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USING AERIAL MAPPING TO ANALYSE THE DENSITY AND SPREAD OF SCOTCH BROOM

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Abstract

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 density and rate of spread of Scotch Broom in Barrington Tops National Park.

The National Parks and Wildlife Services in a cooperative exercise with the State Forest prepared aerial maps showing Scotch Broom infestation in the Park for 1989 and 1999. These maps were used to generate data for the analysis. Map reference points 1km apart along the boundary of the 1989 area of infestation were examined and 1999 areas and densities were measured. Environmental factors measured include natural vegetation type, natural vegetation density, soil type, slope, altitude and the presence of private property or crown land. Areas of natural disaster, feral animal activity and National Parks and Wildlife Service management activities were also included in the analysis. We acknowledge the help of the NSW National Parks and Wildlife Service for providing us with the information and data for the analysis. Lack of data on rainfall at the specific map reference points is a possible limitation of the study.

OLS, Probit and Multinomial Logit models were used to analyse different forms of the dependent variables measuring the density and the spread of Scotch Broom. The analysis shows that the treatments undertaken by the National Parks and Wildlife Services significantly reduce the spread of broom. In fact when this management is undertaken the probability of spread is reduced by 18.9% and on average treatment reduces the spread in kilometres by 45%.

Key words: Scotch Broom; spread; density; Logit model; Probit model.

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1. Introduction

Weeds can be a significant component of vegetation communities in many parts of the world (Lonsdale 1994). More than 10 per cent of the Australian flora is comprised of weed species (Australian Bureau of Statistics 1992). Weeds usually are regarded as undesirable plants that inhibit gardens, agricultural land or public areas, such as roadside verges.

Some weeds, however, also invade natural ecosystems. Such species are collectively termed environmental weeds because they are a problem within the natural environment. Unlike other weeds, environmental weeds do not just affect areas that are continually disturbed by human activities; many species have encroached into relatively undisturbed native vegetation. Consequently, environmental weeds tend to be problems of public lands (such as national parks, state forests, and recreation reserves), although bushland and native vegetation remnants on private land also may be affected. The effective management of environmental weeds, therefore, requires the cooperation of government authorities at various levels as well as the involvement of community groups and private landholders (Vranjic *et al.* 2000).

Environmental weeds may adversely affect native ecosystems through impacts on biodiversity and ecosystem function or processes (Adair 1995). Impacts include effects directly attributable to the presence of the environmental weed, such as shading out native plants, competition for limited resources, changes in the fuel load and concomitant changes in fire frequency and intensity. Indirect effects often are mediated through species other than native plants. For example, the presence of a weed may alter the number of insect pollinators or other herbivores present at a site. The determination of environmental weed impacts usually focuses on direct impacts. However, the indirect impacts may be equally important, albeit less obvious and more difficult to determine (Vranjic *et al.* 2000).

Extensive invasions by environmental weeds have resulted in a loss of native plant abundance and diversity as the weeds out-compete and displace components of the native vegetation (Adair and Groves 1998). The impacts of environmental weeds on ecosystem processes have not been widely researched in Australia. This research deficiency arises partly because such impacts are longer-term and less readily noticeable than changes in species composition.

In this paper, we focus on Scotch Broom (*Cytisus Scoparius*), which has become a major weed in parts of south-eastern Australia. Scotch Broom 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 currently to be over 200,000 ha and still spreading (Hosking *et al.* 1998).

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A research project has been funded by the CRC for Weed Management Systems to investigate the economics of management strategies for Scotch Broom in the Barrington Tops National Park. This involves the construction of a dynamic programming model of the Park (Odom *et al.* 2001) and 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 density and rate of spread of Scotch Broom on Barrington Tops. If we can understand how the spread of Scotch Broom occurred here we can 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 first describe the impacts of Scotch Broom in the Park. Then, we review those factors that promote the spread of Broom, describe the existence of the maps and the mapping process that form the basis of the data used, and discuss the data calculations and the empirical methods used for the analysis. Finally, we present the results and suggest some conclusions.

