Using aerial mapping to analyse factors affecting the spread of Scotch broom

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Summary

Scotch broom is an invasive weed in many subalpine ecosystems. It often has substantial negative effects on ecosystem structure and functions. Decisions on optimal management strategies require predictions of the rates and patterns of Scotch broom spread. This paper explores the environmental and management factors that influence the rate of spread of Scotch broom in Barrington Tops National Park.

The NSW National Parks and Wildlife Service (NPWS) and the then neighbouring NSW State Forests prepared aerial maps showing Scotch broom infestation in the Park for 1989, 1993 and 1999. These maps were used to generate data for the current analysis. Map reference points 1 km apart along the southern boundary of the 1989 area of infestation were examined and 1993 and 1999 differences from the reference points were measured. Also measured were environmental factors including natural vegetation type, natural vegetation density, soil type, slope, altitude and the presence of private property or crown land. The incidence of natural disaster, feral animal activity and NPWS management activities were also included in the analysis.

The regression analysis shows that the three variables contributing most to an expansion of broom are sparse vegetation (62 m pa), flat slopes (23 m pa) and State Forest land (23 m pa). The three variables contributing most to a reduction in broom spread are NPWS general treatment activities (-14 m pa), NPWS specific wetlands treatment (-40 m pa) and steeper slopes (-59 m pa).

Key words: aerial mapping, Scotch broom, spread, park management, regression models.

Introduction

Scotch broom (*Cytisus scoparius* (L.) Link) has become a major weed in parts of south-eastern Australia (Smith 1994, Hosking *et al.* 1998, Schroder and Howard 2000). It now poses a serious threat in many regions including the Barrington Tops National Park in New South Wales, the Australian Alps National Parks in New South Wales and Victoria, and in western Tasmania. It has also been recorded around Perth, Western Australia. The total area infested in Australia is estimated to be over 200 000 ha and still spreading (Hosking *et al.* 1998).

A study to investigate the economics of management strategies for Scotch broom in the Barrington Tops National Park has involved the construction of a dynamic programming model of the Park (Odom *et al.* 2001). This model requires as input a biological model of Scotch broom spread.

Rees and Paynter (1997) developed a spatial model for Scotch broom, which allowed them to explore changes in population size and the proportion of ground covered by the weed. Two versions of this model were presented. The first model was a complex simulation model which was spatially explicit and incorporated spatially local density-dependent competition, asymmetric competition between seedlings and established plants, a seed bank, local seed dispersal and an aged-structured established plant population. This model incorporated much of the known population biology of broom. The second model was an analytical approximation of the simulation model. Analytical approximations were developed in order to allow the simulation model to be interpreted and to illuminate inter-relationships between parameters. Data from many different regions including Australia, New Zealand, the United States, the United Kingdom, France, Eire and Spain were used in this model.

This existing biological model for Scotch broom has not been validated by data explicitly from Barrington Tops National Park. Thus, the aim of this paper is to explore the environmental and management factors that have influenced the rate of spread of Scotch broom on Barrington Tops[1]. An understanding of how Scotch broom spreads here will help decide whether there is a need to modify the relationships between the parameters used in the Rees and Paynter biological model to fit the case of Barrington Tops. In doing this, we look broadly at average rates of spread across the whole Park rather than look in detail at individual plants or sites. The focus is primarily on the policy and management implications. First, the impacts of Scotch broom in the Park are described briefly and those factors that promote the spread of broom are reviewed. Next the aerial maps that form the basis of the analysis are described. These maps provide data on spread and density of broom at different times, and provide an opportunity to evaluate whether the use of maps like these is a viable alternative to extensive fieldwork. Following, the data calculations and the empirical methods used for the analysis are discussed. Finally, the results are presented and some conclusions are drawn.

Impacts of Scotch broom in the Barrington Tops National Park

The Barrington Tops National Park is particularly important ecologically because it comprises one of the fifteen areas of rainforest within New South Wales which are included in the World Heritage Listing of the Sub- tropical and Temperate Rainforest Parks of Eastern Australia. The rainforest of Barrington Tops National Park is the core of one of the five major regions of rainforest originally present in New South Wales before European settlement (Trudgeon and Williams 1989).

It is an area where cold adapted species have survived climatic warming and contains sub-alpine swamps as well as grassland, woodland, open forest and the rainforest mentioned earlier.

