in its first two years.

Conclusion

The Barrington Tops Advisory Committee and the Barrington Tops Broom Council managed to raise awareness of broom as a problem on the Barrington Tops through publicity and public pressure. As a result funds were committed in 1989 for a biological control campaign. This paper describes activities necessary to generate State government support for projects aimed at controlling invasion of key environmental weeds in National Parks.

An introduction to the biogeography and ecology of broom (*Cytisus scoparius*) in Australia

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Summary

Broom (*Cytisus scoparius* (L.) Link), a shrub with several uses in its native Europe, was first introduced to Australia in about 1800 and has now become widely established at many places in moist, cool temperate regions. Single populations are probably rather uniform, but there are genetic variations between populations reflecting multiple introductions. Herbivores, both native and released in a biocontrol program, have so far had little impact. At Barrington Tops (New South Wales), the largest Australian infestation, undisturbed stands in eucalypt woodland expand at *c.* 0.5 m per year. Seed dispersal by animals, vehicles or other agents leads to establishment of new, distant populations. Older plants become prostrate, with thinning eventually leading to patchy regeneration. Major disturbance results in massive regeneration. Broom may have substantial ecological impacts upon regeneration of overstorey trees, survival of understorey plants, and fauna.

Introduction: broom in Australia

Broom (*Cytisus scoparius* (L.) Link) is a member of tribe Genisteae, family Fabaceae, a group of shrubs predominantly native to the Northern Hemisphere. No members of this tribe occur naturally in Australia. However, several species are naturalized here, those of greatest concern (so far) being broom, Montpellier broom (*Genista monspessulana* (L.) L.A.S.Johnson) and gorse (*Ulex europeus* L.) (Hosking *et al.* 1998). Of these, broom is arguably the most serious invader, being widespread in southeastern Australia in little-disturbed as well as in pastoral and peri-urban environments. Montpellier broom, though widespread, is predominantly an invader of relatively disturbed sites, and gorse is significant only within a more limited, southern range.

Broom forms a novel, dense shrub layer in grasslands and open forests, shading out understorey plants, affecting animal distributions and populations, and having serious impacts on various human activities. Its canopy provides a foliage projective cover usually exceeding 50%, and in eucalypt woodland at Barrington Tops its above-ground biomass (of which 13–27% is in the form of green shoots) has been recorded at 0.26–2.63 kg m^{-2} (Hosking *et al.* 1998). Similar values of 1.6 and 2.1 kg m^{-2} have recently been reported in northwest Tasmania (Barnes and Holz 2000), respectively in and between tree rows in young eucalypt plantations.

Although broom is still expanding its range, population, and impact in

Australia, there is hope that its advance will not be inexorable. It appears inevitable that sooner or later native insects or other organisms will adapt their behaviour or physiology to cope with the plant's chemical defences and take advantage of the ecological opportunity offered by this novel, huge source of nutrition. Evolutionary changes permitting herbivores and pathogens to exploit a new food source have been noted in many other cases over timespans of the order of a century or less (Thompson 1998). It is encouraging to note that some native Lepidoptera already sporadically use broom as a larval foodplant, and that garden plants of Spanish broom, *Spartium junceum* L., are damaged extensively by caterpillars of one species (tree lucerne moth, *Uresiphita ornithopteralis* (Guenée), Common 1990), particularly in the Guyra area where they can only be kept alive by repeated use of insecticide.

It is hoped that such a process of bringing broom into better ecological balance within its invaded Australian range will be accelerated using biocontrol, through importation of European species preadapted to feeding on broom. Three insects have already been released (Hosking *et al.* 1998) but have yet to multiply and have a significant impact.

Distribution and uses of broom

Broom's native distribution extends from southern Scandinavia to the Azores, and from Europe's Atlantic coast to Hungary and Ukraine. It commonly grows at higher, cooler altitudes in the more southerly parts of this range. Nevertheless, it straddles a wide spectrum of climatic conditions, and no doubt has a correspondingly wide range of climatically adapted ecotypes. It is not known precisely where Australian broom populations originated, although Britain seems most likely for cultural and communication reasons. Broom has also been introduced to and become naturalized in North America, New Zealand, South Africa, Hawaii, Iran, Japan and India, and is a major pest species in the first two of these places.

In Britain the plant had many uses which would have led to a desire to grow the plant in the new colonies. These included: source of fibre and dye; browse for sheep, goats and deer; a substitute for hops; as well as the manufacture of brooms as its name implies (Usher 1974). Elsewhere in Europe its pickled buds provided a substitute for capers, and its seeds a substitute for coffee (Hedrick 1972). In India, broom has been used as a nurse crop in plantations of *Eucalyptus* and *Acacia*, providing protection from wind and frost, as well as perhaps enhancing the nitrogenous content of soils (Chinnamani *et al.* 1965). In Japan broom has been used for post-fire erosion prevention (Nemoto *et al.* 1993), and in Oregon it was used to stabilize littoral dunes (Isaacson 2000). It has also been widely employed as an ornamental shrub.

Broom foliage contains a variety of alkaloids which have led to its having several medicinal uses (Waterhouse 1986, 1988), but which have also resulted in mild poisoning in grazing animals (Clark 2000, Parsons and Cuthbertson 1992). Grey kangaroos and feral horses browse the plant on Barrington Tops (New South Wales) and keep isolated plants well trimmed, although they soon move on to other feed and have no controlling influence on the plant where it is abundant. Goats and to a lesser extent sheep browse the plant more consistently and can be used for effective control in pastoral situations (Clark 2000, Sheppard, Hosking and Leys 2000).

Broom has probably been introduced repeatedly to Australia, although little is known of its early history here. The first Australian reference to the species appears to be in the form of a request for seeds made by Governor P.G. King in 1798, to be grown and used as a substitute for hops. Broom was apparently growing luxuriantly in the colony only a few years later (Parsons 1981). Subsequent introductions were made for the horticultural trade, and these have included cultivars most of which are hybrids with other species. Broom hybrids are still freely available at plant nurseries in Australia, with about 250 000 plants being sold annually (Atkinson and Sheppard 2000).

The present range of wild broom in Australia includes regions of moist, cool temperate climate in eastern New South Wales, Victoria, Tasmania, the Adelaide Hills area of South Australia and suburban Perth. Overall it infests more than 200 000 ha (Hosking *et al.* 1998) but this represents only a small part of its potential range. For example, in northern New South Wales there are many areas ecologically very similar to Barrington Tops, such as the Walcha pastoral district, and Ben Halls Gap, Mt. Kaputar and New England National Parks, where broom has not been reported.

Genetics of Australian broom

The genetic variation between and within broom populations in Australia is unresearched, but such an investigation would be worthwhile. Most Australian naturalized broom is clearly *C. scoparius* without hybrid introgression. Nevertheless, there is certainly some genetic variation between populations which probably reflects separate introductions from Europe. For example, I raised broom plants from seed collected at both Barrington Tops and at Ebor (New South Wales). Two individuals from each place were grown to maturity side by side in Armidale. Plants from the two sources differed slightly but consistently in date of flowering, foliage colour, and overall shrub shape. (The plants were destroyed after about ten years, but not before leaving a large and troublesome seedbank). In Tasmania, subalpine Victoria, the Blue Mountains (New South Wales) and sporadically elsewhere, wild broom populations include individuals with red lateral petals instead of having the more common all-yellow flowers.

Despite such inter-regional variability, genetic variation within individual Australian broom populations is likely to be narrow due to their having very small founder populations (that at Barrington Tops, for example, thought to have been a single pot plant, later planted in a garden – Waterhouse 1986, 1988). This lack of local variability presumably makes plants in any particular population relatively narrow in their potential ecological tolerance, but raises the possibility that cross-pollination with plants of other provenance might have the effect of broadening such tolerance.

Many garden hybrid brooms, which have a wide range of flower colours, produce relatively few seeds and are far less invasive than the more vigorous pure broom. However, they might have considerable potential significance in that they include genetic material from species with more southern distributions in Europe, having greater adaptation to warm, dry conditions. Broom in Australia is apparently restricted by climatic factors, for example plants growing from seeds transported by rivers off Barrington Tops to warmer sites at much lower altitudes are not vigorous, and so far appear to be restricted to moist, riverine sites. It is possible that although the plant is now ecologically unsuited to the relatively warm, dry environments away from those riverine sites, acquisition of genetic material by cross-pollination with horticultural hybrids in or near gardens might provide such ecological capacity.

Range expansion

Broom has been extending its Australian range since introduction. At Barrington Tops its initial introduction to the property 'Tomalla' in the 1840s was followed by spread to the forested plateau where it was becoming a concern by the early 1960s, and it expanded rapidly after cattle removal in the late 1960s (Hosking *et al.* 1998, Waterhouse 1986). Broom is presently spreading in the Bogong High Plains of Victoria, where it was not conspicuous until after removal of cattle in 1992 (Hore 2000), although there as well as in other places its expansion is now being curtailed at least to some degree by herbicide applications (Robertson *et al.* 1999). The apparent acceleration of its spread in Australia in recent decades is paralleled by its history in New Zealand where most spread (which is continuing) has also occurred in the past thirty years (Fowler and Syrett 2000).

It is convenient to consider range expansion under two headings, stand expansion and jump dispersal (Figure 1), although the two are not discrete processes except in scale. Stand expansion occurs as a population expands its contiguous area by an incremental process of repeated short-distance dispersal. Jump dispersal is accomplished when an individual (leading to a population) becomes established at a distance from the parent population after a (relatively) long-distance dispersal event, with a gap of uncolonized space remaining (at least temporarily) between the parent and daughter populations.

Stand expansion

Most broom seeds are dormant at the time of their explosive release from the pods, which flings them up to 5 m. They may then be collected by ants attracted to an oily caruncle which acts as an elaiosome, and carried by them a further 1 m (Smith and Harlen 1991). That the great majority of seeds is dispersed initially within a few metres of parent plants is confirmed by Robertson *et al.* (1999) who have mapped seedlings only up to about 10 m from burned, mature broom stands on the Bogong High Plains. Dispersal on this scale, together with growth and lean of shrubs within the stand, leads to stand expansion into surrounding, previously uncolonized habitat.

Stand expansion is not rapid under conditions of low disturbance. Four permanent plots have been monitored nearly annually for more than twelve years in eucalypt woodland near Polblue Swamp, Barrington Tops (Downey and Smith, in press). At two of these plots, which initially straddled the edges of broom stands, stand expansion occurred at a rate of only about 0.5 m per year. Disturbance accelerates the process by increasing rates of seed germination and seedling establishment, so that after fire, herbicide treatment or physical disturbance, regrowing stands may be both denser (Moodie 1985) and larger (Robertson *et al.* 1999) than before the disturbance.

Jump dispersal

Initial broom colonization of Australia can be considered to be a human-mediated case of jump dispersal at the largest scale. The expansion of broom's range to the Barrington Tops plateau provides an example on a regional scale: helicopter mapping of broom in this area has shown that there are two discrete, large populations. The first is the original population in and near the pastoral area to the north, derived by spread from the first planting at 'Tomalla'. The second lies to the southwest, on the mainly forested plateau and including large parts of Stewarts Brook State Forest and Barrington Tops National Park, almost certainly derived from the first by dispersal of seeds internally or externally by cattle or horses. Other, more recent long 'jumps', in this case probably through seeds adhering in mud to footwear and logging equipment, or possibly by mammals, have been noted (and daughter populations eliminated) elsewhere in this region, at Gloucester Tops and Giro State Forest.

At a local scale, jump dispersal commonly leads to establishment of individuals tens or hundreds of metres from seeding stands, due to occasional seed dispersal by mammals (pigs and horses – Smith and Harlen 1991, sheep – Clark 2000, probably cattle and possibly macropods) ingesting seeds and passing them in viable condition, in streams, or by humans or their vehicles and equipment. Scattered broom shrubs in grassland areas at Barrington Tops are thought to have been mainly a result of dispersal by feral horses (Smith and Harlen 1991).

Populations derived from such isolated broom plants may eventually coalesce with the original stand as both spread towards each other in a process of infilling. They can also be the sources for further jump dispersal events. At Barrington Tops control efforts using herbicides and through pulling have focused on the eradication of such outlying plants, especially where they occur in places where their seeds might more readily find dispersal agents (e.g. at campsites and along roadsides).

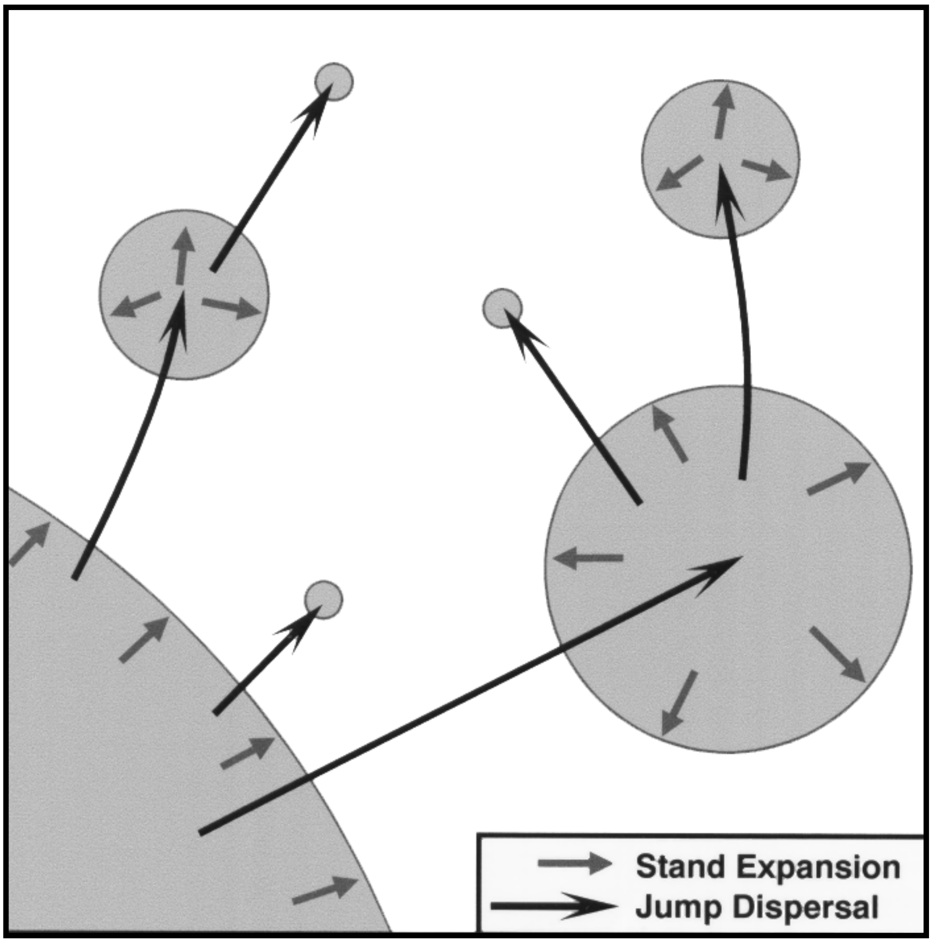

Figure 1. Conceptual model of the processes of range expansion in an invading species such as broom.

Persistence

The process whereby broom regenerates and thereby persists at a site after initial invasion is relevant to management, especially in places of conservation significance where attempted control measures such as heavy grazing, herbicide, fire or other large disturbances are inappropriate or difficult to apply. Broom plants may live up to at least 27 years at Barrington Tops (Downey and Smith, in press), and all regeneration is by seed rather than by vegetative means.

Seed dynamics

Broom seed production has been measured in New South Wales at 28–356 and 107 seeds m^{-2} per year on broom plants below a eucalypt canopy at Barrington Tops and at Deua National Park respectively, and at 8885 and 7700 seeds m^{-2} per year away from overstorey trees at Deua (Hosking *et al.* 1998) and Armidale (Smith and Harlen 1991) respectively. These values are greatly in excess of the minimum necessary for stand replacement, supported by the observation of abundant seedlings appearing within broom stands every year. As a contrast, the relatively common and widespread native fabaceous shrub, sweet wattle, *Acacia suaveolens* (Smith) Willd. (which has similar-sized, hard seeds, and also depends on seedling establishment for its persistence) was found by Auld and Myerscough (1986) to produce annually only about four seeds per plant. This seems to cast doubt on whether curtailment of broom seed production by biocontrol agents is likely to have any practical effect, other than a possible reduction in the frequency of jump dispersal.

The reservoir of dormant seeds accumulating in the soil beneath and near broom stands is undoubtedly the principal factor making broom control so intractable. Broom plants are easy to kill with herbicides, burning, slashing or pulling, and resprout poorly from stumps. However, any disturbance which exposes surface soil to the temperature variations resulting from direct sunlight and nocturnal radiative cooling leads to partial germination of the soil seedbank. If they are adequately lit and do not experience drought, seedlings establish well, and a broom thicket quickly returns to the site usually at higher density than previously (Moodie 1985). This regrowth needs to be killed within four years of the original disturbance before it produces further seeds, but even if this is achieved, seeds from the original seedbank will continue to germinate for many more years, requiring repeated treatment. At a campsite near Polblue Swamp, Barrington Tops, broom seedlings still appear twenty years after the site was cleared of broom, even though no further plants have been allowed to develop to maturity during that period.

Broom soil seedbanks in Australia have been measured at values ranging from 190 to 50 000 seeds m^{-2}, values comparable to those found within the plant's native range (Hosking *et al.* 1998). At Barrington Tops, Mihe (1992) found that up to 40% of seeds were in soil deeper than 5 cm. While such seeds might be too deep for developing seedlings to emerge above the soil surface, they are also less likely than shallowly buried seeds to have their germination triggered by variations in temperature or moisture. They might therefore be expected to remain dormant for extended periods, perhaps until moved closer to the surface by digging animals or other agents, posing long-term difficulties for control operations.

With widening recognition of broom's importance, and in order to curb its spread, control measures have been more vigorously adopted in recent years, particularly herbicide application to small, isolated populations. There is an annual program to locate and destroy regenerating broom at known, marked sites in Kosciuszko National Park (L. Knutson personal communication). If such measures are not maintained, regeneration is likely to lead within a few years to further accessions to the soil seedbank. For example, roadside broom plants were flowering again in 1998 at Glencoe and Ebor in northern New South Wales despite destruction of plants at those sites about four years earlier.

Broom stand dynamics at Barrington Tops

Observations in permanent plots in broom-invaded eucalypt forest at Barrington Tops over more than ten years (Downey and Smith, in press) indicate that broom shading curbs regeneration by broom itself (as well as by many members of the native flora) until the original plants progressively senesce and die to the point where their canopy is significantly opened. Broom seedlings are observed continually at earlier stages, but rarely survive for more than a few weeks or months. The original broom plants, as they age, collapse from their previously erect form to become prostrate, with stems lying along the ground for more than five metres to terminate in green, fertile crowns some two metres in height. At Barrington Tops their collapse is accelerated by falls of heavy, wet snow (Smith 1994a). Over a period of about thirty years from initial invasion, the population comprises progressively fewer, larger and more prostrate individuals (Figure 2). The process of collapse results in crowns falling across each other, the lower of which dies, forming gaps in the previously nearly continuous broom canopy (Smith 1994a). Only when such gaps occupy at least half of the area, and significant sunlight penetrates to the ground, do new broom individuals become established (Downey and Smith, in press).

It seems probable that in forested areas of the Barrington Tops plateau, without intervention, eventually a stable, mixed-age broom population will develop. This permanent broom layer in the vegetation (although less dense than first generation, single-age broom stands, or stands resulting from major disturbances) will have far-reaching ecological consequences. These may include local extinction of rare herbaceous plants (Heinrich and Dowling 2000); thinning or elimination of the eucalypt canopy by prevention of eucalypt regeneration (Waterhouse 1986, 1988); invasion by rainforest plants into former eucalypt woodland (Smith 1994a); multiplication of feral pigs with resultant physical and biotic disturbance; increase in numbers of some native birds (Bell 1990); and invasion by alien birds (Smith 1994b).

In more open sites, it appears that while some physical disturbance is necessary for establishment of new broom plants, small natural disturbances (e.g. animal grazing, digging or trampling) are sufficient to allow range expansion to occur even in the complete absence of human activities. More substantial disturbance leads to massive seedling establishment wherever broom seeds are present, resulting in the creation of dense new broom stands (Moodie 1985) from germination of part of the large, long-lived soil seedbank (Mihe 1992, Smith and Harlen 1991) accumulated beneath former stands. It has been suggested (P. Downey, personal communication 1997, Robertson *et al.* 1999,

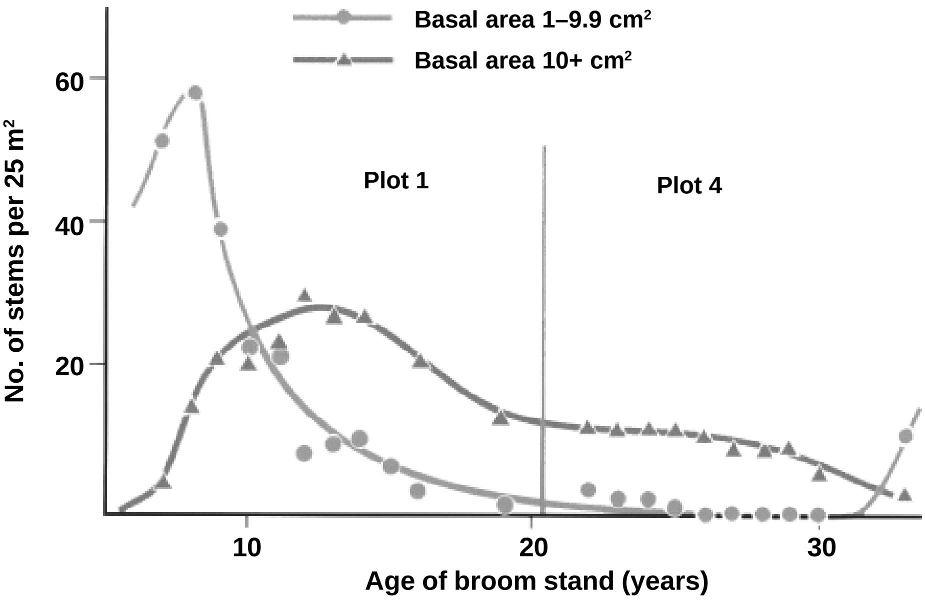

Figure 2. Numbers of live broom plants in two size (basal area) categories in two 5 × 5 m permanent plots near Polblue Swamp, Barrington Tops, over periods of thirteen and twelve years respectively.

Sheppard, Hodge and Paynter 2000) that fire might be employed to stimulate germination to the extent that herbicidal or other treatment of the dense regrowth might then lead to substantial control. Downey (2000) has found up to 80% reduction in the soil seedbank of broom after fire. However, it has yet to be demonstrated that this will lead to sufficient reduction in subsequent broom regeneration to be a useful control tool, and in any case fire is not easy to use in many situations.

References

Atkinson, I. and Sheppard, A. (2000). Brooms as part of the Australian nursery industry. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 176-8.

Auld, T.D. and Myerscough, P.J. (1986). Population dynamics of the shrub *Acacia suaveolens* (Sm.) Willd.: seed production and predispersal seed predation. *Australian Journal of Ecology* 11, 219-34.

Barnes, C.D. and Holz, G.K. (2000). Broom (*Cytisus scoparius* (L.) Link) competition and management in eucalypt tree farms. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 163-5.

Bell, S.A.J. (1990). Effects of the weed Scotch broom on bird communities in open forests on Barrington Tops. B.Sc. Hons Thesis, Dept. Geography, University of Newcastle.

Chinnamani, S., Gupte, S.C., Rege, N.D. and Thomas, P.K. (1965). Afforestation with broom as a nurse crop. *Indian Forester* 91, 573-6.

Clark, A. (2000). Controlling broom (*Cytisus scoparius*) in pasture on the Barrington Tops – a graziers perspective. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 161-2.

Common, I.F.B. (1990). 'Moths of Australia', p. 358. (Melbourne University Press, Melbourne).

Downey, P. (2000). Broom (*Cytisus scoparius* (L.) Link) and fire: management implications. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 178-83.

Downey, P.O. and Smith, J.M.B. (In press). Demography of the invasive shrub Scotch broom (*Cytisus scoparius*) at Barrington Tops, New South Wales: insights for management. *Australian Journal of Ecology*.

Fowler, S. and Syrett, P. (2000). Status of broom in New Zealand. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 148.

Hedrick, V.P. (ed.) (1972). 'Sturtevant's edible plants of the World.' (Dover Publications, New York).

Heinrich, A. and. Dowling, B. (2000). Threats to the rare and threatened plant species of Barrington Tops. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 172-6.

Hore, C. (2000). Herbicides for broom (*Cytisus scoparius* (L.) Link): testing alternatives to Grazon®. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 167-8.

Hosking, J.R., Smith, J.M.B. and Sheppard, A.W. (1998). *Cytisus scoparius* (L.) Link ssp. *scoparius*. *In* 'The biology of Australian weeds', Volume 2, eds F.D. Panetta, R.H. Groves and R.C.H. Shepherd, pp. 77-88. (R.G. and F.J. Richardson, Melbourne).

Isaacson, D.L. (2000). Impacts of broom (*Cytisus scoparius*), in western North America. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 145-8.

Mihe, T. (1992). 'The density and distribution with depth of the soil seed bank of broom (*Cytisus scoparius*) on Barrington Tops NSW'. B.Nat.Res. Project Report, University of New England, Armidale.

Moodie, J.C. (1985). An evaluation of control techniques for broom (*Cytisus scoparius*) on Barrington Tops. B.Nat.Res. Project Report, University of New England, Armidale.

Nemoto, M., Nakagoshi N., Horie, H. and Nishimura N. (1993). Allelopathic potential of broom (*Sarothamnus scoparius*) dominating post-fire stands in southwest Japan, Proceedings of the 10th Australian Weeds Conference and 14th Asian Pacific Weed Science Conference 1, 333-8 (Weed Society of Queensland, Brisbane).

Parsons, W.T. (1981). The history of introduced weeds. *In* 'Plants and Man in Australia', eds D.J. and S.G.M. Carr, pp. 179-93. (Academic Press, Sydney).

Parsons, W.T. and Cuthbertson, E.G. (1992). 'Noxious weeds of Australia'. (Inkata Press, Melbourne and Sydney).

Robertson, D.C., Morgan, J.W. and White, M., (1999). Use of fire to enhance control of English Broom (*Cytisus scoparius*) invading a subalpine snowgum woodland in Victoria. *Plant Protection Quarterly* 14, 51-6.

Sheppard, A.W., Hodge P. and Paynter Q. (2000). Factors affecting broom regeneration in Australia and their management implications. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 156-61.

Sheppard, A.W., Hosking J.R. and Leys, A.R. (2000). Broom (*Cytisus scoparius* (L.) Link) population management strategies. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 134-9.

Smith, J.M.B. (1994a). The changing ecological impact of broom (*Cytisus scoparius*) at Barrington Tops, New South Wales. *Plant Protection Quarterly* 9, 6-11.

Smith, J.M.B. (1994b). Blackbirds reach Barrington Tops. *Australian Birdwatcher* 15, 273-5.

Smith, J.M.B. and Harlen, R.L. (1991). Preliminary observations on the seed dynamics of broom (*Cytisus scoparius*) at Barrington Tops, New South Wales. *Plant Protection Quarterly* 6, 73-8.

Usher, G. (1974). 'A dictionary of plants used by Man'. (Constable, London).

Thompson, J.N. (1998). Rapid evolution as an ecological process. *Trends in Ecology and Evolution* 13, 329-32.

Waterhouse, B.M. (1986). '*Cytisus scoparius* (Broom) on Barrington Tops.' B.A. Hons. Thesis, University of New England, Armidale.

Waterhouse, B.M. (1988). Broom (*Cytisus scoparius*) at Barrington Tops, New South Wales. *Australian Geographical Studies* 26, 239-48.

Impacts of broom (*Cytisus scoparius*) in western North America

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Summary

There are many economic and ecological consequences of the success of the introduced weed, broom (*Cytisus scoparius*), in western North America. Results of a survey of landowners and managers involved in forest regeneration and with roadside vegetation management are presented, and some ecological impacts are described and their extent is discussed. While there are some positive economic impacts, the negative effects of broom are considerable and conservatively amount to more than US $11 million ($A16.5 million) in western North America. Many of the ecological impacts of broom invasion are not known, or are poorly understood, but its role in stabilizing dunes along the western coastline of North America is substantial.