2. 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 & Williams 1989).

Barrington Tops is an area where cold adapted species have been able to survive from climatic warming. The plateau contains sub-alpine swamps, which include species normally found on mountains of higher altitudes and includes peat, which can provide a sequential record of plants that used to inhabit the area.

The Park offers rugged mountain scenery and opportunities for a wide range of outdoor recreation ranging from vehicle-based camping and related activities to solitude and self-reliant recreation.

Scotch Broom invades natural ecosystems where it competes with indigenous plants and changes fauna habitat. It is found in grassland and woodland / open forest, including a wide range of disturbed as well as undisturbed communities in cool moist regions. It invades and persists in treeless vegetation such as subalpine grassland and cleared pastureland but not heavily shaded or swampy locations. On pastureland, Scotch Broom forms thickets that prevent grazing and restrict access to water. Successful seedling establishment occurs usually after soil or vegetation disturbance, but can also readily invade vegetation without major disturbance such as animal tracks and fallen timber (Hosking & Smith 1999). A number of plant and animal species listed as rare or threatened are found only in Broom-infested areas. Most ground cover plants and eucalypt seedlings are shaded out by dense Broom stands. It also provides shelter for large pest animals such as feral pigs.

Extensive tracts of the Barrington Tops National Park, bordering Stewarts Brook State Forest, Barrington Tops State Forests and 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 of formerly 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. As a consequence, the conservation value of vegetation preserved in the Park and non-commercial areas of the State Forest may decline, the economic potential of stands of commercial timber in the State Forests may be jeopardised, and the stock carrying capacity of local grazing lands may be reduced (Waterhouse 1988).

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. Attempts by private landholders, the National Parks and Wildlife Service and State Forests to control the infestation have been costly and largely unsuccessful.

3. Factors that Promote the Spread of Scotch Broom

Scotch Broom produces 30-360 seeds per square metre below a eucalypt canopy, and 7700-8900 seeds per square metre in the open. In Australia seedbanks in the soil have been measured to contain from 190-50,000 seeds per square metre. 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 600m 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 also spreads most on open spaces (where vegetation density is medium or scattered) which implies that Broom does not grow in dense vegetation such as rainforest. Given these sorts of

conditions, Scotch Broom can be spread in four major ways: by ants, by animals, by human beings, and by natural disaster (Smith and Harlen 1991).

Spread through ant activity

The great majority of seeds are dispersed initially within a few metres of parent plants. Most Broom seeds are dormant at the time of their explosive release from the pods, which flings them up to 5m. They may then be collected by ants and carry them up to at least 1m (Smith and Harlen 1991).

Spread caused by animals

Establishment of individual plants tens or even hundreds of metres from seeding stands occurs due to occasional seed dispersal by pigs, horses, and possibly macropods, which ingest seeds and pass them in faeces in viable condition (Smith and Harlen 1991). The initial pattern of the spread of Broom across the Barrington Tops plateau is consistent with the dispersal of seeds internally by cattle (Waterhouse 1988). Scattered Broom shrubs in grassland areas at Barrington Tops are mainly a result of dispersal by feral horses (Harlen 1989). Seeds have been recovered from horse dung at Polblue Swamp. Horses can retain viable seeds for up to 13 days in their alimentary systems (Waterhouse 1988).

Feral pigs can also disperse viable seeds. They mainly feed on Scotch Broom roots, and use the plants as their shelter. Soil disturbance by feral pigs results in massive Broom seedlings, and this is a major problem in Barrington Tops National Park.

Spread caused by human activities

Scotch Broom seeds can also be spread by human activities. Such activities include movements from infested areas to non-infested areas by foot or by vehicles, farming activities that spread seeds due to the soil disturbance, and weed management activities that involve movements on top of the soil.