Extensive tracts of the Barrington Tops National Park, bordering Polblue Conservation Reserve, Stewarts Brook State Forest, Barrington Tops State Forests and adjoining private land on the Barrington Tops plateau, have been invaded by dense stands of Scotch broom. An almost impenetrable shrubby understorey of Scotch broom currently occupies large areas that prior to the 1960s was relatively open vegetation. A major concern is that the invasion by Scotch broom will have long-term effects on the native vegetation of the plateau. A number of plant and animal species listed as rare or threatened are found only in the areas now infested by broom (Heinrich and Dowling 2000). As a consequence, the value of vegetation conserved in the Park may decline and the stock carrying capacity of local grazing lands may be reduced (Waterhouse 1988). Prior to the hand over of NSW State Forest land to the NSW National Parks and Wildlife Service, the economic potential of stands of commercial timber in the State Forests may have been jeopardized.

Dense thickets of Scotch broom have blocked disused tracks and have hindered access to some watercourses on the plateau. Many recreational users of the plateau regard the infestation as a considerable hindrance to access and aesthetically less pleasing than the natural open vegetation. The thickets are thought to provide harbour for feral pigs, which are causing considerable local damage to the ground surface and vegetation in the native forests (Waterhouse 1986, Hosking and Smith 1999). Attempts by private landholders, the NPWS and State Forests to control the infestation have been costly and largely unsuccessful due to large soil seed banks and limited access to most of the infestation (Wapshere and Corey 1999, Smith 1994, Waterhouse 1988).

Factors that promote the spread of Scotch broom

Scotch broom produces 30–360 seeds per square metre per annum below a eucalypt canopy, and 7700–8900 seeds per square metre per annum in the open (Hosking *et al.* 1998). In Australia seedbanks in the soil have been measured to contain from 190–50 000 seeds per square metre (Smith and Harlen 1991). Scotch broom plants live to a maximum of about 20–25 years and all regeneration is by seed rather than by vegetative means (Hosking *et al.* 1998). Long-term control of the plant is complicated by the presence of this large, long-lived soil seedbank (Smith and Harlen 1991).

Scotch broom is restricted to mainly cool temperate areas of Australia. In New South Wales most of these areas are over 600 m above sea level. Broom occurs on soils derived from a wide variety of substrates, particularly basalt. It grows best on moist, fertile soils and is rarely found on undisturbed skeletal sandy soils. It spreads rapidly in open spaces and more slowly in dense vegetation such as rainforest. Apart from normal seed drop, Scotch broom has been shown to be spread over longer distances in four major ways: by ants (Smith and Harlen 1991); by animals (Smith and Harlen 1991, Harlen 1989, Moodie 1985, Waterhouse 1988); by human beings (Smith and Harlen 1991, Harlen 1989, Moodie 1985, Waterhouse 1988, Hobbs 1991, Smith 2000, Robertson *et al.* 1999); and by natural disasters (Williams 1981, Harlen 1989, Smith and Harlen 1991).

The aerial maps

NPWS and State Forests undertook mapping of the Scotch broom infestation in Barrington Tops National Park on several occasions during the 1980s and 1990s. In 1988, data from 1982 aerial photographs were mapped to identify the boundaries of the infestation. This was updated and enhanced in 1989 by the production of a more detailed map showing the density of broom from 1987 aerial photographs. State Forests again mapped the perimeter in 1992/1993, and this map indicated a slight increase in the area of the main infestations from 1989 (Schroder and Howard 2000). The 1993 information was overlaid onto the 1989 map.

Additional aerial surveys of the boundary of the broom infestation were undertaken in 1995/1996 using a helicopter-mounted Global Positioning System 'live linked' to a geographic information system on a lap-top computer (Carter and Signor 2000). This exercise was done for the purpose of locating isolated infestations for on-ground treatment. A survey using this technology was carried out again in late 1998, and maps were produced in 1999, so as to compare with the 1989 map (Schroder and Howard 2000).

Limited fieldwork was undertaken after each aerial survey to validate the outer edge of the broom infestation and to check the density classes (McDonald 1999). Most of the work was undertaken around Polblue Swamp and other easily accessible areas.

Hence, there are 1989 and 1999 maps available from the NPWS with similar information, and these can be compared, together with information for 1993, to show changes in the spread of the broom infestation.