Introduction

Distribution of broom

Broom (*Cytisus scoparius* (L.) Link) has been introduced into and established in Australia, eastern and western Canada, Chile, India, New Zealand, Japan, South Africa and eastern and western regions of the United States (Holm *et al.* 1979, Hosking *et al.* 1996, Luken and Thieret 1997). Its native range extends from Sweden in the north to southern Spain and the Azores, and from Ireland in the west to west central Ukraine (Tutin *et al.* 1968). It is known in Canada from the provinces of British Columbia, Nova Scotia and Prince Edward Island, and in the United States from the states of Alaska, California, Connecticut, Delaware, Georgia, Hawaii, Maryland, Maine, Montana, North Carolina, New Jersey, New York, Ohio, Oregon, Pennsylvania, South Carolina, Tennessee, Utah, Virginia, Washington and West Virginia (Luken and Thieret 1997). Its range in the western United States is expanding, and densities of broom within its established range there are also increasing. Formerly regarded as a species best adapted to coastal climates, broom has established in areas within the continental climate of the Great Basin of the western United States, growing to maturity in five eastern Oregon counties, in eastern Washington (Lantz 1996), and in Idaho (Callihan and Miller 1994). Broom was introduced into western Canada in 1850 (Pojar and MacKinnon 1994), and it now occurs on southern Vancouver Island, north along the mainland coast several hundred kilometres, and eastward from Vancouver about 120 km, with scattered occurrences in eastern British Columbia (Dorworth *et al.* 1996).

The first records of broom in Oregon are from the late 1880s, and broom has steadily increased its range since then to the present (see Figure 1). The current extent of broom in western United States is illustrated in Figure 2.

Status of broom as a pest

In the western United States, broom is now regarded as a pest and is listed on noxious weed lists for California, Washington and Oregon. It is also generally regarded as a pest in British Columbia although it is not listed there as a noxious weed (Dorworth *et al.* 1996). It is listed on the All States' Noxious Weed Seed List maintained by the United States Department of Agriculture (USDA) Agricultural Marketing Service's Seed Regulatory and Testing Branch (Anon. 1998). It is regarded as a common weed in Hawaii and Iran, and as a principle pest in New Zealand (Holm *et al.* 1979) and as a noxious weed in parts of Australia (Parsons and Cuthbertson 1992).

General comments on impacts of broom

There are different perspectives on impacts of broom in western United States. For example, the main concern of foresters is broom's interference with regeneration of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantations; road maintenance personnel are concerned with the influence of broom and other brushy species on sight safety distance and erosion near roadsides; and natural area managers are concerned with broom's interaction with both physical and biotic characteristics of the landscape. In the forestry setting, actions are often taken which directly target broom. In many settings

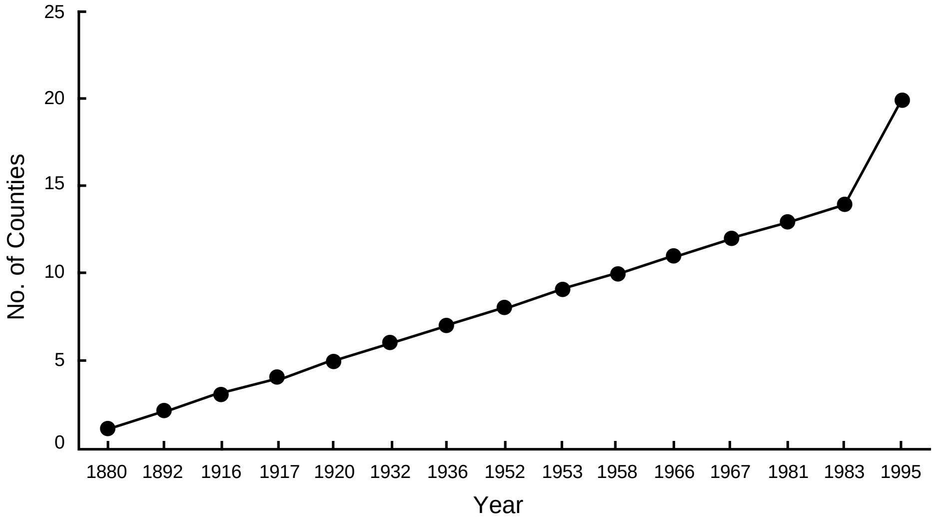

Figure 1. Extent of broom (*Cytisus scoparius*) in Oregon.

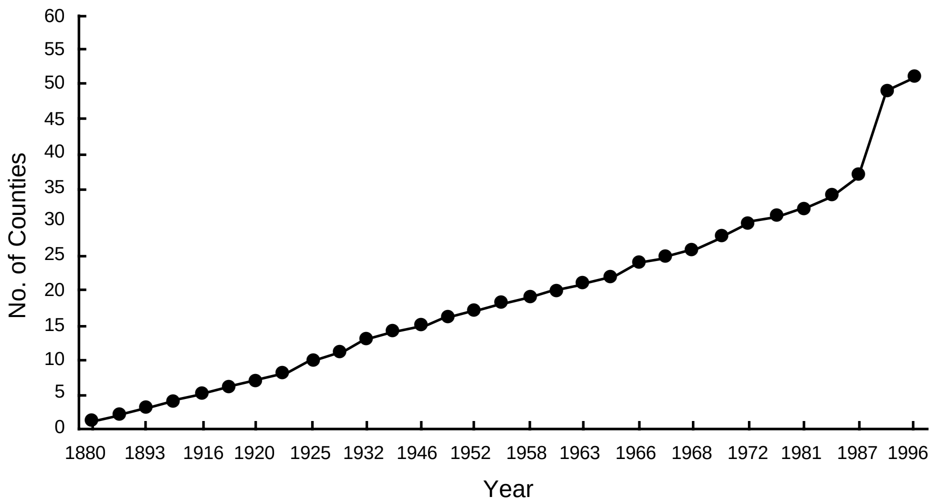

Figure 2. Extent of broom (*Cytisus scoparius*) in the Pacific Northwest of the United States of America.

along roads, broom is but one of the plants that cause problems with sight safety or erosion, and there are fewer instances of actions being taken that directly target broom. In the case of landscape change, broom interacts with other species to alter successional change and physical features of the landscape. Evaluating impacts of broom from such differing perspectives presents a challenge; we would like to have a common measure of utility that would neatly summarize the importance of broom, but we do not.

In this overview, I take two different approaches to evaluating broom's importance. First, I outline some important economic impacts of broom in three different areas; forestry, roadside treatments and nursery production. Secondly, I describe broom's role in one particular landscape setting, that of oceanside dunes, to show the extent and complexity of changes broom may cause.

Economic impacts of broom

There are two recent surveys of the economic impacts of broom. From one, I developed several estimates that summarize: (i) the extent of broom in western Oregon on industrial forest lands and on federal forest lands administered by the United States Department of the Interior's Bureau of Land Management (BLM), (ii) the extent of broom infestations along western Oregon public and private roads, (iii) treatment costs in forest and roadside settings. In the other, I assessed the benefits to the nursery industry in Oregon of brooms.

Economic costs of broom in forest regeneration and road maintenance

Dense stands of broom prevent establishment of native and desirable plant species. This is particularly true in forest settings, where broom interferes with reforestation efforts (Balneaves 1992). Dense stands of broom also cause safety problems. Broom often grows along roadways, and can reach two to three metres or more in height, and this can create sight-safety hazards, particularly at intersections, driveways and around bends. It is also a fire hazard (Goeden 1978), of concern in both forest and roadside settings, and, like gorse (*Ulex europaeus* L.), can be a fuel source for quick-burning fires.

In 1998, Decker (1998) completed a survey of foresters and road maintenance managers in an attempt to quantify some broom impacts in forests and along roadsides in western Oregon. She sent surveys to 48 private industrial forestry firms, 15 BLM forest management units, and 60 private and public organizations with road maintenance responsibilities. Responses were returned from 32 of the 48 forestry firms, representing management and/or ownership of 1.3 million ha, and 12 of the 15 BLM units representing 0.5 million ha of publicly held lands in forest production. There were 42 road maintenance responses, representing nearly 32 350 km of roads.

(a) Forest regeneration. Broom was reported as a significant or dominant plant on 46 000 ha of privately held forest land, and broom was reported as present on about 84% of units undergoing regeneration. Broom was regarded as more difficult to control than other weedy species by 84% of respondees, and only three respondees did not consider that broom increased yearly production and maintenance costs within their operations. Private foresters reported manual and/or chemical treatments on more than 2670 ha of broom annually. These foresters also reported annual treatments on 22 250 ha for brush control where broom was a component of the target vegetation, but where it was not dominant. Annual treatment costs targeting broom averaged \$US424 000 (\$A636 000) over the previous three years at \$US158 (\$A237) ha^{-1}. Manual costs for broom treatments were more costly at \$US238 (\$A357) ha^{-1}, but few areas were so treated.

BLM personnel reported broom as significant or dominant on 49 000 ha in publicly-held forest production. There were no chemical treatments on BLM lands, due to herbicide use restrictions, and one unit initiated a five-year manual treatment program on 32 ha. Infestation and control data for forestry settings are summarized in Table 1.

(b) Road maintenance. Private road managers maintaining 15 050 km of road reported broom on 805 km of their roadsides. Of these, 355 km were seriously affected by broom, and they expended \$US40 250 (\$A60 375) annually for treatment. Non-federal public road managers maintained 19 950 km of road, 3780 of which were reported with broom. Average costs for vegetation management on these roads were \$US1163 (\$A1745) km^{-1}, but there were few treatments that targeted only broom. BLM road managers reported maintaining 13 440 km of roads, 915 of which had broom as a significant or dominant component, with treatment costs of \$US786 (\$A1179) km^{-1}. Infestation and control data along roadsides are summarized in Table 2.

Table 1. Broom control in western Oregon forests (based on Decker 1998).

Forest ownership	Managed area (ha)	Area requiring and/or monitoring treatment (ha)	Area requiring and/or monitoring treatment (%)	1997 treatment costs (\$US)	1997 treatment area (ha)
Private industrial forestry firms[A]	1 300 000	46 000	3.56	424 000	2 670[D]
US Department of Interior, Bureau of Land Management[B]	500 000	49 000	8.13	8 000[C]	32[CD]

[A] 32 responses from 48 surveys. [B] 12 responses from 15 surveys. [C] Not from Decker (1998).
[D] Treatment specifically for broom, not general brush control.

Table 2. Broom control along western Oregon roadsides (based on Decker 1998).

Road owners/managers	Road maintained (km)	Infested with broom (km)	km broom (%)	Broom treatment (km)	Broom treatment costs (\$US)
Private industrial forestry firms	15 050	805	5.3	355	40 250[C]
Non -federal public	19 950	3 780	19.0	–[B]	
US Department of Interior, Bureau of Land Management	13 440	8 940[A]	66.7[A]	915	181 250[C]

[A] From % categories reported for 9 of 15 surveyed units, these figures contain a bias towards over-estimation. [B] No reports of treatments specifically for broom. [C] Treatments by forestry firms mainly chemical treatments; Bureau of Land Management treatments are manual/physical and often directed at maintaining right-of-way rather than of a specific target weed infestation.

Benefits of broom production to Oregon nurseries

Broom is valued for its showy flowers, for its capacity to serve as a visual screen, and for its ability to persist in settings with a minimum of maintenance where other plants do poorly. Because of these attributes, broom and derived cultivars have been produced by nurseries in California and Washington for several decades. Broom has also been imported from other countries for resale. Relative to the industry as a whole, production and demand for these products has declined, and only a few Oregon nurseries are still producing and selling broom products, but production is a significant source of income for a small number of nurseries.

The Oregon Association of Nurserymen annually publishes a directory of its 1400-odd members, which includes production and sales figures volunteered by participating nurseries. Directories from 1991, 1995 and 1997 (Oregon Association of Nurserymen 1997) were reviewed and data extracted on numbers of nurseries handling broom and the volume of broom they processed.

Twenty-five Oregon nurseries reported handling broom or related cultivars in 1997. Ten reported producing or importing seedlings, and 23 reported producing container and / or bareroot plants. Of the 10 nurseries reporting handling of seedlings, nine reported the quantity they handled, and 18 of the 23 nurseries producing containers / bareroot plants reported quantities of production.

Reported production of broom and derived cultivars in 1996 totalled 183 500 plants, up from reported production in 1990 and 1994. The value of 1996 production, at wholesale values of $US0.30 ($A0.45) for seedlings and $US1.25 ($A1.88) for containers and bareroot stock, was $US176 250 ($A264 375), an increase in value of more than 45% over earlier reports.

Washington weed laws prohibit the sale of broom plants and seeds, and the Oregon Department has proposed an administrative rule change, which would likewise prohibit sales of plants and seeds in Oregon. Production and sales of broom products in California and British Columbia are unknown, but certainly would be much less than those in Oregon.

Discussion of economic impacts of broom

Decker's (1998) survey captured data from important major sources, but there are notable omissions. In forestry, neither the holdings of the USDA Forest Service (USFS) nor those of small woodlot owners are represented. In western Oregon USFS holdings would be roughly equal to those of the BLM, and those of small woodlot owners would nearly be so. In designing the survey, Decker determined that the number and diversity of small woodlot owners would complicate the survey beyond her intended scope. While the dispersion of BLM and USFS lands are quite different, with the USFS lands being more 'blocked up' and less dispersed, their management, particularly with respect to the restrictions of the use of herbicides, is similar.

Also, while the return rates for Decker's survey were quite respectable, there were segments of each of the target categories that did not respond. Data summarized from returned surveys thus result in underestimates, and correcting for under-reporting may give more accurate estimates.

Decker's survey targeted Oregon land owners and managers exclusively. If economic impacts for broom are to be representative for the western United States, we must make some assumptions about impacts in Washington and California. Based on the distribution of broom shown in Figure 2, the extent of broom within each of the states is comparable, and we have no other data. British Columbia could also be said to have about the same amount of broom as any of the states mentioned (Dorworth *et al.* 1996). Rough estimates for adverse economic impacts for the western North America then could be about four times those for Oregon.

Assuming that production and sales of broom products in British Columbia and California together equal those of Oregon, current direct economic benefits of broom are on the order of $US350 000 ($A525 000) annually. Oregon will likely prohibit production and sales after 1999, and this figure might then be halved. Decker's study provides us with the perspective to make reasonable and conservative assumptions about treatment and opportunity costs of broom in forest regeneration and along roadsides, and if we assume that British Columbia and the other states invest comparable amounts in broom management, we have justification for saying that more than $US11 million ($A16.5 million) annually is directed to broom efforts. This figure would not include several other important economic cost categories, for example, losses and treatment costs in livestock production.

Broom in oceanside dune areas

Oregon's coastline measures over 485 km north and south. Coastal physiography tends to alternate within this reach between rocky headlands and sandy dunes and spits. The sand-based features of Oregon's coast tend to be dynamic and ephemeral under natural conditions, but there have been a number of human efforts to stabilize these areas to allow their use and to permit transit over them.

A north-south federal road was not completed along Oregon's coast until 1936, and both the rocky headlands and the sandy areas represented challenges to the completion of this road, US Highway 101. After the road was completed, sand movement onto and over the road caused closures and was a major maintenance concern. An effort was mounted to stabilize active dune areas, much of it utilizing combined plantings of marram grass (*Ammophila arenaria* (L.) Link) and broom. This reduced velocity of sand-moving winds and allowed establishment of other vegetation. By 1955, 3992 ha of dunes had been planted on USFS, state, county and private lands along 77 km of coastline between Florence and Coos Bay at a cost of $US618 ($A927) ha^{-1}. The BLM planted another 506 ha (Parker 1958).

In terms of the original rationale for planting broom, these early efforts have been remarkably successful. Sand encroachment on roads is now a minor concern, stabilized sandy areas have been developed as residential and commercial areas, and productive coniferous forests have established over much of the remaining area.

Much of what was, however, termed a 'dune problem area' is now managed by the USFS as the Oregon Dunes National Recreation Area (NRA) and considered a valuable natural resource. Broom and other introduced plants interfere with current management objectives. The protection of snowy plover (*Charadrius alexandrinus* Linnaeus) habitat is an example. Windswept open beaches, the nesting habitat for the plover, decreased with sand stabilization, and the succession of vegetation to spruce (*Picea sitchensis* (Bong.) Carr.) and coast pine (*Pinus contorta* Dougl.) forest provided cover for predators of plovers and their eggs, such as crows, ravens, and skunks. Beach areas suitable for nesting are closed to public use, and large and expensive projects are now underway to remove vegetation from many areas, and broom is one of the main target plants.

Dilemmas like these are not limited to the Dunes NRA. Broom has been planted along much of the west coast of the United States, and there are benefits and costs derived from broom's role in altering patterns of succession in coastal areas. Throughout the area where broom is now established, it is a direct competitor with native legumes, and this is especially troublesome in the case of the threatened *Lupinus sulphureus* Dougl. var. *kincaidii* (Smith) Hitch., which is the exclusive host of another threatened species, Fender's blue butterfly (*Icaricia icarioides* Boisduval).

Broom is a more successful functional analog of lupins in many ecological settings, and in this case is encroaching into the natural meadows, which are habitat for this lupin.

Discussion of broom impacts

One of our main interests in understanding impacts of broom is in having the information needed to support decisions as to whether to, or how much, we should invest in efforts to manage it. In site-based settings, private industrial foresters clearly believe that control is necessary, although the documented amount of their annual investment in such control is modest. Federal land managers are also investing in site-specific control in conservation efforts other than for forest regeneration, and we can observe other examples of site-based attempts at controlling broom. Coordination of large-scale management of broom is, however, lacking. Individuals and organizations make local decisions on broom control, but rarely do they cooperate on management projects even though there is consensus that problems associated with its spread are increasing.

While there is evidence that there is justification for a coordinated project targeting broom, one deterrent is that, in relation to other issues and problems, broom is not a priority with most landowners and managers. Even limiting discussion simply to weed issues, broom would not have highest priority, as other species, particularly European blackberries (*Rubus* spp.), generate more interest and concern.

The one opportunity for coordinated efforts directed at broom control that seems practicable at the present time is biological control. Throughout western North America, successful control of tansy ragwort has put biological control in favour, and there is general support for organizing and sustaining a biological control project aimed at broom. Both public and private interests have supported research to date through modest contributions to a control fund, and prospects for continued support are encouraging.

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References

Anon. (1998). State noxious-weed weed requirements recognized in the administration of the Federal Seed Act. (USDA Agriculture Marketing Service Seed Regulatory and Testing Branch, Washington, DC).

Balneaves, J.M. (1992). A comparison of surfactants to aid control of gorse and Scotch broom with herbicides. *Plant Protection Quarterly* 7, 174-77.

Callihan, R.H. and Miller, T.W. (1994). A pictorial guide to Idaho's noxious weeds. (Department of Plant, Soil and Entomological Sciences, University of Idaho, Moscow, Idaho).

Decker, C. (1998). Scotch broom: a preliminary needs assessment for implementation of biological control in western Oregon. Masters Thesis, Department of Planning, Public Policy and Management, University of Oregon, Eugene, Oregon.

Dorworth, C., Boateng, J., van de Mortel, P. and Ussery, J. (1996). Broom in British Columbia. Unpublished report to The Broom Symposium, April 17–18, Portland, Oregon.

Goeden, R.D. (1978). Part II: The biological control of weeds. *In* 'Introduced parasites and predators of arthropod pests and weeds: a world review', ed. C.P. Clausen, USDA Agriculture Handbook No. 480, pp. 357-414. (USDA Agricultural Research Service).

Holm, L., Pancho, J.V., Hergerger, J.P. and Plucknett, D.L. (1979). 'A geographical atlas of world weeds'. (Wiley-InterScience, New York).

Hosking, J.R., Smith, J.M.B. and Sheppard, A.W. (1996). The biology of Australian weeds 28. *Cytisus scoparius* (L.) Link ssp. *scoparius*. *Plant Protection Quarterly* 11, 102-8.

Lantz, L. (1996). Brooms in Washington. Unpublished report to The Broom Symposium, April 17-18, Portland, Oregon.

Luken, J.O. and Thieret, J.W., eds (1997). 'Assessment and management of plant invasions'. (Springer-Verlag, New York).

Oregon Association of Nurserymen. (1997). Directory and buyer's guide. Oregon Association of Nurserymen, Milwaukie, Oregon.

Parker, K.W. (1958) USDA US Forest Service memo from K.W. Parker, Division of Range Management and Wildlife Habitat Research to W.B. Ennis, Crop Protections Research Branch, Washington DC, Sept. 9, 1958.

Parsons, W.T. and Cuthbertson, E.G. (1992). 'Noxious weeds of Australia'. (Inkata Press, Melbourne and Sydney).

Pojar, J. and MacKinnon, A. (1994). 'Plants of the Pacific Northwest coast'. (Lone Pine Publishing, Redmond, Washington).

Tutin, T.G., Heywood, V.H., Burgess, N.A., Valentine, D.H., Walters, S.M. and Webb, D.A. (eds) (1968). 'Flora Europaea'. Volume 2. (Cambridge University Press, Cambridge).

Status of broom in New Zealand

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Summary

Broom (*Cytisus scoparius* (L.) Link) is the only broom species that is a declared noxious weed in New Zealand. It was first recorded in the wild in 1872 and is now widespread and abundant on a range of soils (esp. of alluvial or colluvial origin), particularly the drier eastern side of the South Island and in central North Island. The range expansion of broom has been most dramatic over the last 50 years, but it continues to invade new areas. Broom grows more vigorously in many parts of New Zealand than in its native range, obtaining a greater maximum age and a larger size. It occupies open habitats, from sea level to 1200 m, invading native tussock grassland, introduced pasture, riverbed and wasteland throughout productive and conservation areas. Broom causes economic losses to agricultural and forestry operations, and detracts from conservation values. Establishment costs of exotic pine forests are increased by the need to clear broom from plantation sites, and re-invasion by the weed reduces the rate of pine growth. Broom is a serious invader of pastoral land, particularly in drier hill country areas, where substantial losses to agricultural production may result. In the South Island it has been estimated to occupy 0.92% of farmable land. In some situations grazing management can contain broom, and where further control is necessary, herbicides, although expensive are effective. Cutting and burning have also been recommended in certain situations. Habitat of nesting native birds on open riverbeds is threatened when broom and other scrub species invade and provide cover for predators. On the positive side, broom is regarded as a useful pollen source by New Zealand beekeepers. In some environments it can play a role in encouraging succession to native bush, and in some areas it may provide an important spring food source for the native pigeon. However, its negative environmental effects are much greater than its positive effects, and a recent update of the cost-benefit analysis for biological control of broom in New Zealand showed a clear net benefit from its control.

Determinants of broom (*Cytisus scoparius* (L.) Link) abundance in Europe

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Summary

This paper reviews ecological literature and presents previously unpublished data concerning population dynamics of broom (*Cytisus scoparius*) in Europe. These studies, together with recent population dynamics modelling, provide strong evidence that insect herbivores regulate European broom populations, suggesting biological control could succeed in controlling exotic weedy populations. Furthermore, grazing by mammalian herbivores and the frequency of disturbances to the soil surface, that create microsites for seedling germination, were also shown to regulate populations, suggesting that grazing and land management strategies could be useful for the integrated control of weedy exotic populations.

Introduction

Broom (*Cytisus scoparius* (L.) Link) is native to Europe (Tutin *et al.* 1968) where it can be a minor weed (Gilchrist 1980, Rousseau and Loiseau 1982, Thompson 1988). In New Zealand, Australia and the United States it is a serious introduced weed of pasture, bushland and forestry and the target of biological control programs (Parsons and Cuthbertson 1992, Hosking *et al.* 1998).

Studying weed population ecology can reveal why introduced populations are weedy (Noble 1989, Crawley *et al.* 1993), can aid biological control agent selection (Briese 1993, Scott 1996), and provides a scientific basis for integrating weed management techniques. The data obtained, when used to develop population models, can help predict the effect of biological control agents on target weed populations (Lonsdale *et al.* 1995, Rees and Paynter 1997) and how population parameters interact to make a plant an invasive weed (e.g. Rees and Paynter 1997). For example, the spatial population models for broom described by Rees and Paynter (1997) predict the area occupied by broom by incorporating measures of disturbance, germination, seed bank decay, survival, time to reproduction, longevity, fecundity, seed dispersal and the probability broom can regenerate after a stand dies. This model requires detailed knowledge of a plant's biology and demography, but reliable estimates of all the population parameters required are only now becoming available.

In a long-term chemical exclusion study, Waloff and Richards (1977) showed insect herbivory dramatically reduced broom growth, fecundity and survival (Figure 1, and below), suggesting it might regulate broom populations in the United Kingdom (UK). However, fecundity may have little effect on abundance of woody shrubs (Andersen 1989). Reducing survival might not affect a broom infestation if gaps made by dying plants are immediately recolonized by broom seedlings. Until recently little population data in relation to broom seed bank dynamics and seedling recruitment has been available. This has prevented any conclusive assessment of whether insect herbivores do indeed regulate European broom populations.

As part of a multi-national broom biological control program, experiments were set up to study factors affecting broom recruitment in France and the UK where broom is native and in Australia and New Zealand where it is an exotic weed (Memmott *et al.* 1993, Fowler *et al.* 1996). Paynter *et al.* (1998) described experiments in the south of broom's native range, in southern France.

This paper first overviews ecological knowledge of broom in Europe then presents broom recruitment experiments as carried out in the UK and France. Unpublished results from the UK are compared with the previously published results from France (Paynter *at al.* 1998) which are only summarized here. Results of these experiments are discussed in relation to the broom models developed by Rees and Paynter (1997).

Overview of the ecology of broom in Europe

Seed production cycles between years of high and low production in the UK, with a

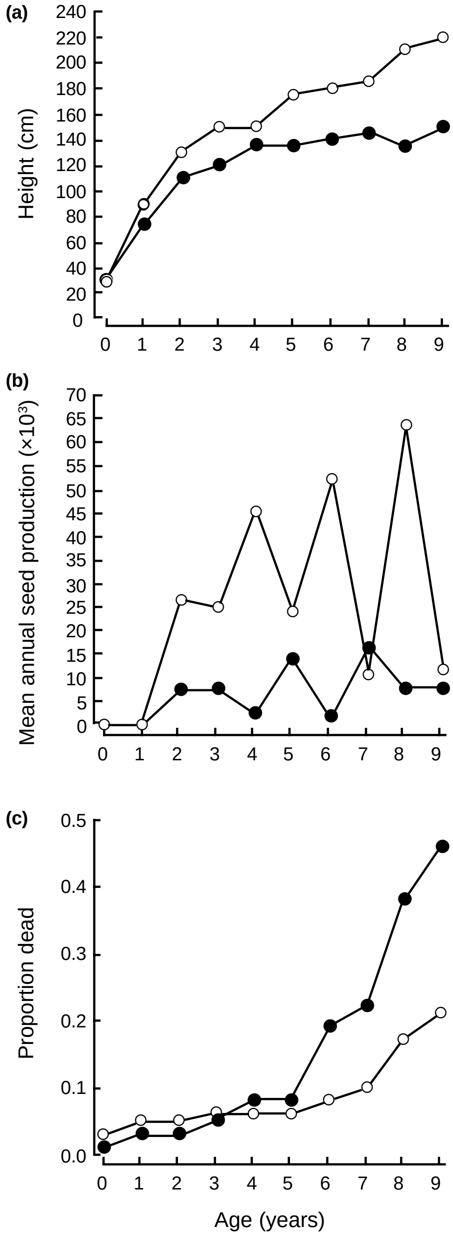

Figure 1. Effect of regular spraying with insecticides on (a) height, (b) fecundity and (c) mortality of broom. Sprayed (○) and unsprayed (●) plants. From Waloff and Richards (1977).

mean yearly output of about 6600 seeds plant^{-1}, but about 26 000 seeds plant^{-1} for insecticide-treated plants, (Waloff and Richards 1977, Figure 1b). In France, yearly fecundity of just 72–728 seeds plant^{-1} was measured for plants growing in shady sites and between 1061-5649 seeds plant^{-1}, for unshaded plants (Rees and Paynter 1997).

Seeds disperse by pod dehiscence, numbers declining exponentially with distance. Most land within 1 m of parent plants; a few can be flung up to 5 m (Paynter *et al.* 1996). Broom seeds are hard-coated and, typically, only a fraction germinates each year (Paynter *et al.* 1996). Seed banks build up (Table 1), despite intense vertebrate seed predation on the soil surface (>90%, Paynter *et al.* 1996). Seedlings do not survive beneath broom stands and broom is often found on disturbed soils in Britain (Waloff 1968). Rousseau and Loiseau (1982) also recognized the importance of disturbance, by fire or mechanical clearing, for seedling establishment in France. High temperature that would occur in a fire breaks dormancy of broom seeds (Tarrega *et al.* 1992, Bossard 1993).

Broom has an average life expectancy of 10–12 years in the UK (Waloff and Richards 1977, Rees and Paynter 1997), and does not live more than *c.* 12 years in France (Rousseau and Loiseau 1982, Rees and Paynter 1997). A large scale insecticide application experiment performed in the UK led to about a 50% reduction in plant mortality over a ten-year period (Waloff and Richards 1977, Figure 1c).

Methods used for European broom recruitment experiments

In the UK, plots were set up in the grounds of Imperial College at Silwood Park, Berkshire (Lat. 51° 24'N, Long. 0° 34'W) at an altitude of 61 m (see Waloff 1968, Memmott *et al.* 1993). In southern France, plots were set up at Mandagout and L'Esperou, for site descriptions see Paynter *et al.* 1998.