Local distribution patterns along roads, and at sites of forestry equipment storage in the Barrington Tops area, strongly suggest that vehicles can carry Broom seeds (Harlen 1989, Smith 1994). Recreationist's vehicles, which had been driven through Broom-infested areas on Barrington Tops, were found to have a number of seeds of which 80% were viable (Harlen 1989). Broom seeds are also spread by human beings through their footwear.

Disturbances such as animal grazing, logging, digging or trampling, mining, clearing, construction of tracks, etc. accelerates the process by increasing rates of seed germination and seedling establishment.

Park management activities like herbicide treatment (the spread is mostly by spraying vehicles or labourer movements) or physical removal of Broom plants, which disturbs the soil, may result in a denser and larger Broom population than before (Moodie 1985, Robertson *et al.* 1999).

Spread caused by natural disasters

Scotch Broom seedbanks can also be severely disturbed by natural, non-human processes such as fire, drought, tree fall, cyclones, storms and floods. All of these events may facilitate the spread.

On Barrington Tops the most common natural disasters are storms and floods. Storms result in uprooting or falling of trees which in turn disturbs the soil and accelerates seed germination and establishment of seedlings. Floods wash away the soil and move the seeds to a new location following the stream of water. For example, the spread of Broom along riverbanks (including to some sites off the plateau) strongly suggests dispersal by running water, as has been demonstrated in New Zealand (Williams 1981). Viable seeds were recovered in 1989 from stream sediments up to 50 meters downstream from Broom bushes (Harlen 1989).

4. The Aerial Maps

Photographic procedures

Accurate mapping of Scotch Broom on Barrington Tops commenced in 1982 using aerial photographs. The National Parks and Wildlife Service first mapped the boundaries of the two main areas of Broom infestation in 1988, from the 1982 aerial photographs. In 1989 State Forests produced more detailed maps showing the density of the Broom (ie. infill within the infestations) from 1987 aerial photographs. Then in 1992/93, State Forests again mapped the perimeter of the Broom infestation using standard aerial photography. This map indicated a slight increase in the area of the main infestations from 1987 (Schroder and Howard 2000).

Additional aerial surveys of the boundary of the Broom infestation were undertaken in 1995/96 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. Mapping using this technology was carried out again in late 1998 as a cooperative exercise between State Forests and the National Parks and Wildlife Service (Schroder and Howard 2000). A scale of 1:10,000 was used for the photos.

The mapping process

The 1999 mapping was undertaken using standard aerial photographic interpretation techniques, backed up with ground verification. The original 1989 photos were examined to make sure that the 1999 map was consistent with the 1989 map (McDonald 1999). A scale of 1:25,000 was used for the maps.

All photo marking were done on clear overlays in black ink. Fieldwork was done on separate field overlays using red ink. The overlays were taped to the photos and the four corner fiducial points pinned so as the overlays could be relocated if removed from the photos. All overlays were labelled with printed labels (McDonald 1999).

Fieldwork was undertaken to test the outer edge of the Broom infestation. Only a few places were tested in the Park. More places were tested in the State Forest and this

was considered enough for a good interpretation. Some private landholders were contacted and valuable information was obtained.

Fieldwork was also undertaken to check the density classes. After doing some preliminary density delineation on the photos, fieldwork was undertaken to check this and calibrate the aerial photographic interpretation (McDonald 1999). Most of the work was undertaken around Polblue Swamp and other easily accessible areas.

The method used to measure density was a simple one (McDonald *et al.* 1990) to give a percentage of crown cover. This field data was then used in conjunction with a density scale overlay to help keep the density classification consistent with the 1989 map and within the defined classes. Because of the need for consistency the original density classes were not changed, however, the medium class was split into two, i.e. medium-high and medium-low (McDonald 1999). The classes used on the 1999 map are: Dense 80 - 100% (crown cover per cent); Medium-high 50 - 80%; Medium-low 25 - 50%; and Sparse < 25%.

Hence, there are 1989 and 1999 maps available with similar information, and these can be compared to show changes in the spread and density of the Broom infestation.