Data collection

The southern sections of the two existing maps showing Scotch broom infestation in Barrington Tops National Park for 1989 and 1999 were the basis of data for the analysis. Some 55 map reference points one kilometre apart along the boundary of the 1989 area of infestation were plotted onto the 1999 map. Changes in the boundary between 1989, 1993 and 1999 were recorded at each point. These observation points were then transferred to the relevant 1:25 000 topographic maps.

For each of the points, both environmental and management factors were obtained. Environmental factors measured include natural vegetation types, natural vegetation densities, soil types, slope and altitude and whether the point was on private property or crown land. Areas of natural disaster, feral animal activity and NPWS management activities were also included in the analysis. These data were estimated as follows.

Broom spread

Broom spread between 1989, 1993 and 1999 was measured in three different ways:

i. whether the broom had spread or not (yes/no). The observation points that showed a positive spread at 1993 and/or 1999 were given a value of one, while those that had no positive spread were given a value of zero,
ii. whether the spread was zero, positive or negative. The observation points that showed no change at 1993 and/or 1999 were given a value of zero, those that showed a positive change at 1993 and/or 1999 were given a value of one, while those that showed a reduction in area were given a value of two, and
iii. how far the broom has spread (in kilometres). The spread distance from 1989 to 1993, 1993 to 1999, and 1989 to 1999 was measured in centimetres on the map and then converted to kilometres.

A summary of the spread of broom at the measured sites over the 10-year period is shown in Table 1.

Table 1. Summary of broom spread, 1989–1999.

Description of spread	Number of sites	Average spread
Expansion	24	34 m pa
No movement	8	0
Contraction	23	35 m pa
Total	55	2 m pa

Vegetation types and density

The broad types of natural vegetation communities for each of the observation points were obtained from NPWS staff. The types identified were open eucalypt forest, rainforest, riparian, and subalpine. The density of the natural vegetation was recorded from the 1985 Barrington Tops topographic map. The densities were dense, medium, and scattered.

Slope

The slope of each of the map reference points was calculated from the topographic map, and recorded as a fraction.

Altitude

The altitude of each of the map reference points was recorded from the topographic map, and recorded in metres.

Soil type

The soil type at each of the observation points was taken from the Heinrich and Dowling (2000) mapping of rare and threatened plants in the Barrington Tops National Park. The soil types identified in that study were peaty, moist loam, medium brown loam, and deep brown loam.

Presence of crown land

If an observation point was located in crown land (the old State Forests area) rather than NPWS land, it was given a value of one, otherwise zero.

Natural disaster

Due to high rainfall on the Barrington Tops the most likely natural disaster is floods. The observation points considered to be most affected are those close to the rivers and water catchments. These points were given the value of one, and all other points were given a value of zero.

Animal activities

On Barrington Tops the animals that cause most disturbance are feral pigs. Based on discussions with the Park staff, those observation points that were thought to have feral pig activity were given the value of one and observation points with no records on feral pigs were given a value of zero.

NPWS management activities
Information on broom management activities at the observation points was obtained from NPWS staff. Some of the points were in areas where broom had been treated, and these were given a value of one. Points in areas where no treatment was applied were given a value of zero. A second treatment variable was created for a particular small area of wet peat where intensive hand pulling of young broom plants has been done.

Method of analysis

Dummy variables were constructed in the usual way for the yes/no variables defined above, where the presence of the factor was denoted by one and the absence by zero. For those independent variables with more than two categories (vegetation type, vegetation density and soil type), a base class was chosen and one-zero dummy variables were constructed for the remaining classes. For example, for the vegetation density variable, medium was chosen as the base class and two dummy variables were constructed for the dense and scattered categories respectively. The categorical dependent variables were constructed as described above. The variables for spread in kilometres, slope and altitude were treated as continuous variables.

Due to the nature of the three dependent variables, three different methods were required to estimate the models:

- an Ordinary Least Squares (OLS) model (Griffiths *et al.* 1993) was used for kilometre spread as the dependent variable,
- a Probit model (Pindyck and Rubinfeld 1998) was used for yes/no spread as the dependent variable, and
- a Multinomial Logit model (Maddala 1992) was used for the categorical zero/positive/negative spread as the dependent variable.