The experiments used paired unfenced and fenced plots to exclude grazing mammals. These plots were divided into 5 × 5 m sub-plots. In the UK, four paired 10 × 20 m plots were used, these had senescent plants left over from extensive broom stands that had been present in the previous decade just prior the experiment. Unfortunately these plants died prior to treatment allocation (ring-barked by rabbits). The broom seed bank was known to be significant (M.J. Crawley personal communication). The 1 m high fences were made of chicken wire (about 5 cm mesh) supported by large fence posts at the corners and 1–3 smaller posts along the sides. Treatments in the UK were allocated by 8 May 1991.

Seed banks were sampled using ten circular soil-cores (5 cm in diameter by 10 cm deep) taken at random from each subplot. Cores were sieved, hand-sorted and the number of broom seeds with fresh endosperm recorded. In the UK cores were taken in 1991 (prior to treatment allocation) and in 1995 after seed fall so the effect of disturbance on the proportion of seed germinating could be determined, while in France cores had been taken annually after seed fall (Paynter *et al.* 1998).

Two subplots per plot were cleared and cultivated, to approximately 10 cm depth to provide a major disturbance event at the start of the experiment. One of these subplots was then repeatedly re-cultivated each summer as in France. At least one remaining subplot per plot went undisturbed to act as controls.

Several additional treatments were used in France (Paynter *et al.* 1998): (a) one subplot per plot was cleared of broom by cutting plants at ground level, leaving the soil undisturbed, (b) hand-weeded competition treatments within a 5 × 10 m fenced, cleared and cultivated area (Mandagout only), where a grid of thirty 0.25 m^2 quadrats was set up to generate initial seedling densities of 5, 20 or 80 seedlings per quadrat and left to grow with or without competing species, (c) insecticide, molluscicide, fungicide and control treatments (applied three times a year) allocated to 2.5 × 5 m subplots within a 10 × 10 m fenced, cleared and cultivated area (see details in Paynter *et al.* 1998).

Broom was sampled within subplots using both 'random' and 'permanent' 0.5 × 0.5 m quadrats where censuses were performed three times per year in spring (April / May), summer (July / August) and autumn (November / early December). The number of broom seedlings and the approximate percentage cover of all plant species were recorded in four randomly positioned quadrats in each undisturbed, cultivated and cut (France only) subplot, which were re-randomized on each sampling date to give statistically independent samples across dates. Using a flag composed of coloured tape wrapped around a cocktail stick, each broom seedling was marked with a unique identification number in two permanent quadrats in each undisturbed, single cultivation and cut (France only) subplot. The position of the two permanent quadrats was deliberately chosen to reflect areas of low and high seedling density in each subplot. Seedling size and presence of arthropod herbivores and fungal pathogens was noted in these quadrats on each sampling date. Age at first flowering and seed set since disturbance treatment allocation was noted for all plants in sample quadrats.

In the competition and pesticide experiments only used in France seedlings within each quadrat / subplot were labelled and measured as in the permanent quadrats above.

Statistical analysis

Analyses of the UK experiments were performed using the GLIM statistical package (McCullagh and Nelder 1983). Analyses of deviance were performed to study variation in the size of seed banks and the proportion of the seeds that germinated. Factors tested were plot, fence treatment (fenced or unfenced), time (1991 or 1995 seed counts) and disturbance treatment (undisturbed, single, and annual cultivation). Seed bank counts were log (n+1) transformed to normalize them prior to analysis. Other analyses tested whether plot, fence treatment and disturbance (undisturbed and single cultivation) affected the proportion of seedlings surviving at each census and whether disturbance, fence treatment, site and time affected percentage cover of broom and competing vegetation. In these analyses the factor 'time' was assigned seven levels, corresponding to the first sample date of seedlings and the subsequent summer samples for each of the six summers (1992-1997). Annual cultivation was excluded from these analyses as it killed all seedlings. All proportion data were analysed after angular transformation. Where analyses revealed significant treatment effects, least significant difference (LSD) multiple range tests were performed to compare treatment pairs, according to Crawley (1993). Analysis of the French data was similar and is described by Paynter *et al.* (1998).

Table 1. Seed banks beneath broom in the native range (seeds m^{-2}).

Seed bank	Site	Country	Reference[A]
5293–5405	Silwood Park, Berkshire	UK	
3392–6733	County Wicklow	Eire	1
c. 3000 (968–19664)	Abandoned terraces, Gard	France	2
460–1405	Gard	France	3
595	Vinuesa	Spain	3

[A] Reference: 1 Smith and Harlen (1991); 2 Paynter *et al.* (1998); 3 Hosking (1995).

Results

Seed banks

The seed bank in the UK averaged (± s.e.) 5405 (± 655) m^{-2} in 1991 and 5293 (± 770) m^{-2} in 1995, and was of similar magnitude to that observed in France (Table 1), but only varied significantly between plots

($F_{3,40}$ = 5.33, P<0.01). The seed banks were not observed to decline by about 50% each year as observed without seed replenishment in France (Figure 1 in Paynter *et al.* 1998). This is probably because mature seeding plants had regenerated in most plots by the time the seed banks were sampled in 1995.

Germination rates

In both the UK and France, germination was virtually confined to spring. The proportion of seeds germinating was highest in disturbed subplots, both in the UK (Table 2, Figure 2) and France (where germination was also correlated to March rainfall; Figure 3 in Paynter *et al.* 1998). In the UK germination in 1991 was highest in initially cultivated subplots and in 1995, germination was significantly higher in annual cultivation subplots than in both control and single cultivation subplots, where germination was negligible (Figure 2).

Survival

In both the UK and France, no seedlings survived to flowering age under a broom canopy, even if it had only been established for one year. Survival, therefore, was confined to the first cohorts following allocation of treatments: no second- or later-cohort seedlings survived more than a few weeks in either France (Figure 4 in Paynter *et al.* 1998) or the UK (Figure 3).

In the UK, the major factor influencing seedling survival was grazing. In fenced and unfenced cultivated plots about 60% and 0% of first-cohort seedlings survived to flowering age respectively (Figure 3). Survival of first-cohort (spring 1991) seedlings was not significantly affected by cultivation (Table 3). In France, about 14% of seedlings survived to flowering age (fenced and unfenced plots combined; Figure 4 in Paynter *et al.* 1998). Survival of first-cohort seedlings was higher in subplots that were cultivated once than in cut subplots. However, there was no significant effect of intra- or interspecific competition on survival in the competition experiment in France, although seedling height declined with increasing initial seedling density (Figure 8 in Paynter *et al.* 1998). There was also no significant effect of pesticide application on seedling establishment from the French experiment.

Seedling growth and flowering

In the UK, seedlings reached a mean height of about 80 cm after just 24 months, setting seed after 27 months and attaining a maximum height of 210 cm after 63 months. In France plants grew slower

Table 2. Analysis of deviance for the proportion of the broom seed bank germinating in 1991 and 1995.

Source	d.f.	*F*-ratio
Plot	3	2.80
Cultivation	2	3.59*
Fence treatment	1	0.48
Year	1	17.25***
Error	40	
Interaction		
Cultivation × Year	2	3.34*
Error	38	

*P<0.05; ***P<0.001

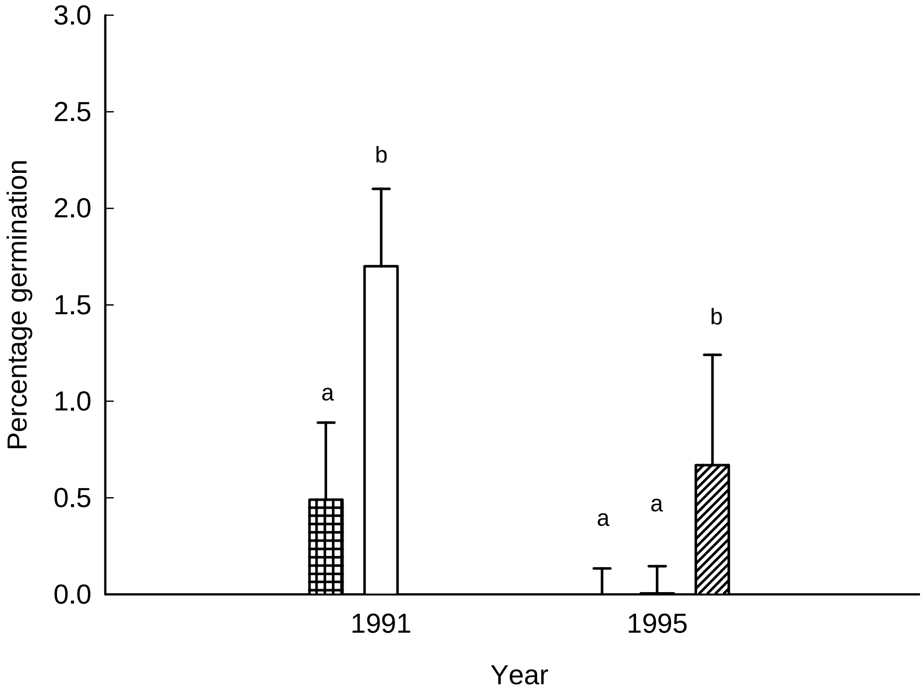

Figure 2. Percentage of seeds germinating each year (± s.e.) in the UK, for the disturbance treatments: ⊞ = undisturbed; ☐ = single initial cultivation; ▨ = annual cultivation. Columns within the same year with the same letter are not significantly different.

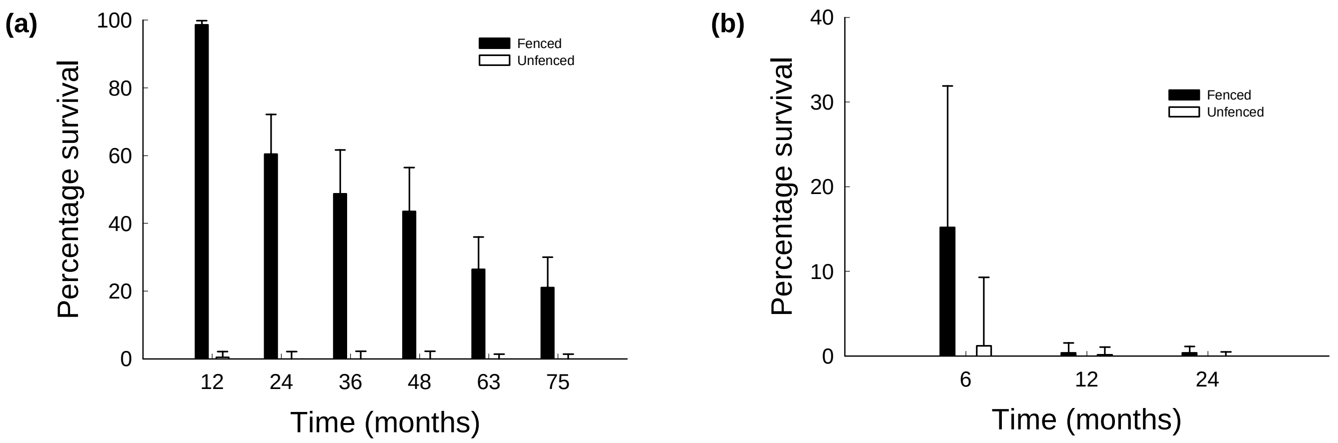

Figure 3. Percentage of seedlings surviving to each census in the UK (± s.e.) in both fenced and unfenced plots. For: (a) first cohort of seedlings that germinated in Spring 1991, where Time = time from the spring census 1991, and (b) second cohort of seedlings that germinated in spring 1992, where Time = time from the spring census 1992.

Table 3. Analyses of deviance for the proportions of broom seedlings from the first cohort surviving to each census in the UK experiment.

Source	d.f.	*F*-ratio
12 month census		
Plot	3	0.30
Cultivation	1	0.88
Fence treatment	1	120.67***
Error	8	
24 month census		
Plot	3	4.61*
Cultivation	1	0.01
Fence treatment	1	53.93***
Error	8	
75 month census		
Plot	3	4.61*
Cultivation	1	0.01
Fence treatment	1	17.89**
Error	8	

*P<0.05; **P<0.01; ***P<0.001

Table 4. Analysis of deviance for percentage cover of vegetation competing with broom (n.b. there are 4 missing values).

Source	d.f.	*F*-ratio
Plot	3	4.57*
Cultivation	1	1.09
Fence treatment	1	0.49
Time	6	3.11**
Error	96	
Interactions		
Plot × Cultivation	3	1.18
Plot × Fence treat.	3	7.76**
Plot × Time	18	2.59
Fence treat. × Cult.	1	0.07
Fence treat. × Time	6	5.87***
Cultivation × Time	6	0.24
Error	59	

*P<0.05; **P<0.01; ***P<0.001

Table 5. Analysis of deviance for percentage broom cover (n.b. there are 4 missing values).

Source	d.f.	*F*-ratio
Plot	3	10.23**
Cultivation	1	0.43
Fence treatment	1	112.19***
Time	6	4.41***
Error	96	
Interactions		
Plot × Cultivation	3	2.72
Plot × Fence treat.	3	20.2***
Plot × Time	18	1.14
Fence treat. × Cult.	1	0.04
Fence treat. × Time	6	15.76***
Cultivation × Time	6	0.71
Error	59	

***P<0.001

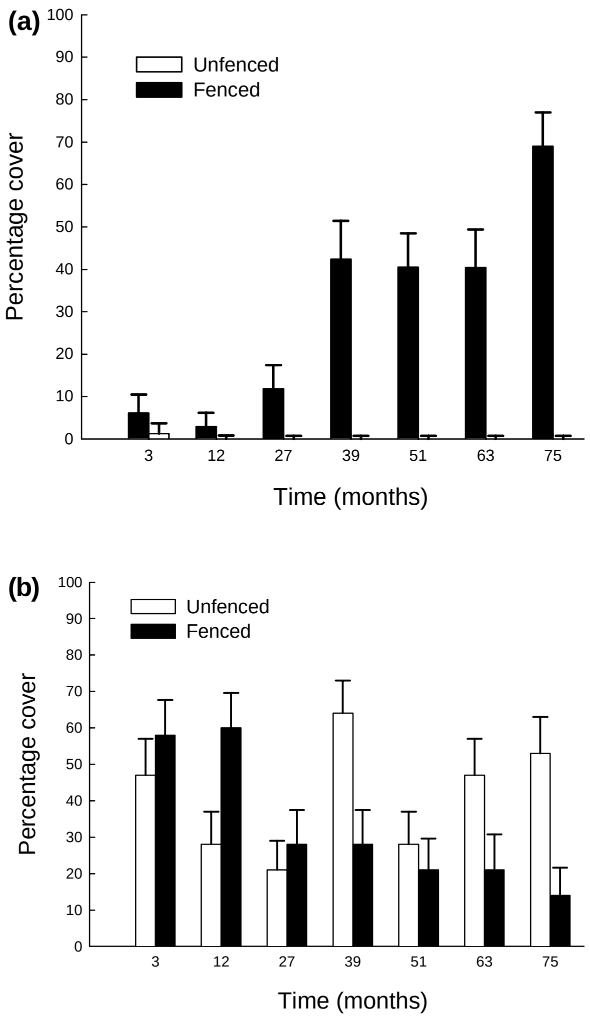

Figure 4. Percentage cover of (a) broom and (b) competing vegetation versus time (months) for both fenced and unfenced plots (cultivated and undisturbed combined) in the UK. Time = time since first census following allocation of disturbance treatments.

than in the UK. The mean height of surviving seedlings in single cultivation and cut subplots was about 80 cm after 39 months. During their fourth year 39% of surviving plants flowered, although most flowers aborted so only 7% of plants set seed and the mean seed production was just 38.3 seeds m^{-2}.

In the French experiment interspecific competition significantly affected fecundity. After just 27 months nearly 10% of surviving plants set seed in the no competition treatment, whereas only 0.3% of plants exposed to interspecific competition set seed. There was no effect of pesticide application on the minimum age of reproduction. However, insecticide-treated plants had a significantly reduced flower abortion rate and, as in Waloff and Richards (1977), produced more seeds per pod and over three times more seeds per plant than unsprayed controls (Groves and Paynter 1998).

Percentage cover

In the UK subplots, percentage cover of broom was significantly affected by plot, fence treatment and time (Table 4, Figure 4a), but not cultivation. The percentage cover of broom increased from about 5% after the first census to 70% after 75 months within the fenced plots, while in unfenced plots it remained negligible throughout the experiment. The percentage cover of competing vegetation varied significantly with fence treatment, plot and time (Table 5, Figure 4b). Within fenced plots it declined from about 60%, recorded 3 months after allocation of treatments to about 15% after 75 months as competing broom regenerated. In contrast, for unfenced plots, percentage cover of competing vegetation showed no obvious trend over time and averaged 40–50%.

In France, percentage cover of broom was not affected by site or fence treatment, but was significantly affected by time and cultivation (Paynter *et al.* 1998). French sites, unlike UK sites, had mature broom cover which remained relatively constant in undisturbed subplots. However, four years after allocation of treatments, percent broom cover in the single cultivation plots was also over 60% and an order of magnitude higher than in cut plots (Figure 6 in Paynter *et al.* 1998). Time and cultivation also significantly affected percentage cover of competing vegetation at the French sites (Figure 7 in Paynter *et al.* 1998). Within 2 years percent cover of competing vegetation within cut plots had risen from 20 to 90%, while it never reached more than 60% in the cultivated plots and scarcely changed within single-cultivation plots.

Discussion

The UK study revealed similarities in broom recruitment to southern France (Paynter *et al.* 1998), germination was highest in cultivated subplots and seedling survival to flowering was confined to the first cohort. Seedling survival beneath established stands was negligible. Grazing in the UK, however, was more intense (mainly by rabbits) and had a dramatic effect there on seedling survival (Figure 3). Plants flowered in their third year in the UK plots, taking no longer to reach maturity than in exotic habitats in New Zealand and Australia (Williams 1981, Smith and Harlen 1991), compared to France, where flowering was delayed a further year (Paynter *et al.* 1998). Although first-cohort seedling survival was higher within fenced plots in the UK than France, this may simply have been because the first census was performed later and some seedling death may have gone unrecorded.

Stand regeneration was not affected by cultivation in the UK, but was faster in the cultivated plots in France (Figure 6 in Paynter *et al.* 1998). Although there were differences in the germination rates between countries, there are other reasons for this. Firstly, the undisturbed treatment in the UK had no live mature broom remaining at the start of the experiment, while the undisturbed treatment in France comprised of broom stands with almost complete canopies. The UK undisturbed treatment was therefore more similar to the 'cut' treatment in France and behaved accordingly. Secondly, the field site at Silwood Park is heavily grazed by rabbits (Crawley 1990) compared to just the infrequent passage of a few goats and cattle in France (Paynter *et al.* 1998). Even the undisturbed treatment in the UK had a rather degraded herb layer that did not compete strongly with emerging broom seedlings. The site could, therefore be considered 'inherently disturbed'. Therefore, disturbance may still be an important factor affecting establishment of broom seedlings in the UK.

Modelling broom population dynamics

All parameters identified by Rees and Paynter (1997) had been investigated by at least one experimental study in Europe described above. Rees and Paynter (1997) investigated importance of individual parameters by varying each parameter while keeping all other parameters constant and at levels typically found in Europe. They showed the proportion of sites occupied was largely determined by disturbance, longevity of broom plants and probability of recolonization after stands die (Figure 5).

Disturbance

Studies described above showed disturbance enhances germination and seedling survival. The model predicted a non-linear relationship between disturbance and broom cover (Figure 5a). Low levels of disturbance result in few opportunities for seedling establishment as seen in the lack of seedling survival under mature broom. Conversely, high levels of disturbance, as in the annual cultivation treatment, allow extensive establishment, but kill seedlings before they attain reproductive age, leading ultimately to seed bank extinction. There is, however, a large range of intermediate disturbance intensities where broom persists.

Paynter *et al.* (1998) argued seed bank depletion is most rapid at the soil surface because buried seeds are more likely to escape predation (Hulme 1994) and less likely to germinate (Tran and Cavanagh 1984, Bossard 1993, Lonsdale 1993). Furthermore, broom seedlings failed to emerge from seeds planted at depths greater than about 5 cm (Williams 1981, Bossard 1993). Therefore, although buried seed has the potential to survive for years, perhaps decades (Turner 1934), disturbance is necessary to bring them close enough to the soil surface to germinate and emerge, and to disrupt competing vegetation that might prevent seedling establishment. The presence of a long-lived seed bank may explain how populations can reappear after long periods without disturbance, but it cannot explain the persistent presence of a dense stand of broom (Rees and Paynter 1997).

The wide range of processes summarized by the term disturbance complicates characterizing and quantifying the effect of disturbance. While our experiments used only cultivation, disturbance also represents, for example, fire, landslide, flooding, frost heavage, grazing and trampling by horses and feral pigs. Broom may have become a more significant weed in exotic habitats because of differences in disturbance rates, but more studies are required to quantify and characterize disturbances that affect broom.

Longevity

Increased longevity of broom plants was predicted to have profound effects on broom abundance (Figure 5b). This is largely due to space being occupied for longer – so that at any given time more space will be occupied. However, there are other consequences of increased broom longevity. Firstly, increased longevity will result in higher seed production over a plant's lifetime. Secondly, denser stands that persist longer may result in greater depletion of competing vegetation and their seed banks. This may have consequences for the probability of self-replacement (see below). Broom lives longer in exotic habitats than in Europe (Rees and Paynter 1997) and this is considered to be due the absence of specialist insect herbivores (Waloff and Richards 1977), so it appears that insects are at least partially responsible for regulation of European broom populations.

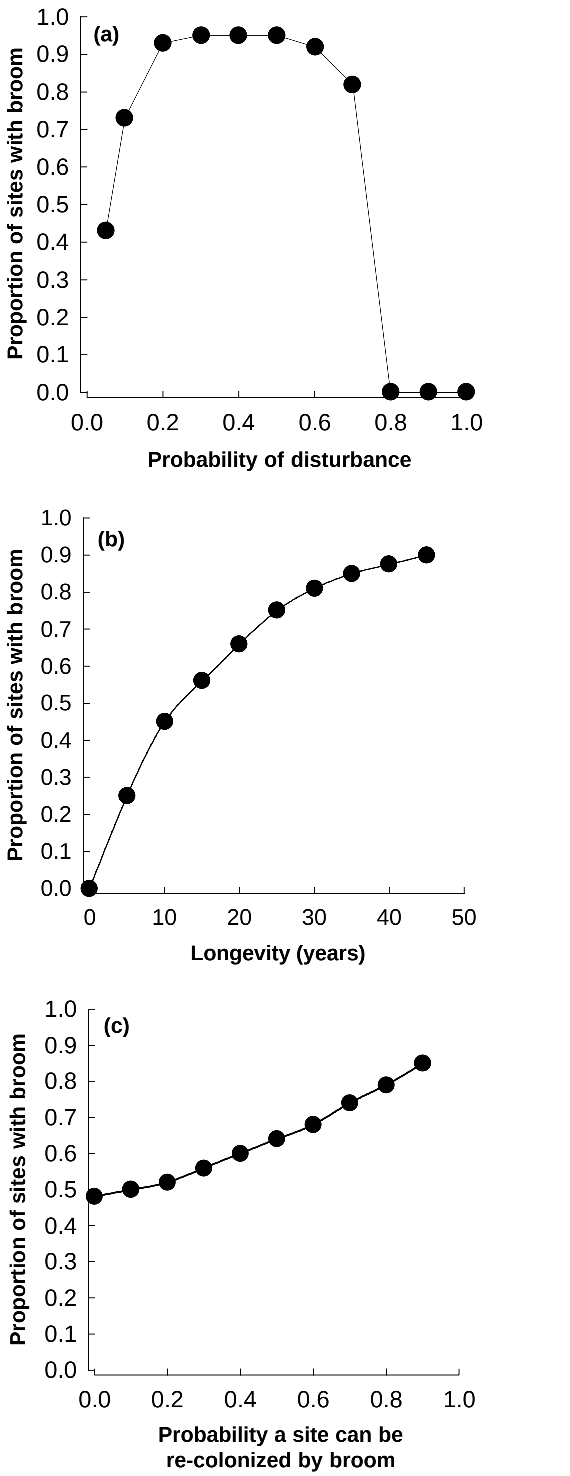

Figure 5. Predicted proportion of sites with broom versus (a) probability of disturbance (b) longevity of broom plants and (c) probability a site is suitable for recolonization by broom, after senescence of the original stand. From Rees and Paynter (1997).

Probability of self-replacement

If the soil surface is colonized by competing plants, following the death of a plant, broom seedlings may fail to establish. Under these circumstances, overall occupancy by broom will be lower than if seedlings can recolonize the parental site (Figure 5c). In France, few seedlings established where broom stands were cut away, stimulating vigorous regrowth of perennial grasses and herbs that had persisted beneath stands (Paynter *et al.* 1998). In Europe, generally, stands do not appear to regenerate after senescence although there is some evidence that they do in Australia (A. Sheppard personal observation).

Other factors

The models did not suggest that variation in seedling survival is important because broom produces so many seeds and seedlings that only mortality rates close to 100% can reduce broom cover (Rees and Paynter 1997). However, in the UK experiment, grazing did have a dramatic effect on broom populations by achieving such a high level of mortality.

Rees and Paynter (1997) predicted delaying flowering by several years would significantly reduce the area of suitable habitat covered by broom. However minimum age for reproduction, at least in the UK experiment, was the same as has been recorded in exotic habitats in Australia and New Zealand where this plant is a major weed (Williams 1981, Smith and Harlen 1991). Paynter *et al.* (1998) showed that in France interspecific competition, rather than pathogens and arthropod herbivores (which are slow to colonize seedlings), can increase the pre-reproductive period, although flowering one year later is probably unimportant. Heavy browsing by herbivorous mammals, not considered in these studies however, could potentially delay flowering considerably.

Implications for the control of broom

Biological control

The results of these studies suggest the prospects for biological control of broom in exotic habitats are good, provided sufficiently specific agents can be found. Insect herbivores can reduce life expectancy of broom plants (Waloff and Richards 1977) and this should have a dramatic effect on broom populations (Rees and Paynter 1997). Seed-feeders will reduce rate of invasion into new habitats (Paynter *et al.* 1996) and may even lead to a decline in broom populations in frequently disturbed habitats such as braided river beds in New Zealand (Rees and Paynter 1997). Furthermore, chronic effects of insect herbivory on plant longevity, size and vigour (Waloff and Richards 1977) might explain why perennial grasses and herbs, which can smother seedlings, persist beneath native but, apparently, not exotic stands. Moreover, where broom is an exotic weed, introduced biological control agents can reach much greater levels of abundance when released from their own natural enemies and competitors to become much more damaging, as has been seen for a number of broom agents already released (Syrett *et al.* 1999).

Other control strategies

Controlling broom stands by chemical or physical means, such as by herbicide, burning and slashing, creates disturbance, which breaks seed dormancy and creates the best conditions for establishment. Thus, all these methods are likely to require subsequent control treatments, within two years (i.e. before the regenerating seedlings are able to reproduce), to prevent extensive regeneration. Indeed, where burning or mechanical control is used in France it provides a temporary solution, but often eventually results in the establishment of an even denser broom stand unless the stocking rate is increased and / or revegetation with native grasses is performed (Rousseau and Loiseau 1982). The results of the modelling also suggest repeated ploughing to deplete the seed bank could also be effective (see also Parsons and Cuthbertson 1992). Grazing could be a major tool for broom control, by preventing re-establishment of stands from the seed bank following stand clearance. However, more work will be needed to establish whether the results described above, pertaining to rabbit grazing, are relevant to other grazing animals. Indeed, broom abundance has been linked to grazing by cattle in New Zealand (Williams 1983). This approach may not be appropriate for every circumstance, such as in national parks, and subsequent relaxation of grazing could create ideal conditions for seedling establishment from the seed bank. Manipulating interspecific competition may also form an important tool for broom management. Rousseau and Loiseau (1982) noted that revegetation with seeds of the perennial grass, *Dactylis glomerata* L., reduced broom population density in pasture two years after mechanical clearing.

A tentative management strategy might involve:

1. Initial clearance of a stand by mechanical or chemical means or by fire.
2. If necessary, a selective spray or ploughing treatment within two years and / or:
3. Revegetation with pasture grasses and / or stocking with sheep or goats.

More work will be required to develop an optimal integrated strategy for control of broom, as there are likely to be both advantages and disadvantages to the various options. For example, burning kills stands and depletes the seed bank by killing seed and stimulating germination (Bossard 1993). However, burning will be much more damaging to competing ground flora than, for example, selective herbicide treatment or slashing and, therefore, more likely to be accompanied by extensive regeneration unless options 2 and 3 (above) are also performed. More work will also be required to study how these strategies can best be integrated to minimize their impact on populations of biological control agents. This study has at least helped outline important factors affecting broom regeneration in the native range.

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References

Andersen, A.N. (1989). How important is seed predation to recruitment in stable populations of long-lived perennials? *Oecologia* 81, 310-15.

Bossard, C.C. (1993). Seed germination in the exotic shrub *Cytisus scoparius* (Scotch broom) in California. *Madroño* 40, 47-61.

Briese, D.T. (1993). The contribution of plant biology and ecology to the biological control of weeds. Proceedings of the 10th Australian Weed Conference and 14th Asian-Pacific Weed Science Society Conference, 6–10 September 1993, Brisbane, eds J.T. Swarbrick, C.W.L. Henderson, R.J. Jettner, L. Streit and S.R. Walker, Volume 1, pp. 10-8. (Weed Science Society of Queensland, Brisbane).

Crawley, M.J. (1990). Rabbit grazing, plant competition and seedling recruitment in acid grassland. *Journal of Applied Ecology* 27, 803-20.

Crawley, M.J. (1993). 'GLIM for ecologists'. (Blackwell Scientific Publications, Oxford).

Crawley, M.J., Hails, R.S., Rees, M., Kohn, D. and Buxton, J. (1993). Ecology of transgenic oilseed rape in natural habitats. *Nature,* 363, 620-23.

Fowler, S.V., Harman, H.M., Memmott, J., Paynter, Q., Shaw, R., Sheppard, A.W. and Syrett, P. (1996). Comparing the population dynamics of broom, *Cytisus* *scoparius*, as a native plant in the United Kingdom and France and as an invasive alien weed in Australia and New Zealand. Proceedings of the Ninth International Symposium on Biological Control of Weeds, 21–26 January 1996, Stellenbosch, South Africa, eds V.C. Moran and J.H. Hoffman, pp. 19-26. (University of Cape Town, Cape Town).

Gilchrist A.J. (1980). Control of woody weeds in forestry with triclopyr. Proceedings of the Conference on Weed Control in Forestry, 1–2 April 1980, Nottingham, United Kingdom, pp. 249-56.

Groves, R.H. and Paynter, Q. (1998). Comparative ecology of *Cytisus scoparius* in France and Australia. Proceedings of the Sixth EWRS Mediterranean Symposium, 13–15 May 1998, Montpellier, France, pp. 119-25.

Hosking, J.R. (1995). The impact of seed and pod feeding insects on *Cytisus scoparius* (L.) Link. Proceedings of the Eighth International Symposium on Biological Control of Weeds, 2-7 February 1992, Lincoln University, Canterbury, New Zealand, eds E.S. Delfosse and R.R. Scott, pp. 45-51. (DSIR/CSIRO, Melbourne).

Hosking, J.R., Smith, J.M.B. and Sheppard, A.W. (1998). *Cytisus scoparius* (L.) Link ssp. *scoparius*. 'The biology of Australian weeds', Volume 2, eds F.D. Panetta, R.H. Groves and R.C.H. Shepherd, pp. 77-88. (R.G. and F.J. Richardson, Melbourne).

Hulme, P.E. (1994). Post-dispersal seed predation in grassland: its magnitude and sources of variation. *Journal of Ecology* 82, 645-52.

Lonsdale, W.M. (1993). Losses from the seed bank of *Mimosa pigra*: soil microorganisms vs. temperature fluctuations. *Journal of Applied Ecology* 30, 654-60.

Lonsdale, W.M., Farrell, G. and Wilson, C.G. (1995). Biological control of a tropical weed: a population model and experiment for *Sida acuta*. *Journal of Applied Ecology* 32, 391-9.

McCullagh, P and Nelder, J.A. (1983). 'Generalized linear models', 2nd edition. (Chapman and Hall, London).

Memmott, J., Fowler, S.V., Syrett, P. and Hosking, J.R. (1993). What makes broom a major problem? Proceedings of the Brighton Crop Protection Conference. Brighton, 22–25 November 1993, Brighton, United Kingdom, pp. 753-8. (British Crop Protection Council, Farnham, UK).

Noble, I.R. (1989). Attributes of invaders and the invading process: Terrestrial and vascular plants. In 'Biological invasions: a global perspective', eds J.A. Drake, H.A. Mooney, F. di Castri, R.H. Groves, F.J. Burger, M. Rejmanek and M. Williamson, pp. 301-10. (J. Wiley & Sons, Chichester).

Parsons, W.T. and Cuthbertson, E.G. (1992). 'Noxious weeds of Australia'. (Inkata Press, Melbourne and Sydney).

Paynter, Q., Fowler, S.V., Hinz, H.L., Memmott, J., Shaw, R., Sheppard, A.W. and Syrett, P. (1996). Are seed-feeding insects of use for the biological control of broom? Proceedings of the Ninth International Symposium on Biological Control of Weeds, 21–26 January 1996, Stellenbosch, South Africa, eds V.C. Moran and J.H. Hoffman, pp. 495-501. (University of Cape Town, Cape Town).

Paynter, Q., Fowler, S.V., Memmott, J. and Sheppard, A.W. (1998). Factors affecting the establishment of *Cytisus scoparius* in southern France: implications for managing both native and exotic populations. *Journal of Applied Ecology* 35, 582-95.

Rees, M. and Paynter, Q. (1997). Biological control of Scotch broom: modelling the determinants of abundance and the potential impact of introduced insect herbivores. *Journal of Applied Ecology* 34, 1203-21.

Rousseau, J. and Loiseau, A. (1982). Structure et cycle de development des peuplements a '*Cytisus scoparius* L.' dans le chaine des puys. *Acta Oecologia Applicata* 3, 155-68.

Scott, J.K. (1996). Population ecology of *Chrysanthemoides monilifera* in South Africa: implications for its control in Australia. *Journal of Applied Ecology* 33, 1496-508.

Smith, J.M.B. and Harlen, R.L. (1991). Preliminary observations on the seed dynamics of broom (*Cytisus scoparius*) at Barrington Tops, New South Wales. *Plant Protection Quarterly* 6, 73-8.

Syrett P., Fowler S.V., Coombs E.M., Hosking J.R., Markin G.P., Paynter Q.E. and Sheppard A.W. (1999). The potential for biological control of Scotch broom (*Cytisus scoparius*) (Fabaceae) and related weedy species. *Biocontrol News and Information* 20, 17N-34N.

Tarrega R., Calvo L. and Trabaud L. (1992). Effect of high temperatures on seed germination of two woody Leguminosae. *Vegetatio* 102, 139-47.

Thompson A.R. (1988). Fluroxypyr, a new herbicide for scrub and woody weed control in forestry and amenity areas. *Aspects of Applied Biology* 16, 177-82.

Tran, V.N. and Cavanagh, A.K. (1984). Structural aspects of seed dormancy. In 'Seed Physiology, Volume 2, Germination and Reserve Mobilisation', ed. D.R. Murray, pp. 1-44. (Academic Press, London).

Turner, J.H. (1934). The viability of seeds. *Bulletin of Miscellaneous Information, Kew* 6 (1933), 257-69.

Tutin, T.G., Heywood, V.H., Burges, N.A., Moore, D.M., Valentine, D.H., Walters, S.M. and Webb, D.A.eds (1968). 'Flora Europaea', Volume 2, p. 89. (Cambridge University Press, Cambridge).

Waloff, N. (1968). Studies on the insect fauna on Scotch broom *Sarothamnus scoparius* (L.) Wimmer. *Advances in Ecological Research* 5, 87-208.

Waloff, N. and Richards, O.W. (1977). The effect of insect fauna on growth mortality and natality of broom, *Sarothamnus scoparius*. *Journal of Applied Ecology* 14, 787-98.

Williams, P.A. (1981). Aspects of the ecology of broom (*Cytisus scoparius*) in Canterbury, New Zealand. *New Zealand Journal of Botany* 19, 31-43.

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

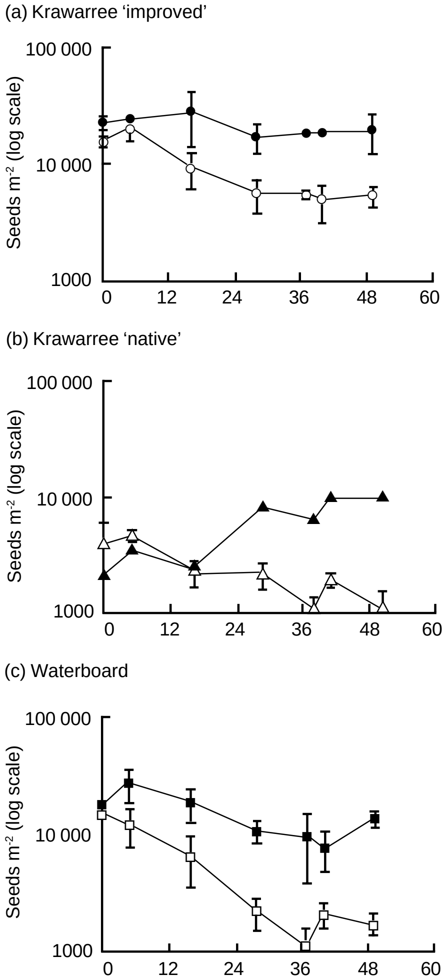

Figure 1. Changes in number of broom seeds in the seedbank over time in undisturbed (●,▲,■) and disturbed (○,△,□) broom plots (mean ± SE).

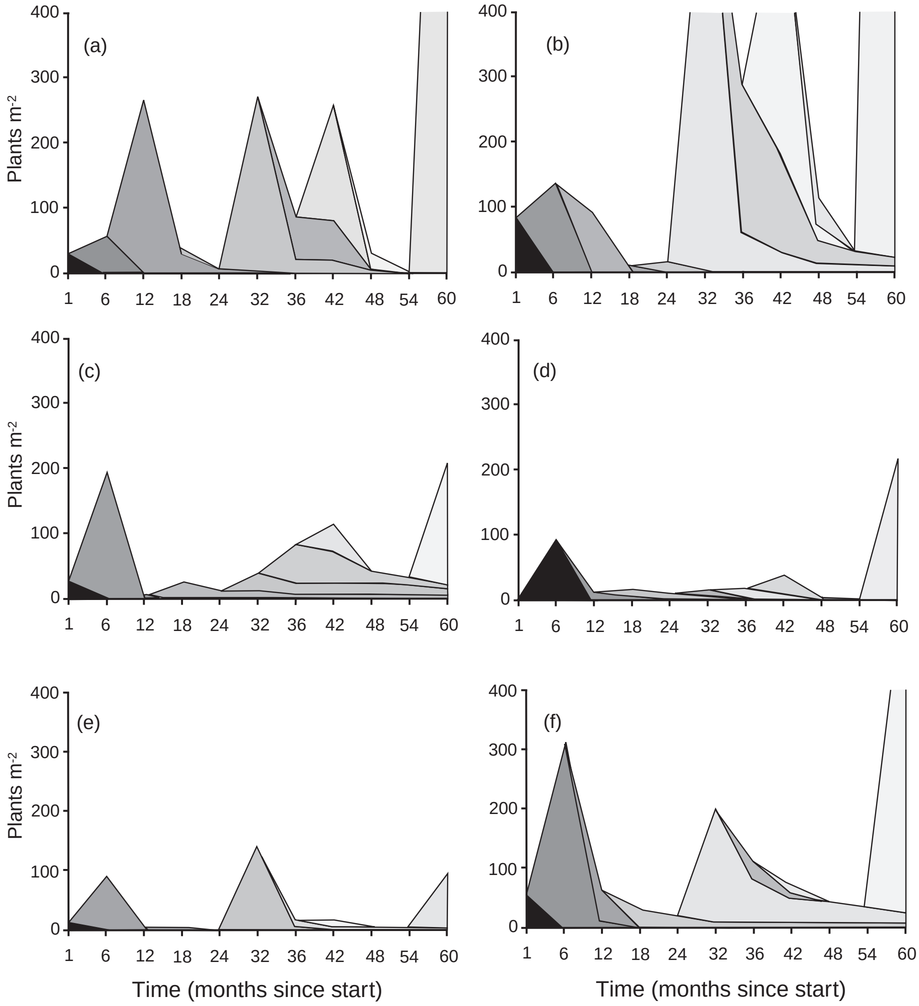

Figure 2. Population curves for broom plants at Waterboard in broom plots for (a) fenced undisturbed, (b) unfenced undisturbed, (c) fenced cultivated, (d) unfenced cultivated, (e) fenced cut and (f) unfenced cut subplots. Different shades are different cohorts.

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.

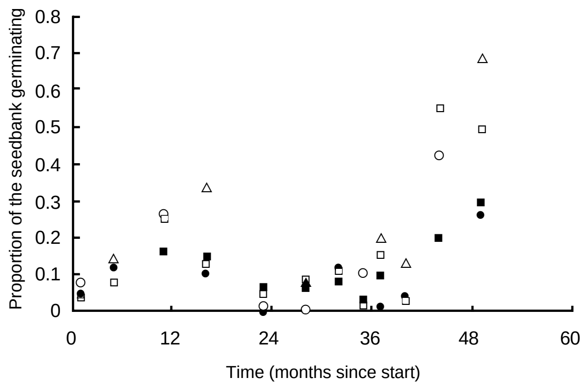

Figure 3. Probability of seed in the seedbank becoming a seedling against time at (a) Krawarree 'improved' (○,●), (b) Krawarree 'native (△,▲) and (c) Waterboard (□,■) both with (○,△,□) and without (●,▲,■) grazing.

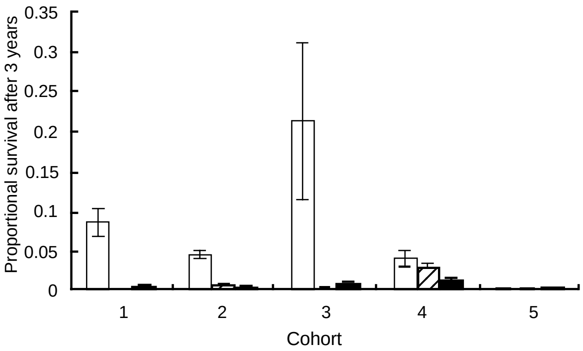

Figure 4. Survival of the first five cohorts of broom seedlings (dates varied between sites), for the first three years after germination, following application of disturbance treatments (back transformed from arcsine transformed data) for the three sites; Krawarree 'improved' (white bars), Krawarree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

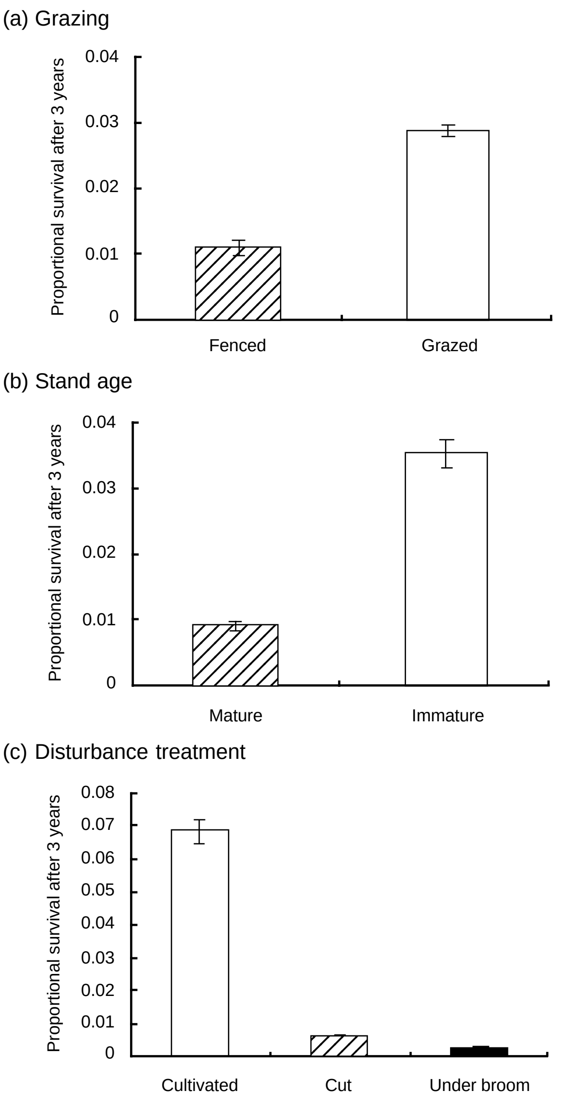

Figure 5. Effect of treatment on survival of the first five cohorts of broom seedlings for the first three years after germination following application of disturbance treatments (back transformed from arcsine transformed data). Mean data for all sites combined ±SE.

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').

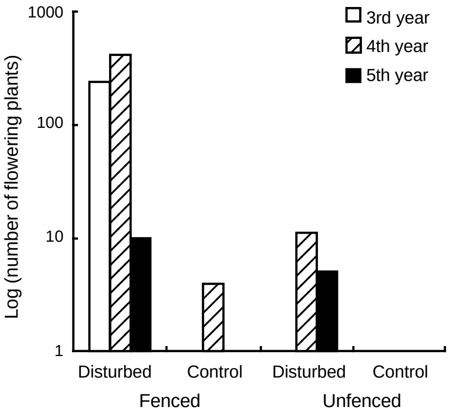

Figure 6. Number of flowering plants in different age classes (third to fifth year) at first flowering in disturbed and control plots inside and outside fenced areas. Data from all sites.

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.

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References

Downey P. (2000) Broom and fire: management implications. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 178-83.

Fowler, S.V., Harman, H.M., Memmott, J., Paynter, Q., Shaw, R., Sheppard, A. and Syrett, P. (1996). Comparing the population dynamics of broom, *Cytisus scoparius*, as a native plant in the UK and France, and as an invasive alien weed in Australia and New Zealand. Proceedings of the Ninth International Symposium on Biological Control of Weeds, 21–26 January 1996, Stellenbosch, South Africa, eds C. Moran and J. Hoffman, pp. 19-26. (University of Cape Town, Cape Town).

Hosking, J.R., Smith, J.M.B. and Sheppard, A.W. (1998). *Cytisus scoparius* (L.) Link ssp. *scoparius*. *In* 'The biology of Australian weeds'. Vol. 2. eds F.D. Panetta, R.H. Groves and R.C.H. Shepherd, pp. 77-88. (R.G. and F.J. Richardson, Melbourne).

McCullagh, P and Nelder, J.A. (1983). 'Generalized linear models', 2nd edition. (Chapman and Hall, London).

Memmott, J., Fowler, S.V., Syrett, P. and Hosking, J.R. (1993). What makes broom a major problem? Proceedings of the Brighton Crop Protection Conference, 22–25 November 1993, Brighton, United Kingdom, pp. 753-8. (British Crop Protection Council, Farnham, UK).

Noble, I.R. (1989). Attributes of invaders and the invading process: terrestrial and vascular plants. *In* 'Biological invasions: a global perspective', eds J.A. Drake, H.A. Mooney, F. di Castri, R.H. Groves, F.J. Kruger, M. Rejmanek and M. Williamson, pp. 301-10. (J. Wiley & Sons, Chichester).

Paynter, Q., Fowler, S.V., Hinz, H.L., Memmott, J., Shaw, R., Sheppard, A.W. and Syrett, P. (1996). Are seed-feeding insects of use for the biological control of broom? Proceedings of the Ninth International Symposium on Biological Control of Weeds, 21–26 January 1996, Stellenbosch, South Africa, eds C. Moran and J. Hoffman, pp. 495-501. (University of Cape Town, Cape Town).

Paynter, Q., Fowler, S.V., Memmott, J. and Sheppard, A.W. (1998). Factors affecting the establishment of *Cytisus scoparius* in southern France: implications for managing both native and exotic populations. *Journal of Applied Ecology* 35, 582-95.

Paynter, Q., Fowler, S.V., Memmott, J. Shaw, R.H. and Sheppard, A.W. (2000). Determinants of broom (*Cytisus scoparius* (L.) Link) abundance in Europe. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 149-55.

Rees, M. and Paynter, Q. (1997). Biological control of Scotch broom: modelling the determinants of abundance and the potential impact of introduced insect herbivores. *Journal of Applied Ecology* 34, 1203-22.

Rousseau, J. and Loiseau, A. (1982). Structure et cycle de development des peuplements a '*Cytisus scoparius* L.' dans le chaine des puys. *Acta Oecologia Applicata* 3, 155-68.

Sheppard, A.W. (2000). Weed ecology and population dynamics. *In* 'Australian weed management systems', ed. B.M. Sindel, pp. 39-60. (R.G. and F.J. Richardson, Melbourne).

Sheppard, A.W., Hosking, J.R. and Leys, A.R. (2000). Broom (*Cytisus scoparius* (L.) Link) population management strategies. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 134-9.

Smith, J.M.B. (2000). An introduction to the biogeography and ecology of broom (*Cytisus scoparius*) in Australia. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 140-4.

Thompson, A.R. (1988). Fluroxypyr, a new herbicide for scrub and woody weed control in forestry and amenity areas. *Aspects of Applied Biology* 16, 177-82.

Tutin, T.G., Heywood, V.H., Burges, N.A., Moore, D.M., Valentine, D.H., Walters, S.M., and Webb, D.A. (eds) (1968). 'Flora Europaea', Volume 2, p. 89. (Cambridge University Press, Cambridge).

Waloff, N. and Richards, O.W. (1977). The effect of insect fauna on growth, mortality and natality of broom, *Sarothamnus scoparius*. *Journal of Applied Ecology* 14, 787-98.

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 herbicide is applied using a 'handgun' sprayer, the whole plant must be covered otherwise it will regenerate from the unsprayed portion. After successful spraying, dead branches of the plant must be destroyed, usually through burning, otherwise they help protect new broom seedlings in the undergrowth and speed up broom stand regeneration.

On 'Tomalla' there are four main factors that prevent successful spraying:

(a) **Weather** – with the high frequency of rainfall and mist on the property it is hard to find days suitable for spraying.

(b) **Timber** – trees and logs, in addition to density of broom itself, make it hard to achieve an even spray cover of broom.

(c) **Rocks** – the rocky terrain is not friendly to spray vehicle gearboxes and differentials causing frequent additional repair costs or preventing access to areas.

(d) **Wombat holes** – these also damage the suspension and chassis of spray vehicles and slow access to infested areas, again making site access difficult.

Spray rigs used for herbicide application to broom on 'Tomalla' include: (a) tractors with spray tanks, (b) 4-wheel-drive trucks with spray tanks, (c) aerial spraying by helicopter (prior to restrictions on this form of control imposed in the 1980s), and (d) manual cutting of bushes followed by the spraying of stumps with Tordon® (active ingredients 2,4-D amine and picloram, applied undiluted). Chemical control of broom on 'Tomalla' is mainly for containment of existing infestations, control along access tracks and roads, and maintenance of previously sprayed areas. Current chemical and labour costs of spraying are approximately $45 000 per annum.

Fire

Fire is one of the most economic ways of controlling broom on 'Tomalla'. The main disadvantage of this control technique is that it stimulates germination of broom seeds. Since frequent use of fertilizer on grazing land from the late 1950s, however, general farm management practise has frowned upon fire, as it tends to deplete soil sulphur levels, thereby reducing effectiveness of fertilizer applications. Since the 1980s, fire was reintroduced as a scrub control technique, but there are very few days suitable for burning at 'Tomalla', and the majority of these fall in periods when a total fire ban has been imposed elsewhere in the region!

Livestock

Goats

Goats (a combination of feral nannies from Cobar, New South Wales and male meat goats from Condobolin, New South Wales) provide about the best form of control using livestock as they eat smaller plants and ring-bark larger stems. Goats, however, seem to be more prone to toxins in the weed than sheep and were difficult to contain within the control area. For example, during the 1980 drought the goat herd escaped through holes in the fencing caused by wombats and now lives as a feral population on the side of Sunny Brae Hill. Here at least they are doing a good job eating blackberries.

Sheep

Sheep have been the main livestock used to control broom and are quite effective. Sheep, especially crossbreeds, behave similarly to goats, being also very difficult to contain within the control area. In contrast, merinos have less of a tendency to escape and are therefore more easily managed. Up until the mid 1960s there were 3000 to 4000 sheep run on 'Tomalla' and, with the use of fire, broom was well contained. However, due to wild dog attack, sheep numbers have been reduced to about 1500 and these can only be run for about 3 months a year until wild dogs find them. At this time sheep need to be shifted to lower country of Ellerston Pastoral Company. In 1985, 4000 sheep were run for three months, November to January, in a 517 ha paddock called Hushes. They ate all the broom seedlings and the larger plants up to a height of 1.2 m. The following year seedlings reappeared all over the paddock. The sheep had eaten the seeds and effectively spread them in their droppings. In 1986 and each year since, 1500 sheep were returned to the paddock in November for four months. When possible the area is now burnt off which also kills plants that have been damaged by sheep. There is some evidence from this that livestock and fire can be effectively used in combination.

Cattle

During a drought a large area of broom in one part of Hushes paddock was sprayed with molasses. Cattle were introduced into the paddock where they broke down bushes to get to the foliage and this also allowed sheep to clean up seedlings. This novel use of cattle with sheep may also have wider application.

Biological control

In 1990 a need to coordinate broom control on 'Tomalla' and the adjoining State Forest and National Park led to the creation of the Broom Council. One of the main objectives of this council was to work towards the long term control of broom through biological control agents (Adams 2000). Ellerston Pastoral Company has been involved in this council and the Management Committee for the Biological Control of Scotch Broom which was set up following the commencement of the biological control program. Ellerston Pastoral Company, along with National Parks and Wildlife Service, State Forests, NSW Agriculture and CSIRO, has contributed to the expense of the biological control campaign since its inception. Three insects have been released for control of broom on 'Tomalla'. These insects are the broom twigminer, *Leucoptera spartifoliella* Hübner, a broom psyllid, *Arytainilla spartiophila* Förster and a seed feeding bruchid, *Bruchidius villosus* Fabricius. Only one insect, broom twigminer, has been seen following release on 'Tomalla' and no impact on broom has been achieved to date. Further releases will be made on 'Tomalla' in coming years and monitoring of releases and evaluation of impact will no doubt continue.

A scale insect, *Parthenolecanium rufulum* (Cockerell), a native of Europe, occasionally kills branches and sometimes entire broom plants on 'Tomalla'. It is not known how this insect reached this area.

Conclusion

There is at present no effective cheap technique for control of broom on 'Tomalla'. Broom is being held in check by herbicides and grazing, but costs of control are too expensive to attempt broom control throughout the entire 2000 ha infestation.

References

Adams, B. (2000). Raising awareness of the broom (*Cytisus scoparius*) problem on the Barrington Tops. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 139-40.

Waterhouse, B.M. (1988). Broom (*Cytisus scoparius*) at Barrington Tops, New South Wales. *Australian Geographical Studies* 26, 239-48.

Broom (*Cytisus scoparius* (L.) Link) competition and management in eucalypt tree farms

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Summary

A trial to evaluate competitive impact of broom (*Cytisus scoparius* (L.) Link) on establishing *Eucalyptus nitens* (H.Deane & Maiden) Maiden was established in a two year old plantation with a uniform broom cover, near Waratah, north-west Tasmania. Treatments consisted of three levels of broom control (total, inter-row and none), combined with two levels of fertilizer (0 and 200 kg ha^{-1} nitrogen). After one and a half years the current practice of inter-row broom control without added nitrogen had no significant impact on *E. nitens* stem volume. There was a significant increase in stem volume of at least 23% due to nitrogen and of 49% increase due to total broom control. This suggested that competition was likely to be for nutrients and that it would be more economic for plantation managers to apply 200 kg ha^{-1} nitrogen at years two to three than to perform post-plant inter-row broom control.

Mapping of broom in the north-west of Tasmania revealed 59 250 ha containing broom. Data generated during mapping was used to develop a broom management plan that includes control of isolated broom plants, isolation of large infestations and adoption of long term control strategies such as release of biological control agents.

Introduction

Broom (*Cytisus scoparius* (L.) Link) is a potential threat to the success of eucalypt tree farms in north-west Tasmania. Anecdotal evidence suggests that broom competes strongly with developing *Eucalyptus nitens* (H.Deane & Maiden), resulting in reduced tree growth with longer rotation ages and fewer trees surviving to maturity. Three years after planting Richardson *et al.* (1996) found a 51% reduction in *Pinus radiata* D.Don stem volumes when grown in the presence of broom. However, there are no references on the impact of broom competition on developing eucalypts.

Broom is currently controlled in plantations through combinations of inter-row tractor mounted slashing and shielded spraying with glyphosate. Since these costs are incurred in years two to three of an on average fifteen year rotation, it is essential that these operations provide optimal tree productivity gains. To evaluate competitive impact of broom in young *E. nitens* a trial consisting of post-plant broom control and fertilizer treatments was established in a three year old *E. nitens* plantation.

In order to assess significance of the broom threat, affected areas were identified in a broom mapping program linked to a Geographical Information System (GIS). The many benefits of using GIS for weed management planning have been reviewed by Prather and Callihan (1993). The GIS software (ArcView) graphically positions map features in relation to known locations, and relates these features to other cartographic features.