In all three cases, the estimated model was of the general form:

Dependent Variable =
F(slope, altitude, vegetation-density dummy variables(2), vegetation-type dummy variables(3), soil-type dummy variables(4), treatment dummy variables(2), flood dummy variable, pig activity dummy variable).

Results

Unfortunately, with the relatively small numbers of observations, the Probit and Logit model results were not reliable with several of the proposed explanatory variables having to be excluded or modified due to perfect correlation with the yes or no choice. The overall level of explanation was also very low at 23% for the Probit model and 10% for the Logit model. These results are not reported here, but interested readers may consult Odom *et al.* (2002). Similarly, the OLS results for the two sub-periods, 1989–1993 and 1993–1999, had low R^2 values and relatively few significant coefficients so they are not reported here either.

The full OLS model outlined above for the dependent variable kilometres spread was estimated first. Few variables showed significance because of the probable high correlations between the various environmental factors. Those sets of environmental factors with multiple dummy variables, natural vegetation densities, natural vegetation types and soil types, were then tested separately as groups using an F test. The results are shown in Table 2. Only the vegetation density variable showed a significant contribution to explaining variance. Vegetation types and soil types were also tested individually and none were found to be significant, so vegetation type and soil type were omitted in all successive estimations.

Table 2. *F*-tests for groups of environmental variables.

Period	Vegetation density	Vegetation type	Soil type
1989–1999			
F value	2.93*	0.96	1.22

* significant at the 10% level.

The possibility of interactions between the explanatory variables was considered but also ignored due to insufficient data points.

The preferred model is reported in Table 3. For each set of values, the estimated coefficient is given first, the standard error second, the t-statistic third, and the probability value fourth. Based on the review material referred to earlier, the expected signs for the explanatory variables can be predicted with some confidence, so one-tail tests are used for the t-statistics.

Table 3. Preferred OLS results.

Variable	1989–1999
Constant	0.377
	(0.123)
	3.057
	0.002
NPWS treatment	-0.198
	(0.122)
	-1.624*
	0.056
State Forest land	0.288
	(0.163)
	1.763**
	0.042
Slope	-0.953
	(0.287)
	-3.318**
	0.001
Sparse vegetation	0.391
	(0.310)
	1.259
	0.107
Floods	-0.354
	(0.151)
	-2.350**
	0.012
NPWS wetland treatment	-0.496
	(0.234)
	-2.114**
	0.020
R^2	0.389

* statistically significant at the 10% level on a one-tail test.
** statistically significant at the 5% level on a one-tail test.

Kilometres spread 1989–1999
In general, the results for the full period show that the coefficients of all of the included variables have the expected signs, and all except one are significant at the 10% level. The R^2 statistic implies that about 39% of the variability in the spread of broom is explained by the model.

At the mean values of the included continuous explanatory variables, the base cases of the included categorical variables and the zero values of the included yes/no dummy variables, the results show that over the 10 year period 1989–1999, the estimated expansion in broom was 0.377 of a kilometre across all sites.

The variable indicating the presence or absence of NPWS treatment at the site had the expected negative sign with a coefficient estimate of -0.198 and a P-value of 0.065, statistically significant at the 10% level on a one-tailed test. This implies that, for areas where treatment was done, the average spread was 0.198 of a kilometre less than the average over the ten year period.

The variable indicating the site was in a wetland area and received special management activity had the expected negative sign with a coefficient estimate of -0.496 and a P-value of 0.020. This additional control activity reduced the spread by 0.496 of a kilometre on average in the areas applied.

The variable indicating that the site was on crown land (previously managed by State Forests) had the expected positive sign with a coefficient estimate of 0.288 and a P-value of 0.042. This implies that, on the crown reserve land, the average spread of broom was 0.288 of a kilometre greater than the average over all sites, over the 10 year period.

The estimated coefficient for the slope measurement at the site had a value of -0.953 and a P-value of 0.001. This coefficient implies that on steeper areas the spread was reduced by 0.953 of a kilometre on average. Unfortunately, this measure included both uphill and downhill slopes, and these could be usefully separated in any future work.

The estimated coefficient for sparse vegetation had the expected positive sign with a coefficient estimate of 0.391 and a P-value of 0.107, just outside the 10% critical level. The coefficient implies that the spread was 0.391 of a kilometre greater than the average on areas with sparse vegetation compared to more dense vegetation cover. This agrees with the literature that broom spreads more in open areas.