Materials and methods

Competition trial

The trial was established on an ex-native forest site near Waratah in north-west Tasmania. Soils at the site were developed on basalt (ferrosol) with soil pH around 5.2. The average annual temperature is 8°C. The average annual rainfall of 2199 mm (decile one = 1748 mm per annum, decile nine = 2675 mm per annum) is distributed throughout the year with a marked winter peak. Rainfall for the period from trial establishment (December 1997) to the most recent measurements (June 1999), was 3399 mm, while evaporation for the same period was 1287 mm.

Following harvesting in 1993, the site was disced then mounded using a Savannah mound plough. *E. nitens* were planted at a spacing of 3.5 × 2.6 m in October 1995 giving a planting density of approximately 1100 seedlings per hectare. The site has a uniform broom cover with few other weeds present.

Trial design was a randomized complete block with four replicates, three levels of broom control (total, inter-row and none) and two levels of nitrogen fertilizer (0 and 200 kg ha^{-1} nitrogen). Inter-row broom control represents approximately 35% of the plantation area. Broom control was performed initially using brushcutters, with all slashed broom left on site. Glyphosate was applied to broom regrowth using a shielded nozzle knapsack at 1350 g active ingredient ha^{-1} three months after brushcutting. An organosilicant penetrant was included at 0.2% v/v. Urea was applied after the initial broom control treatments as a spot application at the base of each tree.

Plots were approximately six tree rows wide by eight trees long, providing an internal minimum of 25 measure trees (i.e. perimeter trees acted as buffers). The above ground biomass of broom (kg ha^{-1} dry matter (DM)) was determined by randomly selecting six 1 m^2 quadrats from both inter- and intra-rows.

Tree heights and DBH (diameter at breast height i.e. 1.3 m) were measured at trial establishment (1997) and again in June 1998 and 1999. This data was analysed using analysis of variance. Results are presented as incremental stem volume calculated as the difference between volume in 1999 and 1997, i.e.

$$\text{Stem volume} = \frac{\text{height} \times \text{DBH}^2 \times \pi}{12}$$

Management of broom

Broom was mapped in the north-west of Tasmania, focusing on the Surrey Hills estate south of Burnie using the Tasmanian Weed Mapping Guidelines (Bishop 1997). Mapping was concentrated on those areas susceptible to infestation, or where broom was known to occur, rather than picking sites at random. The location (Australian Grid Map Coordinates), land use and tenure, dimensions of infestation, plant size and signs of management were manually recorded and entered into a database. The data was processed by ArcView GIS software.

Results and discussion

Competition trial

Biomass measurements indicated there were similar amounts of broom on the intra-rows (16 050 kg ha^{-1}) and inter-rows (16 300 kg ha^{-1}), confirming observations that broom was evenly distributed across the plantation.

As shown in Figure 1 the addition of fertilizer significantly increased the DBH increment from 1997 to 1999 (P=0.0001). Total broom control had a significant impact on DBH increment (P=0.0001), but inter-row broom control had no significant impact (P=0.61).

Incremental gain in tree height averaged 216.9 cm ± 19.9 cm for the 18 months and was not significantly influenced by broom control (P=0.86) or fertilizer treatment (P=0.84).

Incremental gain in stem volume for 18 months after the treatments were applied is shown in Figure 2. Total broom control, with or without fertilizer resulted in a 49% increase in stem volume (P=0.0001) compared with the control. Fertilizer responses with inter-row or no broom control were around 24% (P=0.0038). There was no response to inter-row broom control alone (P=0.54).

As total broom control is expensive (~\$400-\$500 ha^{-1}) the current practice on broom infested sites is to inter-row slash and apply glyphosate (i.e. IRBC and NFER) to control regrowth (~\$180 ha^{-1}).

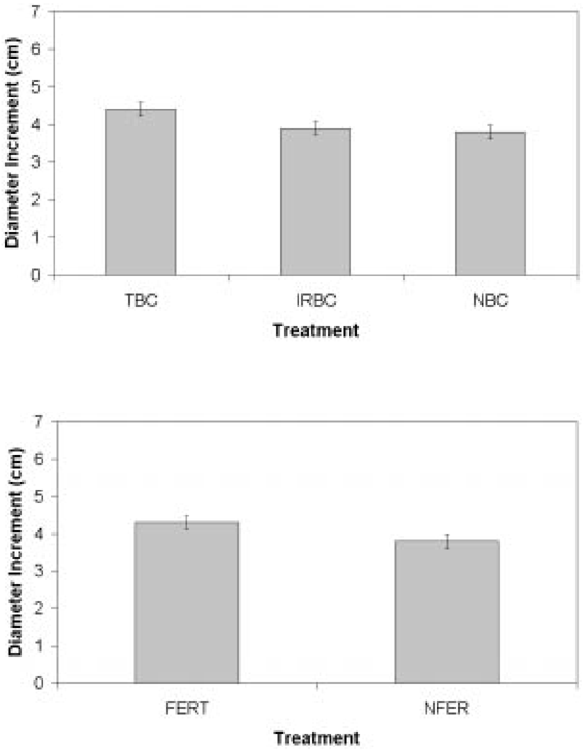

Figure 1. Effect of broom control (standard error = 0.36) and fertilizer treatment (standard error = 0.37) on incremental DBH (diameter at breast height) after 18 months. (TBC = total broom control, IRBC = inter-row broom control, NBC = no broom control. FERT = spot application of nitrogen (200 kg ha^{-1}), NFER = no fertilizer).

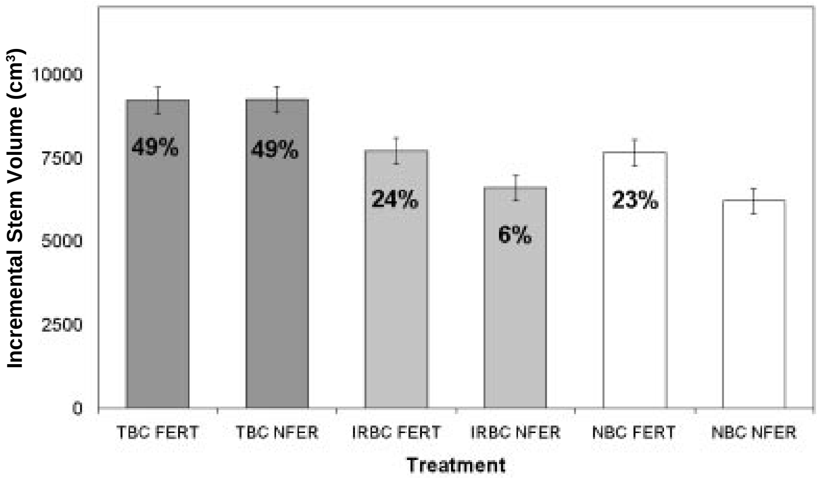

Figure 2. Effect of broom control and fertilizer treatment on incremental stem volume after 18 months (standard error = 771). Percent figures represent increase in volume compared with the control. (TBC = total broom control, IRBC = inter-row broom control, NBC = no broom control. FERT = spot application of nitrogen (200 kg ha^{-1}), NFER = no fertilizer).

After 18 months this had no significant impact on eucalypt growth (6% increase). A cheaper, more effective option is to spot apply 200 kg ha^{-1} nitrogen (i.e. NBC and FERT) at the base of each tree (~$140 ha^{-1}). On many sites access for fertilizing is difficult, and work is currently being undertaken to assess the relative merits of spot versus broadcast (e.g. aerial) fertilizer application.

Mechanisms of competition at this site are unclear. It can be assumed with high annual rainfall that moisture is not a major limiting factor to growth. At trial establishment the eucalypt canopy was above that of broom, which would suggest competition for light is not limiting tree growth, although there maybe some effect on the lower canopy.

Response of eucalypts to nitrogen in the no broom control treatment shows that soil nitrogen is limiting tree growth at this site. Rhizobial nodules on broom roots fix nitrogen, but compared to other agricultural legumes the rate of nitrogen production is low (Wheeler *et al.* 1979, cited in Hosking *et al.* 1998). In controlling broom there would be an increased level of mineralization and nutrient uptake by eucalypts possibly explaining the lack of response to nitrogen associated with total broom control. Nambiar and Sands (1993), suggest that on sites where moisture is not limiting, such as at Waratah, the effect of controlling competitors in improving nutrient supply is equalled to that of applying large amounts of fertilizer. Considering an estimate of nitrogen content in broom shoots (1.45%) by Wheeler *et al.* (1987) and the biomass of broom on site (~16 240 kg ha^{-1}) there is a potential input of 235 kg ha^{-1} nitrogen at this site from total broom control. It may be that we can achieve equivalent growth responses to total broom control simply through the addition of higher rates of nitrogen.

As broom is intolerant of shade (Hosking *et al.* 1998), the key to managing broom in plantations is to achieve canopy closure at the earliest possible age. Application of nitrogen at years two to three can help achieve this.

Management of broom

The survey identified approximately 59 250 ha infested with broom.

Broom maps (Figure 3) were used to develop a management plan aimed at control of isolated plants close to North Forest Products land, management of larger infestations and encouragement of biological control measures. A key to the strategy is to manage spread of major infestations through cultural practices. Moving machines from infested broom sites spreads broom seed. Identifying these sites and implementing a wash down procedure should limit future broom seed spread.

Across the larger broom infested areas, biological control agents, provided by the Management Committee for the Biological Control of Scotch Broom through the Co-operative Research Centre (CRC) for Weed Management Systems are being released. It is envisaged this long term control strategy, rather than chemical control, will be successful in significantly reducing the broom population in the mapped area.

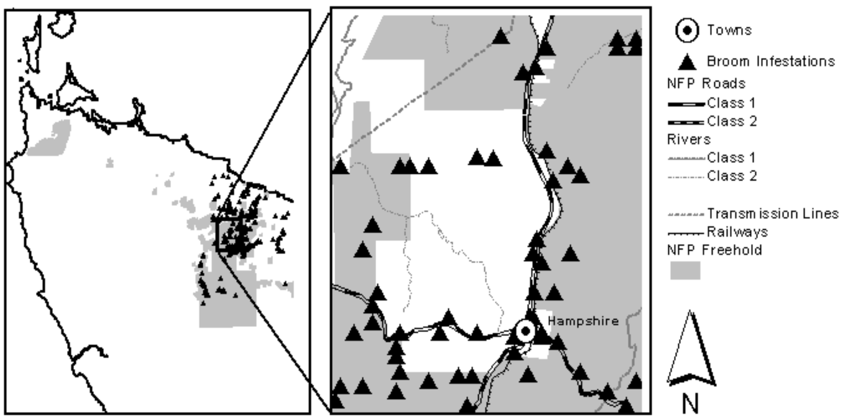

Figure 3. Locations of known broom infestations on and around Surrey Hills, Tasmania (scale of North West Coast 1:50 000). NFP = North Forests Products.

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References

Bishop, A. (1997). 'Tasmanian weed mapping guidelines', 2nd edition. (Tasmanian Weed Mapping Network, Devonport).

Hosking, J.R., Smith, J.M.B. and Sheppard, A.W. (1998). *Cytisus scoparius* (L.) Link ssp. *scoparius*. *In* 'The biology of Australian weeds'. Volume 2, eds F.D. Panetta, R.H. Groves and R.C.H. Shepherd, pp. 77-88. (R. G. and F. J. Richardson, Melbourne).

Nambiar, E.K.S. and Sands, R. (1993). Competition for water and nutrients in forests. *Canadian Journal of Forestry Research* 23, 1955-68.

Prather, T.S. and Callihan, R.H. (1993). Weed eradication using geographic information systems. *Weed Technology* 7, 265-9.

Richardson, B., Vanner, J.R., Davenhill, D. and Coker, G. (1996). Mechanisms of *Pinus radiata* growth suppression by some common forest weed species. *New Zealand Journal of Forestry Science* 26, 421-37.

Wheeler, C.T., Helgerson, O.T., Perry, D.A. and Gordon, J.C. (1987). Nitrogen fixation and biomass accumulation in plant communities dominated by *Cytisus scoparius* L. in Oregon and Scotland. *Journal of Applied Ecology* 24, 231-7.

Controlling broom (*Cytisus scoparius* (L.) Link) in native forest ecosystems

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Summary
From State Forests of New South Wales perspective the major broom infestation is on Barrington Tops – covering over 10 000 ha of State Forest, National Park and private land. The use of State Forests on Barrington Tops as a case study soon explains the frustration of dealing with this environmental weed in forest ecosystems. Adequate access for ground techniques like slashing and spraying is a major issue in its control.

Introduction
On Barrington Tops, the broom (*Cytisus scoparius* (L.) Link) infestation possibly started as early as the 1840s as an imported garden and hedge plant (Waterhouse 1988). Much of the broom infested forest land on the Barrington Tops was vacant crown land until dedication as State Forests and National Park from the early 1960s through to early 1970s. Access to the high country (over 1000 m above sea level) where broom occurs awaited State Forests of New South Wales (SFNSW) road construction programs from 1968-1978. It is perceived by some that broom spread also coincided with displacement of graziers' seasonal burning of the Barrington Tops high country. There is now over 10 000 ha of land infested with broom on the Barrington Tops in State Forests, a National Park and on private property.

Broom seems to mainly occupy areas of open forest and woodland with a snowgrass (*Poa sieberiana* Spreng.) understorey. These areas tend to be mostly non-commercial forests and therefore the impact of broom on forestry of commercial native species is largely untested in terms of commercial timber production. Given the latitude of Barrington Tops, broom, by default, occupies the highest altitudes due to its preference for cool climates. It is feared (but not proven) that broom on the Barrington Tops may develop the capacity to encroach on areas of lower altitude over time through natural selection processes. This possibility is suggested by the occasional observation of short-lived individual broom plants along watercourses at lower altitudes than the main infestation.

Broom has infiltrated some forest logging areas adjacent to the woodlands – mainly in *Eucalyptus fastigata* H.Deane & Maiden, *E. obliqua* L'Hér. and *E. dalrympleana* Maiden ecotones and may well interfere with commercial *Eucalyptus* regeneration by rapidly occupying the site. No formal studies have been done.

As a part of public forest management, access is also provided for recreational traffic, particularly 4-wheel-drive enthusiasts. This development contributed to spread of broom along fire trails in the area. Broom infestations also cause other management problems. Feral pigs favour dense broom clumps (some up to 1 km^2 in size) and this makes pig control more difficult. In turn, pig diggings create a seedbed for new broom, and pigs are believed to transport seed in mud attached to them. Watercourses are another important vector of broom seeds.

Control techniques
Control programs commenced in earnest in the late 1970s using hand slashing and some chemical spraying. Early work trialed hand slashing, then heaping the slash over the site and burning it when dry. Achieving a satisfactory burn is a real problem in this sub-alpine environment. With an intense fire, a very good kill was achieved and some seed was incinerated. The downfall was an excellent seedbed for remaining seed, resulting in very dense regeneration of broom within 12 months.

Given that broom may produce seed within 2–3 years of germination, spraying of broom regeneration was mandatory within that time. Obviously this produced an exponential increase in sites to be treated i.e. maintenance of previously sprayed areas plus any new areas. Control requirements using these methods grew beyond the capacity of available resources. Accessibility of broom infested areas was also a problem. It became increasingly obvious that alternative methods of control were needed, the most likely being long-term control using biological agents.

Spraying with Garlon® (active ingredient triclopyr, 170 mL to 100 L) is very effective, but expensive and labour intensive. The spray program has concentrated on preventing linear expansion of the broom infestation along fire trails, by destruction of broom plants in new locations, as well as by providing a buffer between seed bearing broom plants and the trails. This has been quite successful, but again requires annual maintenance of regenerating broom given the many years that seed remains viable (Hosking *et al*. 1998). The quandary with ongoing or expanded herbicide use is that all past and present efforts will be to no avail if the program is discontinued and broom regeneration occurs. The program is also limited in success due to the need to contain the movement of broom occurring away from trail edges, i.e. beyond the spray hose length of about 100 m. Beyond this distance access is a problem requiring installation of spray tracks where possible (using machinery) if control using herbicide is desired.

Quarantine controls are implemented where logging occurs alongside broom infested areas. This is costly to industry and SFNSW, but is seen as a necessary measure. Quarantine measures mainly involve washing down machinery and trucks, as they leave infested areas, to remove mud containing broom seeds.

Mapping broom

Accurate mapping of broom commenced in 1982 using aerial photographs. In 1995 mapping was conducted using a helicopter mounted Global Positioning System 'live linked' to a Geographic Information System on a lap-top computer. Mapping using this technology was carried out again in 1998 as a cooperative exercise between State Forests and the NSW National Parks and Wildlife Service. It has supplemented mapping work carried out either from the ground or from aerial photographs. Broom mapping is made particularly easy from the air or from photos during the flowering season when it is very distinctive. The mapping work has shown that spread of broom in the last three years has not been as dramatic as some initially expected.

Cost-benefit assessment

The current State Forests broom control budget is around $30 000–40 000 per annum. SFNSW has also contributed to the current biological control programs with contributions of between $5000 and $41 500 per annum from 1989 to 1998. Overall, the physical control measures carried out by SFNSW over the past 20 years have managed to reduce linear spread of broom along trails. However, the above mapping has clearly identified more rapid linear spread of broom along water courses.

Other SFNSW infestations

Other infestations on State Forest land occur in areas of native vegetation and pine forest within the central tablelands pine plantations at Sunny Corner State Forest and in Gemalla State Forest, areas to the east of Bathurst. Here there is over 40 ha of broom, and like the Barrington Tops infestation, the weed is of concern for its environmental effects rather than any significant commercial effect. The Sunny Corner infestation is encroaching on the habitat of the endangered Bathurst copper butterfly (*Paralucia spinifera* Edwards and Common). Control measures in this area are mostly through use of herbicide and mechanical removal to assist in regeneration of the host plant of this butterfly, native blackthorn (*Bursaria spinosa* Cav.).

Conclusion

Broom appears to have no real impact on the commerciality of any State Forests enterprise in NSW, rather broom is an environmental weed that needs to be controlled to ensure aesthetic value of these areas and to protect native biodiversity, and State Forests is committed to carry out control measures as a responsible land management agency. The only sensible solution to broom control in such extensive native forest ecosystems with poor general access lies in biological control with other control methods dovetailed into an integrated program across the entire landscape, independent of tenure. The immediate, if sidestepping, solution for SFNSW to most of the Barrington Tops broom problem has recently been delivered by the NSW Government transfer of these impacted State Forest lands to the NSW National Parks and Wildlife Service as part of the establishment of a 'Comprehensive, Adequate and Representative Reserve System' – complete with broom! SFNSW will continue to apply control methods for broom in the balance of its estate but this is considered to be relatively minor with a fair chance of eradication from State Forest land, provided that adequate resources are focused on that area.

References

Hosking, J.R., Smith, J.M.B. and Sheppard, A.W. (1998). *Cytisus scoparius* (L.) Link ssp. *scoparius*. *In* 'The biology of Australian weeds' Volume 2, eds F.D. Panetta, R.H. Groves and R.C.H. Shepherd, pp. 77-88. (R.G. and F.J. Richardson, Melbourne).

Waterhouse, B.M. (1988). Broom (*Cytisus scoparius*) at Barrington Tops, New South Wales. *Australian Geographical Studies* 26, 239-48.

Herbicides for broom (*Cytisus scoparius* (L.) Link): testing alternatives to Grazon®

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Summary

Grazon® is registered for control of broom (*Cytisus scoparius*) and is used widely by Parks Victoria. Because of its volatility, however, Grazon cannot be used in close proximity to crops (such as grapes or tobacco), waterways and residential areas. An alternative registered herbicide for broom that can be used in such situations was required. This paper describes field trials that were conducted to determine effectiveness of Roundup® and Roundup Biactive®. As a result of this study Roundup and Roundup Biactive have been registered for control of broom.

Introduction

Broom (*Cytisus scoparius* (L.) Link) is a serious environmental weed in Victoria's Alpine National Park and surrounding areas. Communities where it poses a serious threat include the Bogong High Plains and other subalpine areas up to 1700 m above sea level. Many river systems sourced from these catchment areas, such as the Mitta Mitta and Snowy River systems are lightly to seriously infested. The herbicide, Grazon® (DowElanco; active ingredients triclopyr and picloram) is registered for broom control and is used widely by Parks Victoria and the Department of Natural Resources and Environment (DNRE). Because of its volatility, however, Grazon cannot be used in close proximity to crops (such as grapes and tobacco), waterways or residential areas. An alternative registered herbicide for broom that can be used in such situations is required. This paper describes field trials that were conducted to determine the effectiveness of Roundup® and Roundup Biactive® (called Biactive in the tables) (Monsanto; active ingredient glyphosate).

Methods

A trial area was located near the Bright Recreation Reserve. This area was divided into discrete broom plots. Each plot contained broom plants of variable age, including both isolated plants and dense thickets, and was of a size (10 × 10 m) to justify a tank mix volume (40–50 L) that would be representative of normal working rates. The treatments applied in the trials are described in Table 1. A slip-on spray unit with a single hand-gun was used to apply herbicide with a spray gun pressure of 180 psi.

First trial

Two application rates, 1.3% and 2.9% active ingredient were used. Based on other weed control treatments, application rates selected were those recommended for 2 m tall blackberry (*Rubus fruticosus* L. species aggregate) infestations and 1.5 m sweet briar (*Rosa rubiginosa* L.) infestations respectively. As broom may defoliate after flowering, it was considered appropriate to compare results with the addition of a wetting agent that may assist herbicide absorption into woody photosynthetic branches. A relatively high application rate of 0.2% of the wetting agent BS1000 was used to qualitatively assess importance of its inclusion. Roundup Biactive was applied on 13 May 1997, and Roundup was applied on 14 May 1997. Both applications were made in the afternoon. Prevailing weather conditions were calm, fine and sunny, daily maximum temperatures were 17 and 18°C respectively, following frosty nights.

Second trial

The second trial was conducted on 4 December 1997. In this trial additives, the wetting agent, BS1000, and the penetrant, Pulse®, were compared, as the latter is known to enhance absorption of herbicide, particularly by non-foliar areas of the plant. Treatments were applied as in Table 2 to seven plots. Prevailing weather conditions were calm, sunny and the external temperature was 26°C.

Results and discussion

First trial

Assessment was made on 20 November 1997. Observations (Table 1), made independently by several trained personnel, suggested that greater success had been achieved using the 2.9% glyphosate application rates (plots 2, 3 and 5). Nonetheless significant success was achieved by 1.3% glyphosate application rates particularly considering the late application. The addition of wetting agent was determined to be advantageous. The results from this trial prompted the second.

Table 1. Results of glyphosate spray trials on broom.

Plot	Herbicide		Wetting agent		Volume applied (L)	Shoot brownout (%)	Comments
	Type	% active ingredient	Type	% wetting agent			
Trial 1[A]							
1.1	Biactive	1.3	nil		40	>90	
1.2	Biactive	2.9	nil		50	>90	
1.3	Roundup	1.3	nil		40	>90	
1.4	Roundup	2.9	nil		40	>90	
1.5	Roundup	2.9	BS1000	0.2	40	>90	
1.6	Roundup	1.3	BS1000	0.2	40	>90	
Trial 2[B]							
2.1	Roundup	1.3	BS1000	0.1	50	85–90	Possibly due to insufficient coverage. Smaller bushes 100%
2.2	Biactive	1.3	BS1000	0.1	50	100	
2.3	Biactive	1.3	nil		50	100	
2.4	Biactive	2.9	nil		50	100	
2.5	Roundup	1.3	nil		50	100	2 small plants 40% due to insufficient coverage
2.6	Biactive	1.3	Pulse	0.2	50	100	1 large bush 60% due to insufficient coverage
2.7	Roundup	1.3	Pulse	0.2	50	100	Montpellier broom (*Genista monspessulana* (L.) L.A.S. Johnson) also present (also 100% brownout)

[A] Herbicide applied 13 and 14 May 1997, assessment made 20 November 1997.
[B] Herbicide applied 4 December 1997, assessment made 4 June 1998.

Second trial

Assessment was made on 4 June 1998. The results are presented in Table 1. Results overall were a good kill where sufficient coverage was achieved during spraying. Any differences between Roundup or Roundup Biactive, or the value of using various additives in the spray mix, could not be defined given the application rates used.

Table 2. Relative cost of mixed herbicide.

Herbicide	Cost (20 L)	Application rate	Cost (100 L of mix)
Grazon	$660	250 mL / 100 L	$8.25
Biactive	$133	1.3 L / 100 L	$8.65

[A] The advice provided in this document is intended as a source of information only. Always read the label before using any of the products mentioned. The author accepts no responsibility or liability whatsoever for any loss or damage arising from using the above products

Herbicide selectivity

The possibility of non-target damage is a key criteria in herbicide selection. Roundup and Roundup Biactive are non-selective herbicides. The possibility of the understorey surrounding the weed species being affected is high, particularly grass species. Similarly, with Grazon (a selective herbicide for woody weed control), the possibility of nearby woody species being affected is high. The legal use of herbicides near watercourses is covered by label registration. There is worldwide concern regarding the effects that surfactants have on amphibians. Most herbicides either contain surfactants or require their addition during mixing, to enhance adherence and absorption. Roundup Biactive (apparently 'surfactant-free') is claimed to be safe for use in and around watercourses in certain situations. Despite this, the application method should be designed to minimize the amount of spray actually entering any water.

Relative costs

Relative costs are remarkably close (Table 2). Factors affecting herbicide choice that should be considered, prior to cost considerations, are potential non-target damage and potential contamination of watercourses.

Registration for label use

The results were sufficient to start the registration process for Roundup and Roundup Biactive against broom. Lack of this registration did not prevent Parks Victoria from using Roundup for broom control in National Parks, as the agency is allowed to use herbicides at label rates for the control of off-label species provided Parks Victoria management agrees. Off-label recommendations, however, cannot be made to the public until the herbicide is registered. This places the agency in an awkward position, when undertaking control operations in conjunction with neighbouring landholders. Legislation in Victoria does allow for training and certification of DNRE staff to provide off-label advice. These considerations are now academic as Roundup and Roundup Biactive were registered for broom control in March 2000 and this use will appear on future labels.

Conclusions

These trials have shown that glyphosate is an effective herbicide for broom control. Satisfactory results were obtained at the 1.3% application rates if applications were made during periods of active broom growth. With this application rate, wetting agent or penetrant additives gave no additional benefit. Further trials may show that lower application rates are also effective during active growth and that additives may contribute to the level of control at such levels. While applications at the 2.9% rate gave control during early winter periods, when the plant was not actively growing, application at that time is not recommended as applications are most economically made when the amount of active ingredient applied is minimal.[A]

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Controlling broom (*Cytisus scoparius* (L.) Link) in natural ecosystems in Barrington Tops National Park

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Summary

In 1996 the New South Wales National Parks and Wildlife Service (NPWS) developed a formal management strategy for broom containment in Barrington Tops National Park. This strategy was based on a review of the 1987 containment strategy developed by the NPWS in association with the Broom Council. The strategy recognizes the impact of broom on the natural ecosystem and aims to ensure annual implementation of an effective containment program without compromising natural values of the area by causing further impacts on this sensitive subalpine environment.

Introduction

Broom (*Cytisus scoparius* (L.) Link) has become a major weed on the Barrington Tops plateau (including Barrington Tops National Park) since it was first introduced as a garden plant on the property 'Tomalla', at the northern end of the plateau, in the 1840s. Broom was recognized as a major weed by 1964 and its spread was associated with grazing, fire and logging trails throughout the plateau (Waterhouse 1988).

Barrington Tops National Park conserves about 80 000 hectares of rugged landscapes varying in altitude from 1585 m above sea level (asl) on the Barrington Tops plateau down to 170 m asl at Chichester Dam. This large altitudinal range combined with a mosaic of geology, soils, rainfall and aspects provide a diversity of vegetation communities and faunal habitats. Vegetation communities grade from subtropical rainforests and tall open forests in the valleys through to cool temperate rainforests and subalpine woodlands and wetlands on the plateau (the latter two are impacted by broom). Rainforests of Barrington Tops National Park are the southern limit of World Heritage listed rainforests of eastern Australia. The diverse vegetation communities found in the park provide habitat for over 60 rare or threatened plant and animal species.

Broom infests an estimated 10 000 hectares of the Barrington Tops and is having a major impact on the natural ecology of the subalpine environment (Waterhouse 1988, Smith 1994). This weed is established in woodlands and open forest dominated by *Eucalyptus pauciflora* Sieber ex Spreng. with occurrences of other species such as *E. stellulata* Sieber ex DC. and *E. dalrympleana* Maiden (NPWS 1989).

Since the 1980s broom has also began to infest both the edge of subalpine wetlands and the open plains of the plateau (M. Newton personal communication). Vegetation communities below the Barrington Tops plateau within the National Park are dominated by subtropical rainforest, warm temperate rainforest, beech forest (*Nothofagus moorei* (F.Muell.) Krasser) and wet and dry sclerophyll forests. Whilst rainforests do not provide conditions suitable for the establishment of broom, large disturbed areas and drainage lines within rainforests, where there is more light, may provide suitable conditions. Dry sclerophyll forests at high altitude also provide suitable open conditions for broom establishment.

Broom control was initiated as early as 1972 in Barrington Tops National Park. Experimental plots were established to trial various control methods including clearing, fire and a range of chemicals (M. Newton personal communication). Early control methods involved large scale herbicide spraying. This method was largely ineffective as it involved a high degree of disturbance to native vegetation and soils which in turn promoted broom seed germination. There were also concerns about the safety of spray operators using such large amounts of herbicides.

As a result of unsuccessful control techniques the Broom Council was formed in 1987. The council recognized that the distribution and ecology of broom did not allow for its total eradication (Howard 1995). In 1987 a containment strategy was developed between affected landholders, including New South Wales National Parks and Wildlife Service (NPWS), State Forests of New South Wales (SF NSW) and private landholders. The aim of the strategy was to protect non-infested subalpine and lower catchment areas and minimize broom spread from the main infestation. In addition the NPWS has a responsibility to contain broom in a way that minimizes further environmental impacts.

The broom containment program is revised and implemented on an annual basis. Current control techniques have evolved to minimize environmental impact. Since implementation of the containment program in the late 1980s broom has been successfully contained along containment lines within the National Park, however this has not prevented an increase in density of broom within the main infestation. The containment program has been successful in treating isolated infestations and protecting unaffected catchments. Isolated broom plants in the Gloucester Tops area subalpine environment (separated from the infested area on the Barrington Tops by a forested area at slightly lower altitude) have been removed as part of this program.

When the containment strategy was implemented it was recognized that the only long term solution to reducing the size of the main infestation appeared to be establishment of suitable biological control agents. The Broom Council in the 1980s campaigned for funding to undertake research into biological control (Adams 2000).

Broom management strategy for Barrington Tops National Park

The NPWS is developing control strategies for all major weeds in National Parks across New South Wales. In 1996 the NPWS developed a 'Scotch Broom Management Strategy' which includes an annual works program based on the original containment program. No review had been undertaken since the original containment program was developed in 1987 and the annual works program had suffered from limited resources.

The strategy was developed to ensure an integrated approach to containing the infestation. The strategy incorporates the following objectives:

1. **Contain and treat broom within the existing infestation.** Broom is controlled along roadways, walking tracks and recreational areas to minimize spread into non-infested area. The boundaries of the infestation are also treated biennially. These boundaries are either road edges or natural boundaries such as rainforest. Recently broom control has commenced in areas identified as containing threatened plant species.
2. **Identify and treat any isolated infestations outside the main infestation.** Isolated infestations are identified by a biennial aerial survey and subsequently treated. Previously treated infestations are mapped and monitored biennially.
3. **A monitoring program.** Aims to:
   (a) identify isolated infestations,
   (b) measure changes in the density and distribution of the main infestation,

(c) measure success of the annual containment program,
(d) monitor impact and spread of biological control agents.

4. **Co-ordination of management with adjoining landholders.**
5. **Provide community information and awareness.**
6. **Support the biological control program.** Participate in the release of biological control agents and implement suitable monitoring programs.
7. **Identify the resources required to implement the management strategy annually.** An annual works program has been developed for objectives 1 and 2. This provides a detailed account of the location of treatment areas and appropriate control techniques.

Control techniques

Three control techniques are used during the annual program from October to January these include:

1. physical removal of immature broom,
2. cut and paint technique (stems are cut and neat glyphosate is applied),
3. herbicide spraying.

High costs are associated with physical removal and the cut and paint technique because they are labour intensive. Therefore these techniques are only employed on isolated plants, small infestations or in the following areas:

(a) where some populations of threatened plants are located,
(b) along the edge of water ways and in the subalpine wetlands,
(c) in and around recreational areas.

The cut and paint technique minimizes soil disturbance reducing potential broom seed germination. Physical removal reduces impact to non-target species and protects water quality and aquatic fauna. As part of the containment strategy within the main infestation herbicide spraying using triclopyr is undertaken along verges of vehicle trails and walking trails. Treatment extends 10–20 m from the road edge. Treatment of trails reduces seed spread to other areas by vehicles, walkers and animals. Some of the treated areas along trail edges have become refuges for native plant species including rare and threatened plants. Triclopyr is used, as it is not detrimental to *Poa sieberiana* Spreng. var. *sieberiana* which is the dominant groundcover, thus protecting the soil from disturbance. Other non-target species, particularly rare plants can be at risk from herbicides if applied indiscriminately (Heinrich and Dowling 1998, 2000). Staff and contractors are being trained to identify recognizable rare plant populations and less obvious ones are tagged to avoid herbicide application to broom plants within the vicinity. These broom plants are removed either physically or by using the cut and paint technique.

The herbicide, triclopyr, is sprayed from vehicle mounted rigs but is not used near waterways, or in wetlands, in the area because of potential impact to aquatic ecosystems. All staff and contractors are trained in appropriate use of herbicides to decrease potential ecological impacts from herbicide use.

Current treatment techniques have limitations and the cost of physical removal and chemical application on such a grand scale (even for containment only) is high. Table 1 shows the cost of broom and associated control measures since 1985.

Considering the seed longevity and the quantity of soil stored seed (Hosking *et al.* 1998) containment alone must continue to protect subalpine areas outside the main infestation and sensitive communities within the main infestation. This containment program also involves control of vertebrate pests. Dense broom thickets provide shelter for feral animals (Parsons and Cuthbertson 1992) such as pigs and foxes. The annual pig control program reduces soil disturbance and potential movement of broom seed by pigs.

Biological control of broom is integral to the longer-term containment program. Three biological control agents have been released in locations throughout the Barrington Tops plateau, *Leucoptera spartifoliella* (Hübner) (twig mining moth), *Artainilla spartiophila* (Förster) (a broom psyllid) and *Bruchidius villosus* Fabricius (seed feeding bruchid). Release sites have been recorded and impact and spread of agents from these sites is being monitored. Once numbers build up a planned and systematic approach to their redistribution is anticipated.

Monitoring of the broom infestation

Previous *ad hoc* monitoring of the broom infestation has indicated the need for a co-ordinated and consistent approach in the

Table 1. Expenses associated with broom control in Barrington Tops National Park from 1985 to 1999.

Program	1985 / 1986	1986 / 1987	1987 / 1988	1988 / 1989	1989 / 1990	1990 / 1991	1991 / 1992	1992 / 1993	1993 / 1994	1994 / 1995	1995 / 1996[A]	1996 / 1997	1997 / 1998	1998 / 1999
NPWS labour / administration	15 000	15 000	18 000	20 000	22 000	25 000	20 000	15 000	15 000	5 000	5 000	4 000	4 000	5 000
Broom spraying (temporary labour)	2 500	3 500	4 000	5 000	5 000	3 000								
Broom spraying (contract labour)										6 000	8 000	25 000	30 000	35 000
Broom physical removal												6 000	10 000	20 000
Herbicide and materials	7 000	11 500	13 000	16 000	10 000	6 000	4 500	5 500	4 000	4 500	5 000	12 000	12 000	10 000
Pig control staff and materials	3 000	3 000	4 000	4 000	4 000	4 000	5 000	4 000	4 000	5 000	7 000	10 000	7 000	7 000
Biological control program						25 000	25 000	27 000	33 000	33 000	27 000	27 000	25 000	20 000
Rare and threatened plant survey													30 000	
Aerial survey (by helicopter)												2 000		2 000
Mapping of main infestation														20 000
Total	27 500	33 000	39 000	45 000	41 000	63 000	54 500	51 500	56 000	53 500	52 000	86 000	118 000	119 000

[A] In 1996 the Barrington Tops National Park received new additions which included 1000 hectares of crown land infested with broom. As a result of this new land resources were increased to support the Scotch Broom Management Strategy.

future. The two main infestations were first mapped by NPWS in 1988 from 1982 aerial photographs. In 1989 SF NSW produced maps showing the density (i.e. infill within the infestations) from 1987 aerial photographs. In 1992 / 3 SF NSW mapped the perimeter of the broom infestations. This map indicated a slight increase in the area of the main infestations from 1987. Broom densities have only been recorded on one occasion, therefore density changes within the main infestation are currently unknown. Additional aerial surveys of the boundary of the broom infestation were undertaken in 1996 and 1998 with particular emphasis on locating isolated infestations for on-ground treatment. Aerial photographic runs were completed in December 1998. Aerial photographic interpretation (API) has recently been undertaken and will provide information regarding the rate of spread and densities. This information will be compared with the 1989 maps.

Threatened species and other environmental impacts

Broom is causing major ecological changes to the natural environment of the Barrington Tops plateau (Waterhouse 1988, Smith 1994). The subalpine natural environment of Barrington Tops National Park provides habitat for a range of threatened species. In 1997 the NPWS employed consultants to undertake a rare plant survey of the plateau area (Heinrich and Dowling 1998). Although the survey had limitations it was designed to identify the location, abundance and provide further information on rare or threatened plants likely to occur within the broom infestations. The information gained has been invaluable in assisting with the protection of those species. Distribution records from the survey are being used to assist in targeting broom control.

In total, 28 species of rare or threatened plants have been identified within the main broom infestations of the Barrington Tops plateau (Heinrich and Dowling 1998). Of these, four are listed as vulnerable under the New South Wales Threatened Species Act 1995 and seventeen (including the four vulnerable species) are listed as rare or poorly known in Briggs and Leigh (1996). Five possible new species of orchids were also discovered in the 1998 survey (Heinrich and Dowling 1998). The study highlighted the importance of the Barrington Tops plateau for rare, threatened and endemic plant species and indicated the need for further survey work to be undertaken. For more information on rare and threatened plant species of the Barrington Tops see Heinrich and Dowling (2000).

Twenty seven species of threatened fauna (NPWS Wildlife Atlas 1999) occur within Barrington Tops National Park. Many of these species utilize the sub alpine woodlands and wetlands.

Fauna species listed on the Threatened Species Conservation Act 1995 and known to occur within Barrington Tops National Park and likely to occur on the plateau are:

Birds

Powerful owl
Ninox strenua (Gould)
Masked owl
Tyto novaehollandiae (Stephens)
Sooty owl
Tyto tenebricosa (Gould)
Rufous scrub-bird
Atrichornis rufescens (Ramsay)
Painted snipe
Rostratula benghalensis (Linnaeus)
Glossy black-cockatoo
Calyptorhynchus lathami (Temminck)
Olive whistler
Pachycephala olivacea Vigors & Horsfield

Mammals

Spotted-tailed quoll
Dasyurus maculatus (Kerr)
Parma wallaby
Macropus parma Waterhouse
Broad-toothed rat
Mastacomys fuscus Thomas
Brush-tailed phascogale
Phascogale tapoatata (F.A.Meyer)
Koala
Phascolarctos cinerus (Goldfuss)
Eastern freetail-bat
Mormopterus norfolkensis (J.E.Gray)
Eastern false Pipistrelle
Falsistrellus tasmaniensis (Gould)
Common bent-winged bat
Miniopterus schreibersii (Kuhl)
Little bentwing bat
Miniopterus australis (Tomes)
Yellow-bellied sheathtail-bat
Saccolaimus flaviventris (Peters)
Greater broad-nosed bat
Scoteanax rueppellii (Peters)

Amphibians

Glandular frog
Litoria subglandulosa Tylers & Anstis
Stuttering frog
Mixophyes balbus Straughan

In the case of the broad-toothed rat, broom is invading the edges of the subalpine wetlands, outcompeting grasses such as *P. sieberiana* var. *sieberiana* which are an important shelter and food source for the rat. Further research on the plateau is required to determine the distribution of threatened fauna species and the potential impact of broom upon them.

The wetlands within the subalpine area feed six river systems. Use of herbicides for broom control within wetlands and along waterways is unacceptable because of potential impacts on aquatic flora and fauna. Broom is becoming more common within the wetlands and along the edges of rivers (M. Newton personal communication). Wetlands of high ecological significance are being prioritized for physical broom removal.

Since the 1970s fire on the plateau has been largely restricted. Prior to this time, low intensity summer burns associated with cattle grazing were common (NPWS 1989). Broom infestation has resulted in increased soil moisture levels (Waterhouse 1988) and a lack of ground cover. There are now very few days where conditions are dry enough to carry fire resulting in a decline in fire events. Further research is required to gain an understanding of fire ecology on the Barrington Tops plateau and potential changes to fire ecology due to broom infestations.

Research

There have been various research projects undertaken on broom on the Barrington Tops. More information, however, is required to improve overall management of the broom infestations particularly in reference to the ecology of species native to the Barrington Tops plateau. The authors consider further research would be valuable on:

(a) impact of broom on threatened species,
(b) impact of broom on the fire ecology of the Barrington Tops plateau,
(c) relationship between broom and introduced vertebrate pests,
(d) changes in broom density within the main infestation,
(e) changes to the soil profile in areas of infestation,
(f) impact of broom on subalpine wetlands, waterways and open plains.

Future broom management

Broom containment forms just part of the annual operational management of Barrington Tops National Park, which also includes management of feral animals, fire, recreational use as well as natural and cultural resources. Part of the success of the broom containment program has been due to ongoing communication with surrounding landholders to ensure a coordinated program. The NPWS is committed to a regional / catchment approach to pest management (Leys 1998).

As land managers the NPWS have a responsibility to continue to implement containment programs that will not compromise existing natural ecosystems. NPWS will continue environmental assessment of control techniques. The broom infestation is likely to expand unless the containment program is successful. The success of this program is reviewed annually.

The program will continue to prevent infestation of unaffected catchments and subalpine environments. NPWS also aims to protect sensitive communities within the main infestation by using an integrated management strategy. In addition to the containment program, effective monitoring and continued research are an integral component of managing broom in the future. The use of biological control agents is regarded as the only economic long-term method of reducing the size of the main broom infestations. A planned systematic redistribution program for biological control agents will be undertaken in collaboration with researchers once numbers of agents build up.

Acknowledgments

We would like to thank M. Newton, Senior Field Supervisor, NPWS, for information on broom control on the Barrington Tops. He has been involved with broom control in Barrington Tops National Park since the 1970s.

Postscript

In March 1999 the Barrington Tops National Park was expanded to include areas of Barrington Tops State Forest and Polblue Crown Land Reserve. The NPWS are now responsible for management of most of the broom infestations occurring on community lands. The NPWS is currently reviewing the 1996 Management Strategy to include new areas of the National Park.

References

Adams, B. (2000). Raising awareness of the broom (*Cytisus scoparius* (L.) Link) problem on the Barrington Tops. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 139-40.

Briggs, J.D. and Leigh, J.H. (1996). 'Rare or threatened Australian plants'. (CSIRO Publishing, Melbourne).

Heinrich, A. and Dowling, B. (1998). Rare and threatened plant survey of Barrington Tops National Park - plateau area. Unpublished report prepared for the NSW National Parks and Wildlife Service.

Heinrich, A. and Dowling, B. (2000). Threats to the rare and threatened plant species of the Barrington Tops. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 172-6.

Hosking, J.R., Smith, J.M.B. and Sheppard, A.W. (1998). *Cytisus scoparius* (L.) Link ssp. *scoparius*. *In* 'The biology of Australian weeds' Volume 2, eds F.D. Panetta, R.H. Groves and R.C.H. Shepherd, pp. 77-88. (R.G. and F.J. Richardson, Melbourne).

Howard, C. (1995). Hunter District Submission to the Wilderness Assessment Report for Barrington Tops. Unpublished report.

Leys, A. (1998). NSW National Parks and Wildlife Service Summary of Pest Management Programs 1997/98. Unpublished.

NPWS (1989). Draft plan of management of Barrington Tops National Park, New South Wales National Parks and Wildlife Service, Raymond Terrace office of NPWS.

NPWS (1999). The NSW National Parks and Wildlife Atlas database, CD ROM.

Parsons, W.T. and Cuthbertson, E.G. (1992). 'Noxious weeds of Australia'. (Inkata Press, Melbourne and Sydney).

Smith, J.M.B. (1994). The changing ecological impact of broom (*Cytisus scoparius*) at Barrington Tops, New South Wales. *Plant Protection Quarterly* 9, 6-11.

Waterhouse, B.M. (1988). Broom (*Cytisus scoparius*) at Barrington Tops, New South Wales. *Australian Geographical Studies* 26, 239-48.

Threats to the rare and threatened plant species of Barrington Tops

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Summary

Future management of rare and threatened plant species in the Barrington Tops National Park on the Barrington and Gloucester Tops plateau is dependent upon knowledge of their locations, abundance and threats to their survival. A literature and field survey was carried out in summer 1997–98 and further field surveys in summer 1998–99 and spring 1999. Surveys found that 30 species of rare or threatened plants, 18 of which are possibly endemic, are likely to occur, or are known to occur, on the plateau area of Barrington Tops and Gloucester Tops. Nine possible new species, all Orchidaceae, were located during the literature and field surveys. Populations of rare and threatened plants were found both in the National Park and in forestry land. Threats include further spread of broom (*Cytisus scoparius*), spread of other weeds, feral pigs, recreational use and fire. Managers of the National Park, State Forests and private land should place high priority on the protection of the whole subalpine habitat as well as populations of rare plants by focusing funding priorities to reduce these threats.

Introduction

The plateau in the Barrington Tops National Park covers an area of 11 000 ha and is dominated by subalpine woodland where the major tree species is *Eucalyptus pauciflora* Sieber ex Spreng. interspersed with *Eucalyptus stellulata* Sieber ex DC., *Eucalyptus dalrympleana* Maiden and *Eucalyptus fastigata* H.Deane & Maiden. In addition the plateau has an extensive system of subalpine wetlands and patches of cool temperate rainforest dominated by *Nothofagus moorei* (F.Muell.) Krasser up to 1550 m above sea level (asl).

A considerable part of the plateau is occupied by subalpine wetlands which are extensive areas of almost treeless, wet heath and sedgelands occurring in drainage depressions of both Barrington and Gloucester Tops. These areas are often very open and therefore exposed to drying winds, ice and snow. Some wetlands were more protected from the extreme weather conditions as they occur between wooded areas e.g. Little Murray wetland. Mean annual rainfall over Barrington Tops and Gloucester Tops is approximately 1470–1700 mm (CMPS&F Environmental 1995). Some areas on the escarpment side receive higher rainfall than areas further north-west, away from the escarpment (CMPS&F Environmental 1995). Mean annual temperature is about 9°C (Tweedie 1963).

According to Veness and Associates (1995) the two parent rock types on the plateau area are granodiorite and tertiary basalt. Resulting soils are friable with scattered stones. Granodiorite soils consist of a dark reddish brown, silty clay loam A horizon while basalt topsoils are characterized by strong pedal layers of a very reddish brown, subplastic, silty clay loam. The A2 horizon in basalt areas consists of a dark reddish brown, silty clay or is unbleached (Veness and Associates 1995).

Much of the 11 000 hectares in the National Park and extensive areas outside the Park are affected to varying degrees by broom (*Cytisus scoparius* (L.) Link subsp. *scoparius*) which has the potential to reduce the available habitat for rare or threatened plant species. The Gloucester Tops (*c.* 1000 hectares) has no known broom infestations. A broom management strategy has been prepared to contain broom within affected catchments using annually applied control measures along roadways and at the boundaries of the infestation. There are also management strategies to control other weeds, to better manage recreational usage and fire and to control feral animals. However in order to protect rare and threatened plant populations, their locations, abundance and threats to their survival needed to be determined.

Surveys for rare and threatened plant species were carried out on the Barrington Tops (1350–1585 m asl) and Gloucester Tops (1140–1300 m asl) plateau in the National Park, State Forests and private land ensuring coverage of all the different plant communities.

Before the survey documented here, botanical surveys of the Barrington Tops and Gloucester Tops plateau although quite extensive in their coverage had very few details on rare and threatened species (Fraser and Vickery 1938a,b, Mort 1983, Adam 1987). One survey of State Forests (Binns 1995), did identify a number of rare and threatened plants as did the New South Wales north east forest biodiversity study (NPWS 1995). Other recent surveys have usually been of short duration, of only accessible areas and by botanists interested in one group of plants (e.g. the Orchidaceae).

Methods

Field searches for each rare or threatened plant were made based on priority areas i.e. known locations and habitats obtained during the literature search and following consultation with National Parks and Wildlife Service staff. Various sources were used, including scientific journals, previously collected specimens at the National Herbarium of New South Wales and from people with specific knowledge.

Transects within the priority areas were surveyed by walking many kilometres through the selected vegetation communities. These included: the edges of wetlands, wetlands, open grassland, woodland and forest. Rare plant information was gathered within 20 m of the transects. If a rare plant population was located the area searched was extended at each site using the following guidelines (adapted from the National Resources Audit Council significant plant project (NPWS 1995)).

When a rare plant was found:

- Small populations were counted by searching along parallel lines and temporarily marking plants to avoid double counting.
- Large or widespread populations were subsampled in several random quadrats (10 × 10 m).
- The location of broom plants within 50 m of the rare plant population at risk was recorded.
- Signs of potential threats were noted e.g. access, feral animal activity, fire.

Sites were only surveyed once or twice given the size of the survey areas so some terrestrial orchids and annual plants would have been missed.

Identities of all rare and unknown plants were confirmed by voucher specimen sent to Sydney or Canberra. Plant names follow Harden (1990–1993), except where there have been more recent revisions.

Results

Rare and threatened plants located on the plateau

A list of rare and threatened plants on the plateau of Barrington and/or Gloucester Tops and their status is given in Table 1.

Potential threats to rare and threatened plants

1. Broom. Broom has altered grassland and woodland understorey habitats of most of the rare plants by shading out herbaceous plant species. Nearly all rare and threatened plant populations on Barrington Tops have been affected to some degree by either individual broom plants or thickets of broom. Table 1 gives an indication of the percentage of rare plant populations within 50 m of broom. Some rare plant habitat has probably already been lost to broom. Broom also provides shelter for feral pigs.

Like broom one of the rare plants, *Ozothamnus* sp. 1, appeared to re-colonize disturbed areas especially along the edges of tracks but broom had not yet reached the main population of *Ozothamnus* sp.1.

2. Feral pigs. Feral pigs turned over soil in many places. Sods of snowgrass (*Poa sieberiana* Spreng.) were often completely turned over as though a plough had worked the area, often in the vicinity of the rare Orchidaceae, suggesting their diet includes orchid tubers. Pigs also dig out large wallows in peaty soils at the edges of the wetlands which is part of the habitat of *Chionogentias barringtonensis*, *Corybas* sp. A, *Euphrasia ciliolata*, *Microtis* sp. aff. *rara*, *Plantago cladarophylla*, *Plantago palustris*, *Prasophyllum* sp. aff. *odoratum*, *Prasophyllum rogersii* and *Pterostylis* sp. D.

3. Recreational use. Many of the rare plants were found in or near frequently used picnic or camping areas. Such sites were associated with large areas of regenerating broom.

4. Other weeds. Blackberry (*Rubus fruticosus* L. complex) also present on the plateau could have an adverse impact on the rare plants as this is a serious pest in similar climatic areas in the southern tablelands of New South Wales. This threat to rare plants would be similar to broom except that the seeds of blackberry are spread by birds and mammals present on the plateau.

5. Rare plant populations not adequately conserved. The largest population of *Corybas* sp. A so far located on the Barrington Tops and another smaller one remain outside reserves on Barrington Tops. This orchid is however reserved at Ben Halls Gap National Park. Similarly *Chiloglottis platyptera* has a large population in a forestry area surrounded by logging activities and is present in Ben Halls Gap National Park. Populations of *Grevillea granulifera* and *Pterostylis* sp. D were found at only one unreserved site.

Discussion

The plateau of Barrington Tops and Gloucester Tops appears to be a centre of endemicity as well as providing suitable subalpine habitat for many other rare and threatened plants. Such plants occurred in all habitats of the plateau. However, concentrations of these plants occurred in or near the edges of the subalpine wetlands and along creeks on the Barrington Tops and Gloucester Tops plateau.

Broom appears to be the major threat to the rare and threatened plants on the Barrington Tops plateau. Populations of plants which appear to be most threatened by broom include: *Chionogentias barringtonensis*, *Diuris venosa*, *Microtis* sp. aff. *rara*, *Plantago cladarophylla*, *Plantago palustris*, *Prasophyllum rogersii*, *Pterostylis* sp. aff. *cycnocephala*, *Prasophyllum* sp. aff. *fuscum*, *Prasophyllum* sp. aff. *odoratum* and *Tasmannia glaucifolia*. Broom increases shading and leads to high litter accumulation as well as competing for growth sites. Smith (1994) found that common plants typical of well-lit snowgrass grassland on Barrington Tops neither remained nor became frequent as broom plants aged. Many of the plants identified in this report occupy grassland habitats and would probably be similarly affected. Studies of individual rare plant populations may be required to determine how long they can survive with broom invasion of their habitat. For example how long will terrestrial orchids survive in the shade of broom? Can *Ozothamnus* sp. 1 survive competition with broom seedlings for newly disturbed sites?

Management of broom on the Barrington Tops plateau should be given high priority in areas in and around the subalpine wetlands, creeks and rivers. It is also important to reduce broom spread along trails and from the edge of existing infestations. Biological control of broom is

Table 1. Vulnerable, rare, poorly known and significant plant species identified on the Barrington Tops or Gloucester Tops plateau during the survey or in consultation with David L. Jones, Centre for Plant Biodiversity Research, Australian National Herbarium, Canberra. The ROTAP code (Appendix A has the ROTAP Conservation Code) and Risk Code (under the New South Wales Threatened Species Conservation Act), plant population distribution status and the percentage of known rare plant populations within 50 m of broom plants are noted.

Name of taxa	Family	ROTAP (Appendix A)/ Risk Code		Plant population distribution on plateau (reference)	% of known populations within 50 m of broom
Category –Vulnerable					
Diuris venosa Rupp	Orchidaceae	2VC	Schedule 2	Disjunct (13)	100
Pterostylis sp. D	Orchidaceae	3VCa	Schedule 2	Endemic (13)	40
Tasmannia glaucifolia J.B. Williams	Winteraceae	3VCi	Schedule 2	Disjunct (3)	80
Tasmannia purpurascens (Vickery) A.C.Sm.	Winteraceae	2VC-t	Schedule 2	Disjunct (3)	50
Category – Rare					
Acacia barringtonensis Tindale	Fabaceae (Mimosoideae)	3RCa		Disjunct (4)	40
Chiloglottis palachila D.L. Jones	Orchidaceae	3RC-		Disjunct (5)	0
Chionogentias barringtonensis L.G. Adams	Gentianaceae	2RC-		Endemic (6)	100
Corybas sp. A	Orchidaceae	2RC-		Disjunct (13,15)	30
Chiloglottis sphyrnoides D.L. Jones	Orchidaceae	3KC-			0
Leptospermum argenteum Joy Thomps.	Myrtaceae	2RC-		Endemic (8)	80
Plantago cladarophylla B.G. Briggs, Carolin & Pulley	Plantaginaceae	2RC-		Endemic (9)	80
Plantago palustris L.R. Fraser & Vickery	Plantaginaceae	2RC-		Endemic (9)	90
Poorly known					
Chiloglottis platyptera D.L. Jones	Orchidaceae	2KC-		Disjunct (5)	0
Euphrasia ciliolata W.R. Barker	Scrophulariaceae	2KC-		Endemic (10)	64
Ozothamnus sp. 1	Asteraceae	2KC-t		Endemic (11)	33
Grevillea granulifera (McGill.) P. M. Olde & N. Marriott	Proteaceae	3KC-		Disjunct (12)	0
Pterostylis elegans D.L. Jones	Orchidaceae	2KC		Altitudinal range extension to 1530 m (1, 14)	0
Significant taxa / no ROTAP codes					
Prasophyllum sp. aff. *fuscum*[A]	Orchidaceae			?Endemic (1)	100
Prasophyllum sp. aff. *odoratum*[A]	Orchidaceae			?Endemic (1)	50
Prasophyllum rogersii Rupp	Orchidaceae			Endemic (1)	100
Microtis sp. aff. *rara*[A]	Orchidaceae			?Endemic (1)	100
Chiloglottis sp. aff. *pluricallata*	Orchidaceae			Disjunct (5)	not known
Orthoceras strictum forma *viride*	Orchidaceae			Very rarely seen (1)	0
Pterostylis sp. aff. *cycnocephala*[A]	Orchidaceae			?Endemic (1)	100
Pterostylis sp. aff. *parviflora*[A]	Orchidaceae			?Endemic (13)	30
Pterostylis sp. aff. *longifolia*[A]	Orchidaceae			Range extension (13)	0
Pterostylis sp. aff. *monticola*[A]	Orchidaceae			Endemic (13)	0
Caladenia sp. aff. *carnea*[A]	Orchidaceae			Disjunct (13)	0
Caladenia sp. aff. *patersonii*[A]	Orchidaceae			?Endemic (13)	not known

[A] Possible new species.