Finally, the variable indicating that the site was prone to floods had an unexpected negative and significant effect, with a coefficient estimate of -0.354 and a P-value of 0.012. This implies that in flood-prone areas the spread of broom was 0.354 of a kilometre less than the average over the ten-year period. Rather than floods being responsible for spreading broom down watercourses, a possible explanation for the opposite sign is that the NPWS concentrated more management effort on flood prone areas to reduce the spread and also to prevent a reduction in water yield to downstream users.

Discussion and conclusion

In summary, the OLS analysis reported above demonstrates that NPWS management activities, the effects of floods and the influence of the environmental factors such as slope, crown land and natural vegetation density have a significant impact on the spread of Scotch broom in Barrington Tops National Park. The spread is greatest on crown land, where there has been limited treatment, on less steep slopes and where the natural vegetation is sparse. Pig activity also contributed to a greater spread in the initial sub-period. The spread is least with treatment, on steep slopes, and where there have been floods. In terms of their statistical levels, the most important factors are slope, floods, treatment in the wetlands, crown land, general treatment and sparse vegetation.

In comparison to the average values across all sites, the results reported in Table 3 can be summarized as follows:

- general treatment activities by the NPWS reduced spread by 0.198 km over the 10 year period, although in the specific wetland areas the treatment there reduced spread by 0.496 km,
- on lands which were previously managed by State Forests, spread increased by 0.288 km on average during the 10 year period,
- where vegetation is sparse, the spread increased by 0.391 km on average during the period,
- where slopes are steep, the spread is 0.953 km less than average, and
- where there are floods, spread is 0.354 km less than average.

Another way of interpreting the results is to predict from the OLS model the ranges of spreads, under different environmental and management factors, as metres per year, with all other variables at their mean values. From such a prediction, the three variables contributing most to an expansion of broom are sparse vegetation (62 m), flat slopes (23 m) and State Forest land (23 m). The three variables contributing most to a reduction in broom spread are NPWS general treatment (-14 m), NPWS specific wetlands treatment (-40 m) and steepest slope (-59 m). Many of these factors work together. For example, the old State Forest land has sparser vegetation and flatter slopes as well as less management input.

The predicted ranges of spread from the OLS model, in metres per year, of certain management and policy variables, are as follows:

In ex State Forest land	Average = 23 m
In NPWS land	Average = -4 m
Without treatment	Maximum = 17 m
With treatment	Minimum = -14 m

For management purposes, it would be useful to say how much of the spread could be reduced by another $1 spent on broom control, but this is difficult. All that can be reported from these results is to say whether the control was effective or not. Treatment stops the spread by 0.198 of a kilometre on those sites where it was undertaken[2]. This result suggests that the containment policy adopted by the NPWS within Barrington Tops National Park has been effective, while any control measures applied in the old State Forests land have not been effective. In this respect, the use of the aerial maps has proven to be effective in isolating the factors impacting on broom spread and could be usefully applied to other weeds.

Given the low level of variation explained by all the models and the difficulty of obtaining meaningful solutions from the Probit and Multinomial Logit models, there are obviously other factors influencing the spread of broom which are not included in this analysis. Another approach may be to increase the size of the sample to cover the whole area of the broom infestation and then to redo the analysis. It would be expected that the results would show some improvement in statistical properties and in the inclusion of other significant variables. It would be expected also that those factors causing changes in the density of broom could be more confidently examined.

The next step is to decide whether the biological model for Scotch broom needs to be modified by including the significant environmental and management factors that influence the density and the rate of spread. By doing this, the relationship between the parameters used in the biological model of Scotch broom may be improved to fit the case of Barrington Tops National Park, and more reliable policy implications may be able to be derived.

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Footnotes

[1] An attempt was made to explore the environmental and management factors that have influenced changes in both the spread and density of Scotch broom. However meaningful results were not obtained for the density analysis due to the lack of changes in density across most of the measurement points (only 14 of the 55 sites). The focus on the analysis reported here is therefore on the spread of Scotch broom.

[2] From the Probit model results (see Odom *et al.* 2002), statements can also be made about the probability of broom spreading or contracting. For example, from the results for the 1989-1993 period, with NPWS treatment the probability of broom spreading is reduced by about 40%. On the other hand, the probability of broom spreading is estimated to increase by about 4% on the old State Forests land.

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