References

(1) pers. comm. D.L. Jones 1998
(2) D.L. Jones pers. comm. in Binns 1995
(3) Harden 1990
(4) Binns 1995
(5) Bishop 1996
(6) Adams 1995
(7) Jones 1993
(8) Thompson and Logan 1991
(9) Briggs 1992
(10) Barker 1992
(11) pers. comm. C. Puttock 1998
(12) Olde and Marriott 1994
(13) pers. comm. D.L. Jones 1999
(14) Jones 1997
(15) pers. comm. J.R. Hosking 1999

desirable as other control measures are more likely to damage native plants. It was observed during the present surveys that broom spraying had at least temporarily affected some *Tasmannia purpurascens* and *Tasmannia glaucifolia* bushes. Damage was possibly caused by spray drift, though localized damage will need to be tolerated given the overall benefit to native plant communities. The impact of broom spraying on *Chionogentias barringtonensis*, *Euphrasia ciliolata* and terrestrial orchids (for example *Diuris venosa*, *Microtis* sp. aff. *rara, Pterostylis* sp. aff. *cycnocephala*, *Prasophyllum* sp. aff. *fuscum*, *Pterostylis* sp. aff. *parviflora, Pterostylis* sp. aff. *patersonii*) may be more harmful, as spraying coincides with the vegetative and flowering periods of these species.

Feral pig control should also be a priority as they often concentrate their activities in and around the wetlands where a number of the rare plants were affected. Feral horses appeared to be too few to be having an impact on the rare or threatened plants. However, their numbers should not increase as this may add to the impact

Appendix A. ROTAP Conservation Code.

Conservation Code (Briggs and Leigh 1996)

Distribution Category (can be 1, 2 or 3)

1. Known by one collection only
2. Geographic range in Australia less than 100 km
3. Geographic range in Australia greater than 100 km

The Conservation Status (can be X, E, V, R, or K)

X Presumed Extinct: taxon not collected or otherwise verified over the past 50 years despite thorough searching in all known and likely habitats, or of which all known wild populations have been destroyed more recently.

E Endangered: taxon in serious risk of disappearing from the wild within 10–20 years if present land use and other threats continue to operate. This category includes taxa with populations possibly too small (usually less than 100 individuals) to ensure survival even if present in proclaimed reserves.

V Vulnerable: taxon not presently endangered , but at risk over a longer period (20–50 years) of disappearing from the wild through continued depletion, or which occurs on land whose future use is likely to change and threaten its survival.

R Rare: taxon which is rare in Australia (and hence usually in the world) but which currently does not have any identifiable threat. Such species may be represented by a relatively large population in a very restricted area or by smaller populations spread over a wide range or some intermediate combination of distribution pattern.

K Poorly Known: taxon that is suspected, but not definitely known, to belong to one of the above categories. At present accurate field distribution information is inadequate.

C Reserved: indicates taxon has at least one population within a national park, other proclaimed conservation reserve or in an area otherwise dedicated for the protection of flora. The taxon may or may not be considered to be adequately conserved within the reserve(s), as reflected by the conservation status assigned to it. Where applicable, the 'C' symbol immediately follows the conservation status symbol in the written code, e.g. 2RC.

Size-class of all reserved populations (can be a, I, or t)

a 1000 plants or more are known to occur within a conservation reserve(s),
I less than 1000 plants are known to occur within a conservation reserve(s);
- reserve population size not accurately known;
t total known population reserved.

of native grazing animals (kangaroos, wombats etc.).

Although rare plants are persisting under current park usage, continuation of the present level of visitor use or any increased usage of the camping areas and tracks may adversely impact upon the plants. The most serious threat here is the impact of broom spread along tracks. Closing key areas to vehicles and campers until broom is better controlled and native vegetation rehabilitated should be considered.

Fires on the Tops could adversely affect some rare plant populations, however, aging populations of *Acacia barringtonensis* may benefit from a fire through germination of soil-stored seed. Broom is a threat here too as it also germinates in huge numbers following fire (Smith 1994) and out competes native plants.

The only known populations of some of the rare plants (*Grevillea granulifera* and *Pterostylis* sp. D) and the largest known population of *Corybas* sp. A on Barrington Tops are not conserved.

The rare and threatened plant survey of Barrington Tops and Gloucester Tops identified the subalpine wetlands, the streams and their surrounding catchments to be of extremely high conservation value. Not only are they habitat for many of the rare and threatened plants but they are quite distinctive areas which warrant special management attention.

Postscript

A number of plant species considered to be endemic to the Barrington Top plateau are now known to occur in Ben Halls Gap National Park. Due to lack of access this Park has few weed problems and does not have a broom problem. However, broom would be a major problem in this Park if it established as the altitude, soil and the climate are similar to the Barrington Tops plateau. *Corybas* sp. A and *Chiloglottis platyptera* are present in Ben Halls Gap National Park, as are *Tasmannia glaucifolia* and *Tasmannia purpurascens*. Additional surveys are required to determine if other rare or threatened plants are also present.

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References

Adam, P. (1987). 'New South Wales Rainforests. The Nomination for the World Heritage List'. (National Parks and Wildlife Service, Sydney).

Adams, L.G. (1995). *Chionogentias* (Gentianaceae), a new generic name for the Australasian 'snow-gentians', and a revision of the Australian species. *Australian Systematic Botany* 8, 935-1011.

Barker, W.R. (1992). *Euphrasia*. *In* 'Flora of New South Wales', Volume 3, ed. G.J. Harden, p. 583. (New South Wales University Press, Kensington).

Binns, D. (1995). 'Flora survey Gloucester and Chichester management areas environmental impact statement supporting document No. 4.' (Research Division, State Forests of New South Wales, Sydney).

Bishop, A. (1996). 'Field Guide to the Orchids of New South Wales and Victoria.' (University of New South Wales Press, Kensington).

Briggs, B.G. (1992). *Plantago*. *In* 'Flora of New South Wales', Volume 3, ed. G.J. Harden, p. 592 (New South Wales University Press, Kensington).

Briggs, J.D. and Leigh, J.H. (1996). 'Rare or threatened Australian plants'. (CSIRO Publishing: Melbourne).

CMPS&F Environmental (1995). 'Gloucester and Chichester management areas environmental impact statement. Supporting document No. 2 hydrology and water quality.' (Forestry Commission of New South Wales, Pennant Hills).

Fraser, L. and Vickery, J. (1938a). The ecology of the upper Williams River and Barrington Tops districts. II The rainforest formations. *Proceedings of the Linnean Society of New South Wales* 63 (3-4), 139-84.

Fraser, L. and Vickery, J. (1938b). The ecology of the upper Williams River and Barrington Tops districts. III The eucalypt forests and general discussion. *Proceedings of the Linnean Society of New South Wales* 64, 1-33.

Harden, G.J. (1990–1993). 'Flora of New South Wales.' Volumes 1–4. (University of New South Wales Press, Kensington).

Jones, D.L. (1993). *Pterostylis*. *In* 'Flora of New South Wales', Volume. 4, ed. G.J.

Harden, p. 171. (University of New South Wales Press, Kensington).

Jones, D.L. (1997). Six new species of *Pterostylis* R.Br. (Orchidaceae) from Australia. *The Orchadian* 12, 247-54.

Mort, S.J. (1983). 'The Barrington Tops swamps – flora, ecology and conservation.' (Unpublished document, School of Geography, University of New South Wales).

National Parks and Wildlife Service (1995). 'North East Forest Biodiversity Study.' (National Parks and Wildlife Service).

Olde, P.M. and Marriott, N.R. (1994). A taxonomic revision of *Grevillea arenaria* and *Grevillea obtusiflora* (Proteaceae: Grevilleoideae). *Telopea* 5, 711-33.

Smith, J.M.B. (1994). The changing ecological impact of broom (*Cytisus scoparius*) at Barrington Tops, New South Wales. *Plant Protection Quarterly* 9, 6-11.

Thompson, J. and Logan, V. (1991). *Leptospermum*. *In* 'Flora of New South Wales', Volume 2, ed. G.J. Harden, p. 154. (New South Wales University Press, Kensington).

Tweedie, A.D. (1963). Part III. Climate of the Hunter Valley. *In* 'General report on the lands of the Hunter Valley. Land Research Series No. 8.' (Commonwealth Scientific and Industrial Research Organization, Melbourne).

Veness and Associates (1995). 'Gloucester and Chichester management areas environmental impact statement. Supporting Document No. 1 Soils Report G. and C. Forest management areas EIS Study'. (State Forests of New South Wales, Central Region).

Brooms as part of the Australian nursery industry

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Summary

Nursery plants that come under the heading of 'brooms' are estimated to be currently worth about $1.5 million to the industry. Their taxonomic origins are often complex and uncertain, however, *Cytisus scoparius*, is the most common parent species and this and some other naturalized species are banned from sale by selected states. While the continued sales of some broom varieties closely related to weedy species may pose a threat to the environment through the opportunity of bringing in greater genetic diversity, so the activities of biological control programs against brooms pose a threat to horticultural brooms, and may lead to greater use of chemicals by gardeners. It will be important that decisions taken to manage weedy brooms, that may have an impact on the nursery industry, are done so in direct consultation with the industry. This paper discusses these issues.

Introduction

'Brooms' for the nursery industry encompasses a whole suite of species, hybrids and varieties associated with the genera *Argyrocytisus, Chamaecytisus, Cytisus, Genista, Retama, Spartium* and *Teline* (Spencer 1997). These genera also contain species that, worldwide, have either agricultural value or are recognized and noxious weeds (Holm *et al*. 1979, Parsons and Cuthbertson 1992, Hosking *et al*. 1998). As such, some of these weed species have restrictions on their sale and distribution in Australia (see http://www.weeds.org.au) and similar legislation covers weedy brooms in New Zealand. Confusion has reigned with respect to this for horticultural varieties of broom, whose origins remain hard to trace.

There has been much switching of taxonomic names of the parents of horticultural broom varieties in the botanical literature, which has led to plenty of confusion in the appropriateness of names used in the market place. For example the parent of the broom variety called 'weeping bridal veil', *Retama monosperma* (L.) Heywood, has in the past been included in both *Cytisus* and *Genista*, and many parental species have been swapped between *Cytisus* and *Genista.*

The aim of this contribution is to:

(1) discuss the taxonomic origins of the different types of broom available in nurseries,
(2) to summarize the economic importance of brooms to the nursery industry in Australia, and
(3) discuss potential impacts of efforts to manage broom (*Cytisus scoparius* (L.) Link) on the industry.

Taxonomic origins of horticultural brooms

The most important genus for brooms in the nursery industry is *Cytisus*. Species from this genus have contributed most to the broom horticultural varieties available in the market place. The main *Cytisus* species that have been parents of horticultural varieties in Australia are *C. scoparius*, *Cytisus multiflorus* (L'Hér.) Sweet, *Cytisus purgans* (L.) Boiss., *Cytisus ardoini* E.Fourn. in this order of frequency (D. Cooke personal communication). Horticultural brooms developed from this genus exist as varieties of wild-type species as well as hybrids developed from two or even three species. Often the exact origins of some of the commercial broom varieties, have themselves a degree of uncertainty. Table 1 shows a list of commercial varieties of broom available from one supplier of plant labels to the nursery industry (Norwoods Industries) together with flower colour and currently accepted botanical origins. Included in this list are varieties derived directly from recognized species (e.g. *Cytisus* 'Cornish cream'), from horticultural varieties of recognized species (e.g. *Cytisus* 'Andreanus'), and from hybrids between two species (e.g. *Cytisus praecox* 'Warminster broom') (Rowell 1991, D. Cooke personal communication).

The two commonest *Cytisus* species that have been used to generate horticultural varieties (*C. scoparius* and *C. multiflorus*) are both naturalized in Australia and the most frequently used parental species is *C. scoparius* (Table 1). Having stated this, however, there is not necessarily a clear relationship between the amount of parental make up that is from a known weed and the likelihood that the developed variety will pose a threat to the environment if planted. There is also no direct evidence that any of the currently marketed varieties as listed in Table 1 are of identical genetic make up to the naturalized brooms in Australia. For example, some varieties have reduced growth rates or poor seed set, although if such varieties are compatible with naturalized weeds this will provide a potential source of increased genetic diversity and hence weediness should crossovers occur (Smith 2000). There is plenty of anecdotal evidence from gardens to suggest that most varieties fail to naturalize or self-seed following planting, however clearly one or more 'Andreanus' like varieties of *Cytisus scoparius* have naturalized given the frequency of its 'egg and bacon' flower colour in weedy populations in several areas.

The value of 'brooms' to the Australian nursery industry

From the 1996/97 Australian Bureau of Statistics (ABS) report commissioned by the Nursery Industry Association of Australia (NIAA) and the Horticultural Research and Development Corporation (Atkinson 1998), there are over 3000 production nurseries with sales amounting to slightly over $539 million, at farm gate, in Australia. Approximately 55% of total sales are made to 3500 retail garden centres. Consequently the industry is strongly driven by the desires of it's main customers, the Australian gardening public. However most gardeners are after a particular 'look' rather than specific species so, with appropriate education, changes can be made to the lines sold by nurseries.

There are no direct figures available from the ABS survey for broom sales. They would mostly be included in the 'exotic trees and shrubs sold in pots sizes 76 mm to 300 mm' category which makes up 17.4% of total greenlife sales. However, working from the number of plant labels sold by Norwood Industries (confidential communication) and estimates of the average sale price per pot, the authors estimate broom sales in Australia at approximately $1.5 million annually.

Potential impacts on industry of efforts to control broom

The degree of diversity in the types of broom available through the nursery industry has an additional consequence. It is both hard to educate people about the differences in varieties and hard to police sales of species already banned from sale within Australia and varieties considered to pose a risk to broom weed management in Australia. The question remains to what extent does the continued sale of broom varieties pose a threat to the Australian environment?

Some states in the US have considered that certain nursery varieties still do pose a significant risk and have brought in legislation preventing the sale of such brooms (Isaacson 2000). However if such a stance was to be considered in Australia, then it would be extremely important to tackle this issue directly with the nursery industry through consultation. We should also consider the distribution of plants by gardeners and amateurs as these may not actually be 'sold'.

Industry would have good grounds for arguing against a blanket ban on all 'brooms' given the taxonomic diversity included under that title. There would also be justifiable concerns regarding sale of existing stock and the capital bound up in that, prior to any ban coming into effect. Appropriate 'lead in periods' should be negotiated as well as significant efforts made to educate the buying public, horticultural media and industry about the need for bans.

The introduction of biological control agents for control of broom may also impact negatively on industry. Information and research on the host specificity of potential agents must include those brooms produced by industry. Actual impact of biological control agents, which do attack plants in the trade, will have two dimensions. Firstly impacts upon stock being grown by a production nursery and secondly impacts on plants growing in garden and landscape situations.

Firstly brooms in production nurseries will be subject to some level of pest and disease management and the biological control agents may well succumb to existing control measures. However the nature of some agents would limit options for control even in nurseries e.g. boring insects are always very difficult to control. Secondly plants in gardens and landscape situations are mostly expected to flourish without active pest and disease management. The consequences of such problems over time are likely to include an undesirable increase in chemical use by gardeners and a decline in demand for brooms if they are seen as difficult to grow.

Conclusions

The sale of brooms by the Australian nursery industry is a significant trade ($1.5 million annually) that could be adversely impacted by controls on sale of brooms and introduction of biological control agents. Research on potential biological control agents must include an assessment of their impact upon brooms sold by the nursery industry. Any move towards banning the sale or movement of selected brooms would require significant resources for informing the media, and educating the industry and the buying public. However, with appropriate consultation and education, industry can move towards sale of alternative non-weedy species to the gardening public.

Table 1. 'Brooms' supplied by Norwoods (from their collection of available plant tags) together with flower colour and currently accepted parental origins (Rowell 1991, D. Cooke personal communication).

Horticulturally used latin names[A]	Variety name	Flower colour	Probable parental origins (Rowell 1991, D. Cooke personal communication)
Cytisus	'Burgundy'	Red with white	*Cytisus scoparius* var. *andreanus* × *Cytisus multiflorus*[B]
Cytisus	'Burkwoodii'	Red and white	*Cytisus scoparius* var. *andreanus* × *Cytisus multiflorus*[B]
Cytisus	'C.E. Pearson'	White and red	*Cytisus scoparius* var. *andreanus* × *Cytisus multiflorus*[B]
Cytisus	'Chocolate soldier'	Brown and white	*Cytisus scoparius* var. *andreanus* × *Cytisus multiflorus*[B]
Cytisus	'Cornish cream'	White and yellow	*Cytisus scoparius*
Cytisus	'Crimson king'	Pink and White	*Cytisus scoparius* var. *andreanus* × *Cytisus multiflorus*[B]
Cytisus	'Dorothy Walpole'	Red and white	*Cytisus scoparius* var. *andreanus* × *Cytisus multiflorus*[B]
Cytisus	'Lilac time'	Purple and white	*Cytisus scoparius* var. *andreanus* × *Cytisus multiflorus*[B]
Cytisus	'Peter Pan'	Pink and white	*Cytisus scoparius* var. *andreanus* × *Cytisus multiflorus*[B]
Cytisus	'Snow queen'	White	*Cytisus multiflorus*
Cytisus	'Andreanus'	Yellow and red	*Cytisus scoparius* var. *andreanus*
Cytisus praecox	'Warminster broom'	White and yellow	*Cytisus multiflorus* × *Cytisus purgans*
Cytisus racemosus (*Genista fragrans*)	'Yellow broom'	Yellow	*Genista canariensis* × *Genista stenopetala*
Cytisus racemosus nana	'Dwarf genista'	Yellow	*Genista canariensis* × *Genista stenopetala*
Genista lydia		Pale yellow	*Genista lydia* Boiss
Cytisus/Genista (*Genista monosperma*)	'Weeping bridal veil'	White	*Retama monosperma* (L.) Heywood

[A] As they appeared on the labels thus names in brackets may be synonyms used in the industry.
[B] The F1 hybrid from which **most** of these varieties were developed is called *Cytisus* × *dallimorei* developed at Kew in 1900, most varieties are selections of F2 or later, or possibly some back crosses (D. Cooke personal communication).

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David Cooke has put together an invaluable, unpublished list of horticultural varieties, names of brooms in Australia and their most likely parentage. Table 1 would not have been possible without this (Full list available from him at Animal and Plant Control Commission, GPO Box 1671, Adelaide, South Australia 5001). Sharon Corey, John Hosking and Kate Blood for critically reviewing the manuscript.

References
Atkinson, I. (ed.) (1998). Lies damned lies and statistics! The Nursery Papers, issue 1998/016, 1-2.

Holm, L., Pancho, J.V., Herberger, J.P. and Plucknett, D.L. (1979). 'A geographical atlas of world weeds'. (Wiley, New York).

Hosking, J.R., Smith, J.M.B. and Sheppard, A.W. (1998). *Cytisus scoparius* (L.) Link ssp. *scoparius*. *In* 'The biology of Australian weeds', Volume 2, eds F.D. Panetta, R.H. Groves and R.C.H. Shepherd, pp. 77-88. (R.G. and F.J. Richardson, Melbourne).

Isaacson, D. (2000) Impacts of broom (*Cytisus scoparius*), in western North America. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 145-8.

Parsons, W.T. and Cuthbertson, E.G. (1992). 'Noxious weeds of Australia'. (Inkata Press, Melbourne and Sydney).

Rowell, R.J. (1991). 'Ornamental flowering shrubs in Australia'. (New South Wales University Press, Kensington).

Smith, J.M.B. (2000). An introduction to the biogeography and ecology of broom (*Cytisus scoparius*) in Australia. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard and J.R. Hosking. *Plant Protection Quarterly* 15, 140-4.

Spencer, R. (1997). A clean sweep for new brooms. *Australian Horticulture* Dec. 1997, p. 18.

Broom (*Cytisus scoparius* (L.) Link) and fire: management implications

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Summary
Fire is often employed to control populations of weeds especially over large and/or remote areas. However, how fire may favour subsequent re-invasion, either from the original or other weeds is poorly understood. There is a need to know how weed species respond to fire and to incorporate this knowledge into management strategies for both fire and weeds. This paper explores how broom (*Cytisus scoparius*) responds to fire. Fire can cause high seed mortality in broom seedbanks reducing them to less than 10% of pre-fire levels, depending on the timing and intensity of the fire. It is the only potential management tool available that can directly target the seedbank, however, remaining viable seeds in the soil are sufficient for stand replacement. Any effects of fire on seedbank germination and subsequent seedling survival in the field had negligible consequences on recruitment 12 months after the fire. However, seedbank decline in burned soil samples potted out in the glasshouse showed a marked difference compared to unburned over the same period. Burned broom plants die, but lightly scorched plants have the capacity to resprout. Using fire to control broom should be avoided, unless intensive follow-up treatments are planned as part of an integrated weed management strategy.

Introduction
Over 220 plant species were declared as noxious weeds in Australia in 1992 (Parsons and Cuthbertson 1992), and approximately ten times this number have become naturalized since the arrival of European settlers, some 210 years ago (Humphries *et al.* 1991). They occur in almost every landscape and can modify the pre-invasion disturbance regimes to their advantage and the demise of native species (Mack and D'Antonio 1998). A dominant and frequent disturbance in the Australian landscape is fire. With a long history of Aboriginal burning (Nicholson 1981) many native plant species have developed strategies to survive periodic fires. Many weed-invaded environments are subject to fires, be it a wildfire or a controlled burn. Fire is still frequently used in weed management even though very little is known about its effectiveness and how weed species respond to fire (Downey 1999). This practice may have arisen from the transfer of agriculture-based weed management to native ecosystems and the logistic constraints of broad-scale weed management in remote areas (Humphries *et al.* 1991).

Broom (*Cytisus scoparius* (L.) Link subsp. *scoparius*) is an exotic, leguminous and deciduous shrub, which invades agricultural and natural ecosystems in temperate areas of high annual rainfall. It is a major weed in many parts of the world (Hosking *et al.* 1998, Peterson and Prasad 1999, Smith 2000), often forming a dense monoculture to 5 m in height and quickly establishing large long-lived seedbanks (up to 60 000 seeds m^{-2}, P. Downey unpublished data). Broom responds well to disturbance and if subject to favourable conditions can grow 1.5 m in less than one year (P. Downey unpublished data), reaching reproductive capacity in a minimum of three years (Hosking *et al.* 1998, Downey and Smith 2000).

At present herbicides are the main control option for broom in its exotic range. Herbicides are expensive, logistically difficult and costly to apply in remote locations (Carter and Signor 2000, Schroder and Howard 2000). The biological control program in Australia is still in its infancy, but based on overseas experience could prove increasingly beneficial over time (Syrett *et al.* 1999). Due to broom vigour and longevity of its seeds, any control strategy must be long-term. Fire can deplete the seedbank to 8% of pre-fire levels either by killing or stimulating germination of seeds (Bossard 1990). Following fire there is a three-year window of opportunity to intensely manage broom seedbanks and subsequent recruitment, before freshly produced seed will re-enter the system. In light of this the potential benefits of fire are very attractive to landholders.

Rigorous and comparable experimental data on how fire affects broom seedbank size and its dormancy profile from a range of sites are hard to obtain as fire intensity varies, particularly between experimental and wild fires. Data presented here are from three sites. Two of the sites had fires deliberately lit to manage broom. These fires were relatively low in intensity and in one case no pre-fire data were available. Data from a third site were collected opportunistically following a spatially variable, but in some spots, quite intense wildfire, which in places probably approached the maximum fire intensity possible given fuels derived solely from broom.

The aim of this paper is to present data on how broom responds to fire, as measured through changes in the soil seedbank, germination and mortality of seedlings. These findings are subsequently discussed in a management context for this species.

Methods

Study sites

Three sites were selected in widely separated locations in south-eastern Australia, on the basis of their known fire history. Two sites were in New South Wales at Majors Creek (35° 30'S, 149° 43'E) and Barrington Tops (31° 57'S, 151° 28'E), while the third site, 'The Lanes', was on the Bogong High Plains in the Victorian Alps National Park (36° 55'S, 147° 25'E). Each site had a mature broom infestation prior to burning. Majors Creek had been burned in March 1998 by a wildfire over approximately 15 ha leaving about 65% of the broom infestation intact. A 25 × 25 m plot at Barrington Tops had been slashed with chainsaws in October 1997 and the slash spread evenly across the site and left to dry. This plot became part of a control burn in February 1998. After this the height reached by scorching on the surrounding vegetation was recorded. At 'The Lanes', two areas had been burned under experimental conditions; one in March 1994 (approximately 1 ha, see Robertson *et al.* 1999) and the other in April 1997 (several ha). The second burn was an attempt to control broom by Parks Victoria.

Seedbank sampling

Sampling consisted of 10 cm deep soil cores. Below this depth few broom seeds are found (A. Sheppard personal communication).

Following the wildfire at Majors Creek, four sampling areas were selected (each approximately 0.5 ha in area). One was not burnt while the others appeared to have experienced different fire intensities. The unburned area was in mature broom within 30 m of where the fire had passed, while the other burned areas were allocated the relative fire intensities of low, medium and high, based on the height and minimum diameter of burned broom stumps remaining (see below). Samples consisted of 25, 3.1 cm diameter soil cores positioned at random within each sample area. Areas were sampled in September 1998, six months after the fire. The unburned and high intensity burn areas were re-sampled at 12 months in March 1999. The other areas could not be relocated for sampling at that time.

The plot at Barrington Tops was sampled twice prior to the burn in October (four months pre-burn) and December 1997 (two months pre-burn), using 25 and 30, 3.2 cm diameter soil cores respectively. Cores taken in December were lumped into groups of three prior to processing, due to the high frequency of seedless cores in the October samples. Following the fire, samples were taken after 12 months (in February 1999). In addition, five soil samples of 20 × 20 cm in area and to a depth of 10 cm were randomly collected and combined (to form one sample), from both the yet-to-be burned and unburned areas, at the Barrington Tops site, in January 1998. Similar samples were taken from the burned site three months after the burn in June 1998. These samples were put out in trays in the glasshouse and weekly broom germination rates were established for both burned and unburned samples to establish seedbank decay rates under controlled conditions. After 13 months (i.e. 12 months post fire) and nine months soil from each tray was washed through a 0.5 mm mesh sieve and remaining broom seeds counted.

At 'The Lanes' samples were collected in January 1999 in two areas corresponding to 21 and 58 months after the fire. Thirty, 7.3 cm diameter soil cores were taken at random throughout each area. No control site could be established here as all mature broom stands had been removed by Parks Victoria staff.

Soil from each core was washed through a 0.5 mm mesh sieve and all broom seeds extracted from the remains. All un-germinated seeds present in the post-fire soil cores were tested for germinability in a growth cabinet, regulated at 15–25°C (min-max) with 10 hours of light per 24 hours. Each seed was scarified with a scalpel (by placing a small nick in the seedcoat) and then placed into a Petri dish with damp filter paper and watered daily. Daily germination rates were taken over a period of 12-13 days, at which stage all remaining seeds were tested for viability with Tetrazolium® according to methods set out by Grabe (1970). Seeds from the controls were not tested for germinability or viability as previous tests had shown that 98% of broom seeds are viable (Hosking *et al.* 1998), a similar level being found in California (Bossard 1990).

Assessing germination and establishment

At each site, on each of the same sampling dates, number and approximate age of seedlings in 12 random quadrats of 25 × 25 cm was recorded using the following categories: this season's seedling (TS – non-woody plants with cotyledons), this year's older seedling (TY – woody, unbranched plants) and last year's seedling (LY – woody, branched plants).

Analysis

These data were used to obtain mean number of broom seeds and seedlings m^{-2} at each site by back-transforming means of ln (x+1) transformed data of seeds per core and seedlings per quadrat. Mean number of seeds m^{-2} was considered to be the 'actual' seedbank (some seeds in the soil cores were in the process of germinating and were thus considered part of the actual seedbank) on the given sampling date, while mean number of seeds m^{-2} plus mean number of new seedlings m^{-2} was considered to be the 'original' seedbank.

Fire intensity – Majors Creek

In three, 1 m^2 randomly placed quadrats in each of the three burned areas at Majors Creek, the heights and minimum stem diameters at the base and at the top of all burned stumps were recorded. Basal diameters only were recorded from the control area (i.e. of live plants). All measurements were taken at the first sampling date only and then used to define relative fire intensity between the three burned areas. The area with the lowest average stump height and the largest minimum mean stem diameter at the top was considered to have experienced the highest fire intensity and the area with the tallest mean stump heights and the smallest mean stem diameter at the top was considered to have experienced the lowest fire intensity. These data were also used to estimate number and sizes of broom plants that had died as a result of the fire.

Results

Fire intensity assessments at Majors Creek

Observed values of stem height and apical and basal stem diameters of burned stumps left after the fire in the three burned areas at Majors Creek are given in Figure 1. The area with the tallest stumps also had the smallest apical stem diameters and vice versa. The area with the tallest stumps was also the only burned area where any broom resprouting post-fire was observed (see below). This allowed relative fire intensity to be allocated to each burned area at this site and used subsequently for presentation of seedbank and seedling density data in Tables 1–3.

Seedbank depletion

At the Majors Creek site broom seedbanks were 3.3–11% of the level in unburned areas six months after the wildfire (Table 1). Assessed fire intensity had relatively little effect on magnitude of seed loss to fire, as the smallest estimated decline in seedbank density after the fire (89%) was found in the area where the fire intensity was assessed as being highest. In this area the seedbank was again estimated 6 months later (i.e. 12 months after the fire) and found to have declined to 98% (688 seeds m^{-2}) of the background seedbank.

The control burn at Barrington Tops was of very low intensity with a scorch height of 2–3 m. Seedbanks at the site a year after the fire were approximately 57% of the density two months before the fire (Table 1). At 'The Lanes', where lack of an adequate control site prevented assessment of seedbank depletion in response to fire, viable seeds were still present in the seedbank at about 1500 seeds m^{-2}, 58 months after the fire when regenerated plants were starting to shed seeds (Table 1).

Seedbank and seedling density

Six months after the fire at Majors Creek, seedling density in burned areas demonstrated seedbank depletion to levels an order of magnitude lower than in the unburned area (Tables 1 and 2). Fire did not appear to affect the chance of a seed in the seedbank becoming an established seedling as 18–47% of the 'original' seedbank had established as seedlings in the burned area, while 19% of the 'original' seedbank had established as seedlings in unburned plots (Table 1). At Barrington Tops six months after the fire, seedling density was higher in burned plots 210 seedlings m^{-2}) than in unburned plots (79 seedlings m^{-2}, Table 2), but lack of data prevented assessment of whether this reflected the available seedbank and 12 months after the fire there was no difference in seedling density between burned and unburned plots (Table 2). Broom seed germination rates from Barrington Tops, based on soil collected two months pre-burn and placed in glasshouse trays, showed a 28.7% reduction in the seedbank at the 12 month post-fire stage (Table 3). Soil collected from within the burned area showed a 52.3% reduction in the seedbank, over the last nine months of a 12 month post-fire period. The difference observed in germination rates between burned and unburned sites was highest in the 3–6 month period, but still present 12 months after fire (Table 3).

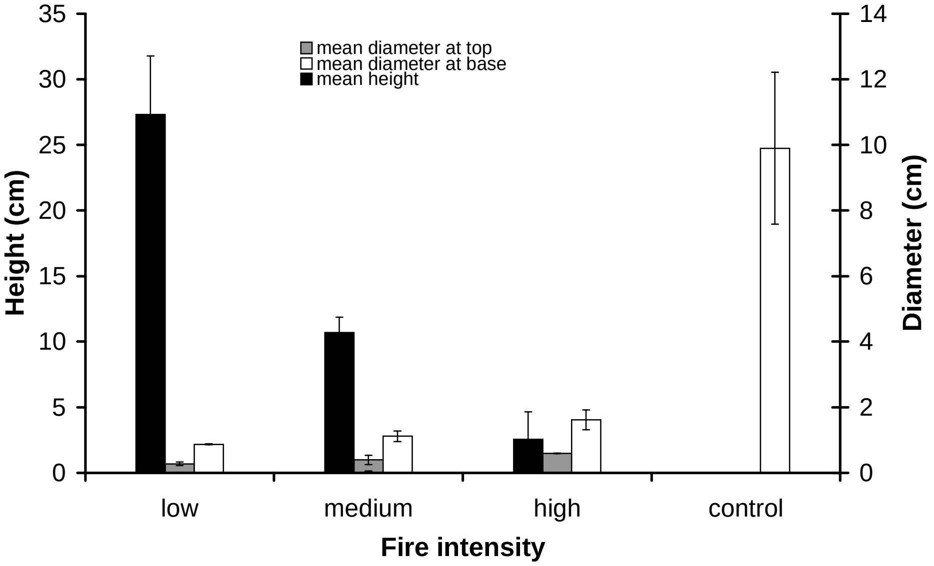

Figure 1. The mean height of burned broom plants and their base diameters and top diameters.

Germinability and viability of broom seeds

Broom seeds which remained in the soil following fire exhibited a high level of germinability which appeared to decline with time as highlighted by only 3% of seeds being germinable after 58 months. Despite this viability of ungerminated seedbank seeds was 94–100% even after 58 months.

Seedling survival

At Majors Creek seedlings appeared to survive longer in burned (assessed high intensity) than in unburned areas as reflected by densities of TS seedlings found six months after the fire and numbers of TY and LY seedlings found 12 months after the fire (Table 2). Actual seedling

Table 1. Broom seedbank and seedling density at different times following fires of differing intensity, at three sites in eastern Australia.

Site	Burn condition	Time since fire (months)	Viable seeds m^{-2} in seedbank[A] (mean ln (x+1) transformed seeds per core ± SE given in brackets)	% seedbank reduction with respect to unburned area	Total seedlings m^{-2} (back-transformed from mean ln (x+1) transformed quadrat^{-1} ± SE given in brackets)	Seedlings as a % of 'original' seedbank[B] seedlings
Majors	Unburned	6	28 377 (22.86 ± 0.2)		6 620 (34.48 ± 0.2)	19
Creek		12	18 814 (15.15 ± 0.2)		61 (0.32 ± 0.1)	0.4
	Low intensity[D]	6	1 862 (1.50 ± 0.2)	93	699 (3.64 ± 0.2)	27
	Medium intensity[D]	6	699 (0.56 ± 0.1)	97	626 (3.27 ± 0.2)	47
	High intensity[D]	6	3 117 (2.50 ± 0.2)	89	692 (3.60 ± 0.3)	18
		12	688 (0.55 ± 0.1)	98	484 (2.52 ± 0.3)	13
Barrington	Pre-fire	-4	1 756 (1.33 ± 0.2)			
Tops	Pre-fire	-2	1 117 (2.53 ± 0.4)			
	Very low intensity	12	482 (2.02 ± 0.2)	57[C]	103 (0.8 ± 0.2)	18
'The	Control burn	21	2 482 (10.40 ± 0.1)	No data	1 486 (7.7 ± 0.2)	37
Lanes'	Low intensity[E]	58	1 470 (6.16 ± 0.2)	No data	261 (1.4 ± 0.3)	15

[A] Calculated from back-transformed values of seeds per core, where core size varied across sites (see text for details).
[B] Original seedbank = seedlings + viable seeds at the time samples were taken.
[C] % of sample taken 2 months before the fire.
[D] Intensity estimated (see text for details).
[E] See Robertson *et al.* 1999.

densities were eight times higher in this burned area than in the unburned area 12 months after the fire despite being an order of magnitude less at six months after the fire (Table 2). This pattern was not reflected at Barrington Tops where the burned plot had a higher TS seedling density at six months but a lower TY+LY seedling density at 12 months. This suggests seedling survival may be more related to initial seedling density than the effect of the fire per se. It should also be noted that seedlings at the unburned site at Majors Creek, but not at Barrington Tops, were under an undisturbed mature broom canopy.

Mature broom mortality

At Majors Creek most plants that were severely burned died irrespective of age. Scorched or partially burned plants (e.g. those on the edge of a fire) could re-sprout. Re-sprouting (3% of stumps) at six months post-fire was only observed in the area assessed as having experienced a low intensity fire. This was similar to 'The Lanes' site, but due to the interval between the fire and sampling date, it could not be conclusively stated that fire alone led to plant death there.

Discussion

Fire intensity and seedbank depletion

The degree to which broom seedbanks were depleted by fire in this study were comparable with the 92% reduction observed by Bossard (1990) in California. The effect of fire intensity on seedbank depletion could not be detected at Majors Creek, the only site where an attempt was made to select areas experiencing differing fire intensity. However the much lower (54%) reduction in the seedbank 12 months after the low intensity fire at Barrington Tops suggests fire intensity may influence the degree of seedbank depletion to some degree.

Variation in seedbank depletion following fires will be influenced by interactions between fire intensity and soil moisture and how this affects heat penetration into the soil. Soil temperatures during a fire cannot exceed 100°C until soil moisture has been boiled away. However, a fire over dry soils can lead to temperatures of several hundred °C in the top few centimetres (M. Gill personal communication), which is where the majority of broom seeds are present (P. Downey unpublished data). Bossard (1990) found that once temperatures reach 150°C broom seeds are killed outright, while temperatures around 65°C stimulate germination. Fire intensity can also prolong the period of heat exposure, thereby killing more seeds (Bossard 1990). Clearly, the drier the soil at burning the greater the level of seedbank depletion achieved. In their study at 'The Lanes' Robertson *et al.* (1999) found that as it rained the day prior to burning, the soil temperatures during the fire were low. Hardman (1980) found similar limitations during ten years of using fire to control broom on Barrington Tops. While he concluded that burning of broom should be carried out in drier hotter months, the availability of suitable climatic conditions for broom control burns is a limiting factor in its applicability as a management tool. The greatest seedbank depletion estimated in this study was at Majors Creek, where broom was burned by a wildfire during a period when conditions were such that there was a total fire ban in the shire. This fire therefore occurred when soil moisture was low and thus soil heat penetration was maximal, leading to similar levels of seedbank depletion across all three fire 'intensities'. Factors other than observed fire intensity (when assessed in terms of combustion of above ground biomass), such as site location and soil moisture levels and the size of the broom seedbank relative to that of native species may therefore be more important for understanding fire impact on the seedbank and subsequent stand regeneration.

Bradstock and Auld (1995) found that post-fire soil temperatures were similar to or higher than those recorded during a fire, for longer periods of time, suggesting that post-fire dynamics may be important for germination of leguminous shrubs. Despite this and not collecting samples till either three or six months post-fire, there seems to be little difference at the 12 months stage in terms of recruitment, which may be due to high levels of seedling mortality (Downey and Smith 2000).

As in this study, others who sampled seedbanks following a fire, found that there was still enough viable seed left in the soil to allow stand replacement (Robertson *et al.* 1999). Studies on similar weeds such as *Spartium junceum* L. (Fernandez-Santos *et al.* in press) and *Genista monspessulana* (L.) L.A.S.Johnson

Table 2. Broom seedling density in the field at different times following fires of differing intensity, at three sites in eastern Australia divided into three seedling age classes.

Site	Burn condition	Time since fire (months)	Density of TS seedlings m^{-2} [A]	Density of TY seedlings m^{-2} [A]	Density of LY seedlings m^{-2} [A]
Majors Creek	Unburned	6	6613	6	3
		12	0	32	0
	Low intensity[B]	6	699	0	0
	Medium intensity[B]	6	626	0	0
	High intensity[B]	6	692	0	0
		12	9	384	92
Barrington Tops	Unburned	6	70	6	3
		12	43	47	10
	Low intensity	6	210	0	0
		12	83	21	0
'The Lanes'	Control burn	21	1486	0	0
	Low intensity[B]	58	155	6	10

[A] from back-transformed data; TS – this season's, TY – this year's, LY – last year's (see text above).
[B] see notes on table 1 for details.

Table 3. Germination of broom based on weekly counts taken from soil collected at Barrington Tops and put out in trays in the glasshouse. Soil collected from burned area three months post-fire.

Period:	3–6 months post-fire		6–12 months post-fire		0–12 months post-fire
Burned condition	total number of seedlings germinated	% of actual seedbank in tray that germinated	total number of seedlings germinated	% of actual seedbank in tray that germinated	total germination number and % in brackets
Unburned	28 (76[A])	7.3 (19[A])	34	8.9	110 (28.7)
Very low intensity	48	36.4	21	15.9	69 (52.3)

[A] value for the full 0–6 months, burned samples weren't collected until three months after the fire.

(J. Lloyd personal communication) have also shown that fire does not completely destroy viable seed.

Germination rates

Results from trays indicated that germination can occur throughout the year without any major flushes when there is no seed input, suggesting that seasonal flushes in germination are attributable to fresh seed, and that seedbank decay/decline may be a slow process (7% in the first six months reaching 11% after 12 months). However, based on glasshouse experiments that were monitored weekly, the rates were much higher with 16.7 and 23.7% respectively. There are two reasons for this. Firstly the glasshouse is a more benign environment, and secondly seedling mortality in the field is extremely high (Downey and Smith 2000) and by sampling at six month intervals in the field many seedlings will die without being recorded, as demonstrated by the discrepancies between actual germination and the change in the seedbank at Barrington Tops (113 seedlings m^{-2} recorded in 12 months, but a reduction in the seedbank of 566 m^{-2}). Decreased germination rates of seed from the longer fire interval sites suggests that the longer seed remains in the soil the more difficult germination becomes, despite high seed viability.

Seedling survival

The present study found clear evidence that fire created a seedbed that led to higher survival of seedlings. Seedling survival, estimated by counting number of new seedlings after six months, and then number of woody and branched seedlings after 12 months suggested that absolute initial seedling density was more related to later numbers than whether these seeds had appeared in a burned plot. Unfortunately this conclusion is only based on comparisons at two sites.

Broom and fire

Like other exotic species (Mack and D'Antonio 1998), broom may modify ecosystems it invades to the detriment of surrounding native species. Prior to broom invasion, Barrington Tops was subalpine open eucalypt woodland, with a grassy understorey, supporting a low density of shrubs. As in most invaded areas, broom now forms a dense shrub layer, over topping a depleted grass layer. A fire in this situation would be a higher intensity shrub fire instead of a grass fire in which fire temperatures and duration would be lower (M. Gill personal communication). There is some debate as to whether living broom is very flammable (Csurhes and Edwards 1998) or a fire retardant (Hardman 1980). The degree to which broom will modify fire regimes may depend on density, standing biomass/fuel loads (combination of broom and the other vegetation present) and to a lesser degree climatic conditions preceding and during the fire. The general effect broom has on fire regimes remains unanswered, but potential effects on the native community may be more devastating than weed invasion alone (Mack and D'Antonio 1998).

Fire and broom management

To develop a safe fire-based management strategy that both removes broom stands and usefully depletes underlying broom seedbanks requires greater understanding of fire intensity requirements in relation to soil conditions and how this can be most effectively manipulated (e.g. by slashing broom prior to use of fire). Selecting appropriate climatic conditions for the fire will also be important in the balance between fire effectiveness and safety. In remote areas an intense wildfire may provide a window of opportunity for broom management, but strategies will need to be quickly available to benefit from this type of event. Fire management strategies need to include follow-up treatment for an extended period as broom seeds have a long dormancy period. These follow-up strategies need to be incorporated into a integrated weed management strategy for broom.

Post-fire strategies are important in enabling native species to regain ground previously occupied by weeds as highlighted by Robertson *et al.* (1999). Post-fire treatments should minimize disturbance and target regenerating broom just before first flowering (three years). Disturbance may enhance the chance of a seedling surviving to reproduction which is generally very low in Australia (less than 2%, Rees and Paynter 1997, Downey and Smith 2000). Broom seedling survival can be reduced by a grass cover (P. Downey unpublished data) which can be encouraged by selective post-fire treatments. Observations from all three sites suggests that recruitment of native *Poa* species is slow following fire, giving broom a competitive edge in these grass-dominated environments.

Conclusions

Fire alone cannot control broom, but if used as part of an integrated weed management strategy it could be very effective. As fire is the only management tool that can directly remove broom stands and deplete broom seedbanks, it can provide a window to manage broom before the stand regenerates. This study has shown, however, that using fire effectively is not an easy task and requires an understanding of fire behaviour and intensity (through variables like soil moisture, climate and fuel loads). Failure to plan and carry out long-term post-fire management will quickly nullify benefits of fire and may indeed increase broom dominance due to the favourable seedbed created. It will be important therefore not to apply fire as a management tool to broom areas too large to effectively manage thereafter, and large-scale fires are probably the main reason why wildfires in broom cause more harm than good to cohabiting native species. Follow up treatments may become less time consuming as germinability of the remaining seedbank declines in the presence of competing ground cover. Collection of better data relating to this is of paramount importance for designing long-term post-fire weed management plans.

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References

Bradstock, R.A. and Auld, T.A. (1995). Soil temperatures during experimental bushfires in relation to fire intensity: consequences for legume germination and fire management in south-eastern Australia. *Journal of Applied Ecology* 32, 76-84.

Bossard, C.C. (1990). Secrets of an ecological interloper: ecological studies on *Cytisus scoparius* (Scotch broom) in California. Ph.D. Thesis, University of California, Davis.

Carter, K. and Signor, A. (2000). Controlling broom (*Cytisus scoparius* (L.) Link) in native forest ecosystems. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard, J.R. Hosking. *Plant Protection Quarterly* 15, 165-6.

Csurhes, S. and Edwards, R. (1998). Potential Environmental Weeds in Australia: candidate species for preventative control. National Weeds Program, Environment Australia, Canberra.

Downey, P.O. (1999). Fire and weeds: a management tool or Pandora's box?

Proceedings of the Bushfire 99 conference, Albury, 7–9 July 1999, pp. 111-7. (Charles Sturt University, Albury).
Downey, P.O. and Smith, J.M.B. (2000). Demography of the invasive shrub Scotch broom (*Cytisus scoparius* (L.) Link) at Barrington Tops, NSW: insights for management. *Austral Ecology* 25(5).
Fernandez-Santos, B., Gomez-Gutierrez, J.M. and Moreno-Marcos, G. (In press). The effect of traditional Spanish rural-practice perturbations on the regenerative response in *Cytisus multiflorius*.
Grabe, D.F. (ed.) (1970). Tetrazolium Testing Handbook for Agricultural Seeds, The tetrazolium testing committee, The Association, Amherst, Massachusetts, 62 pp.
Hardman, D.C. (1980) Scottish Broom (*Sarothomnus scoparius*): Control Programme, Barrington Tops National Park. New South Wales National Parkes and Wildlife Service unpublished report.
Hosking, J.R., Smith, J.M.B. and Sheppard, A.W. (1998). *Cytisus scoparius* (L.) Link ssp. *scoparius*. *In* 'The Biology of Australian Weeds', Volume 2, eds F.D. Panetta, R.H. Groves, and R.C.H. Shepherd, pp. 77-88. (R.G and F.J. Richardson, Melbourne).
Humphries, S.E., Groves, R.H. and Mitchell, D.S. (1991). Plant invasions of Australian ecosystems: a status review and management directions. *Kowari* 2, 1-134.
Mack, M.C. and D'Antonio, C.M. (1998). Impacts of biological invasions on disturbance regimes. *Tree* 13, 195-8.
Nicholson, P.H. (1981). Fire and the Australian Aborigine-an enigma. *In* 'Fire and the Australian Biota', eds A.M. Gill, R.H. Groves and I.R. Noble, pp. 55-76. (Australian Academy of Science, Canberra).
Parsons, W.T. and Cuthbertson, E.G. (1992). 'Noxious Weeds of Australia'. (Inkata Press, Melbourne).
Peterson, D.J. and Prasad, R. (1999). The biology of Canadian weeds. 109. *Cytisus scoparius* (L.) Link. *Canadian Journal of Plant Sciences* 78, 497-504.
Rees, M. and Paynter, Q. (1997). Biological control of scotch broom: modelling the determinants of abundance and the potential impact of introduced insect herbivores. *Journal of Applied Ecology* 34, 1203-22.
Robertson, D.C., Morgan, J.W. and White, M. (1999). Use of prescribed fire to enhance control of English broom (*Cytisus scoparius*) invading a subalpine snowgum woodland in Victoria. *Plant Protection Quarterly* 14, 51-6.
Schroder, M. and Howard, C. (2000). Controlling broom (*Cytisus scoparius* (L.) Link) in natural ecosystems in Barrington Tops National Park. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard, J.R. Hosking. *Plant Protection Quarterly* 15, 169-72.
Smith, J.M.B. (2000). An introduction to the biogeography and ecology of broom (*Cytisus scoparius*) in Australia. Proceedings of the broom symposium held at Ellerston and Moonan, 16–17 November 1998, eds A.W. Sheppard, J.R. Hosking. *Plant Protection Quarterly* 15, 140-4.
Syrett P., Fowler S.V., Coombs E.M., Hosking J.R., Markin G.P., Paynter Q.E. and Sheppard A.W. (1999). The potential for biological control of Scotch broom (*Cytisus scoparius*) (Fabaceae) and related weedy species. *Biocontrol News and Information* 20, 17N-34N.

Cutting and mulching broom (*Cytisus scoparius* (L.) Link): a Tasmanian perspective

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Summary

This paper reviews current practices for broom control used in north-west Tasmania and describes the instigation and operating of the first community-based regional weed management strategy developed in Australia. It also presents and costs the 'cut and mulch' method developed for broom control as part of a project by the West Coast Weed Strategy and funded by the National Heritage Trust.

Introduction

Broom (*Cytisus scoparius* (L.) Link), has a long history of cultural uses in its native range. In addition to being adopted by the English king, Henry II (the 'Plantagenet' from *planta genista*) as a personal emblem, these cultural uses also included: an agent for tanning leather; as a source for yellow dye; for broom, rope and paper manufacture; as rabbit feed; and for making an alternative medicine for use as a heart tonic, diuretic, emetic, purgative and relief from liver complaints (Launert 1981, Chevallier 1996). Despite this diverse utilitarian history, none of these uses have yet been transferred to Australia where the plant has become as serious noxious weed.

Following introduction into Tasmania soon after colonization, broom has spread to be a significant weed of forestry, mining company and public land and native vegetation in north-west Tasmania, particularly around the town of Waratah where this weed has special 'secondary weed' status under the State *Noxious Weeds Act* 1964. It is also a scattered weed in other parts of Tasmania (J. Ireson personal communication). It is now estimated to have infested at least 33 000 ha in the state (Hosking *et al.* 1998). This paper first describes the West Coast Weed Strategy; a project which developed a five-year plan to coordinate major weed control efforts in north-west Tasmania and then reviews past broom control methods in this region and describes a successful 'cut and mulch' control method for broom.

West Coast Weed Strategy

The West Coast Weed Strategy was a five-year plan put forward by Bob Curley (Ranger, Parks and Wildlife Service) in 1992 to coordinate weed control activities currently being undertaken by a number of organizations with independent goals. This was the first community-based regional weed management strategy set up in Tasmania and led to the setting up of a West Coast Landcare Group. The major weed species included were gorse (*Ulex europaeus* L.), brooms (*C. scoparius* and *Genista monspessulana* L.A.S.Johnson), pampass grass (*Cortaderia* spp.), blackberry (*Rubus frutisosus* L. complex), and Elisha's tears (*Leycesteria formosa* Wall.). Landcare and various private and government organizations sponsored a part-time coordinator position from May 1994. The coordinator's role is to coordinate weed control efforts in the group, provide relevant information, represent the group at meetings, organize weed control meetings and promote and sustain interest in the Strategy. The coordinator is also responsible for maintaining in-kind funding from affected organizations and councils and to obtain external grants (e.g. from the National Heritage Trust) to run this weed control initiative. However, without active involvement of supporting organizations and their adherence to the agreed plan the strategy would fail. Areas of concern to the Strategy were to tackle weed problems in urban areas, monitor spread of weeds into bush via off-road tracks and control weeds in areas adjacent to the World Heritage Areas.

Since 1997 the West Coast Weed Strategy has obtained regular financial support from the National Heritage Trust, the West Coast Council and other stakeholders such as the Hydro Electric Commission and Renison Bell Gold Mines. The main successful management strategy for broom trialed by the West Coast Weed Strategy is the cut and mulch method.

Lessons to be learned from north-west Tasmania

A number of different broom control procedures have been used in the region. These and their effectiveness are discussed below.

Bulldozing and fire

Bulldozing infestations into heaps and burning resulting weed mounds has been a common practice. This causes massive soil disturbance and physical movement of broom plants not only burying seeds but also spreading seeds beyond the original infestation and leaving a perfect seed bed for regrowth. Topsoil is often buried in the process. In at least one situation (i.e. Waratah, Tasmania) this practice and a lack of follow up treatments exacerbated the broom problem throughout the town.

Herbicides

In the past the general practice in the region has been to control broom along roadsides with herbicides. This approach generally led to poor control. Plants along roadsides were sprayed to a set distance onto the verge resulting in only half of many plants being affected by herbicide. Such plants regrew and produced many seeds allowing continued spread out into adjacent paddocks or bush. These attempts to control broom also failed due to inadequate consultation with adjoining landowners. Since the instigation of the Strategy cooperation between adjacent landholders and a strategic spraying program by the Civil Construction Company has improved the success of chemical control programs.

Treating large infestations

Large infestations have been generally treated haphazardly, such as by spraying herbicides around the perimeter, then when dry setting fire to the infestation. There are inherent fire risks in this practice and it has failed to be used in any regulated manner. Risks of such methods getting out of control will be high in, for example, semi-urban settings. The treatments also initially leave the land unusable due to the many burnt stems sticking out of the ground.

Figure 1. Broom demonstration site at Waratah prior to the cut and mulch method being applied on 26 March 1996.

Figure 2. Picture of tractor and mulcher attachment used during the broom control demonstration trial.

Cut and mulch method using machinery

The cut and mulching method was developed as a response to the tendency of many landholders to think that herbicides are the only answer to woody weed control. The Coordinator teamed up with the commercial operations of a small company (Silvi Culture Contracting, Launceston) marketing vegetation mulching of inter-row weeds in plantations, where access was required for pruning, thinning or as a means of retarding fire. The longest running trial started on 29 March 1996 and used the cut and mulch method on a 0.4 ha plot of relatively flat ground that was densely covered by mature broom (3.5 m high) that had been present on the site for many years (Figure 1).

The tractor and mulcher consisted of a 115 horse power four wheel drive tractor pulling a Seppi Heavy Duty Forest Mower which has a large rotating drum equipped with what are termed ‘Hammers’, driven by the power take-off (Figure 2). As the tractor pushes and flattens plants the machine chews them up and deposits the leftovers as mulch. The mulcher did not disturb the soil surface and the tractor caused much less disturbance than a bulldozer and therefore offered little opportunity for sunlight to stimulate buried dormant seeds. Both a forward and reverse cut were necessary and the treatment lasted 2–3 hours at a contracted cost of \$1110 ha^{-1}. A further contract cleared 21 ha at a total cost of \$17 800, which reduced costs ha^{-1}, and was cheaper and more effective than earlier contracts to clear the land of broom using bulldozers.

The thickness of the mulch depended upon biomass of broom plants per unit area. Mulch, 15–20 cm thick, significantly suppressed and retarded broom regeneration. No regeneration from seed was observed in these areas after 12 months. Variation in terrain and broom biomass, however, did lead to some variation in mulch thickness and effective broom suppression. In 1998, at 24 months (Figure 3), a few regenerating broom plants were found that had reached 30 cm, amongst a thick layer of regenerating grasses that excluded most broom seedlings. These plants were easily treated by hand pulling, slashing or carefully sprayed with an appropriate herbicide by ground staff. The cut and mulch control is based on the principle of removing seed producing plants before dealing with recruitment from the seedbank and is effective because of specific aspects of broom biology. These are that the broom only reproduces by seed and, in the area of Waratah, only flowers and sets seed between October and December when it is at least 40 cm tall. In the trial, the cut and mulch method allowed approximately three years of breathing space between mulching and follow up treatments that must be part of any integrated management strategy.

The cut and mulch method may also be applicable on a smaller scale for small infestations using a smaller portable mulcher in combination with the cut stump method of applying herbicide (see Hosking *et al.* 1998). The cut and mulch technique may be equally effective against gorse.

Figure 3. Picture of broom demonstration trial site showing degree of broom regrowth on 1 February 1998.

Conclusions

On suitable ground the cut and mulch method described here is cost effective and, with forward planning, will decrease costs of long-term broom control. It is most effective when applied to a small area initially. This area can be extended in stages. This method results in a longer period before broom regeneration needs to be treated when compared with other mechanical broom control methods. This allows the incorporation of biological control to assist in control of any untreated regrowth.

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References

Chevallier, A. (1996). 'The encyclopedia of medicinal plants.' (Dorling Kindersley Ltd, London).

Hosking, J.R., Smith, J.M.B. and Sheppard, A.W. (1998). *Cytisus scoparius* (L.) Link ssp. *scoparius*. *In* 'The biology of Australian weeds', Volume 2, eds F.D. Panetta, R.H. Groves and R.C.H. Shepherd, pp. 77-88. (R.G. and F.J. Richardson, Melbourne).

Launert E. (1981). 'Country life guide to edible and medicinal plants of Britain and Northern Europe'. (Hamlyn Publishing Group Ltd., London).

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Acronyms

CSIRO	Commonwealth Scientific and Industrial Research Organisation
NPWS	National Parks and Wildlife Service
KTRI	Keith Turnbull Research Institute
CRCWMS	Cooperative Research Centre for Weed Management Systems
MCBCSB	Management Committee for the Biological Control of Scotch Broom
BTBC	Barrington Tops Broom Council
BTNP	Barrington Tops National Park