Time of year

Broom mapping is done more easily from the air or from photos during the flowering season when it is a very distinctive yellow. The December 1998 photographs coincided well with the flowering season. Most of the Broom was in full flower and easily recognisable on the photos. However, there is quite a lot of young Broom less than about 1 metre tall, commonly 0.5 metre, which is not visible on the photos. The only time it is visible is when it is in dense clumps. This was especially true around areas of wet gullies or around rainforest where a host of other plants often look like young Broom. This problem was field checked, particularly in freehold areas (McDonald 1999).

Accuracy

The 1999 mapping is considered to be of high accuracy due to the photo scale, good colour balance and good flowering event, even though fieldwork was limited by wet weather and restricted access on the freehold land (McDonald 1999; Carter and Signor 2000; Schroder and Howard 2000). Thus the mapping on freehold land is not as reliable as on the State Forest and the National Park. There might also be some minor errors from transferring the photo scale of 1:10,000 to the map scale of 1:25,000.

5. Data Collection

The two maps showing Scotch Broom infestation in Barrington Tops National Park for 1989 and 1999 were the basis of data for the analysis. 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 and density were recorded at each point, and data were generated for 55 such points. 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 vegetation types, vegetation densities, soil types, slope, altitude and the presence of private property and crown land. Areas of natural disaster, feral animal activity and the National Parks and Wildlife Service management activities were also included in the analysis. These data were estimated as follows.

Spread

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

- (a) whether the Broom had spread or not (yes/no). The observation points that showed a spread were given a value of one, while the observation points that had no spread were given a value of zero;
- (b) how far the Broom has spread (in kilometres). The spread distance from 1989 to 1999 was measured in centimetres on the map and then converted to kilometres; and
- (c) whether there had been a change in the density in the new infestation (no change/up one class/up two classes/down one class). The density of the new infestation was recorded from the 1999 map, where various densities were differentiated by different colours, and compared to the density at the observation point in 1989.

Vegetation types and density

The types of natural vegetation for each of the observation points were obtained from a discussion with the Park staff. The types identified were eucalypt, 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 fraction.

Altitude

The altitude was recorded from the topographic map. Some of the observation points were located on a contour line which had the altitude level recorded on it. These figures were recorded directly. For the rest of the observation points, the altitude level was calculated by adding (if the contour lines are converging) or subtracting (if the contour lines are diverging) the interval of 10 times the number of contour lines, counted from the line with the recorded altitude.

Soil type

The soil type at each of the observation points was taken from the Heinrich and Dowling (2000) survey of rare and threatened plants in the Barrington Tops National

Park. The soil types identified were peaty, wet peat, moist loam, medium brown loam, and deep brown loam.

Presence of private property

Unfortunately, none of the 55 observation points from the southern section of Broom infestation borders the private property. Hence this variable was ignored.

Presence of crown land

If an observation point was located in crown land (the old State Forests area) rather than Park land, 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 thought 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.

Management activities

Information on management activities at the observation points was obtained from the Park 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.

6. Method of Analysis

Dummy variables were constructed in the usual way for the yes/no variables defined above. For those variables with more than two categories (vegetation type, vegetation density and soil type), a base class was chosen and dummy variables were constructed for the remaining classes. For example for vegetation density, medium was chosen as the base class and two dummy variables were constructed for the dense and scattered categories respectively.

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 where km spread is the dependent variable; a probit model (Pindyck and Rubinfeld 1998) was used for the yes/no spread dependent variable; and a Multinomial Logit model (Maddala 1992) was used for the categorical change in density variable.

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

$$\begin{array}{lcl} \text{Km spread, or} & = & F(\text{slope, altitude, vegetation density dummies(2),} \\ \text{Spread(Y/N), or} & & \text{vegetation type dummies(3), soil type dummies(4),} \\ \text{Change in density} & & \text{treatment dummy, flood dummy, pig dummy).} \end{array}$$

7. Results

Number of Km Spread

The full model outlined above was estimated first with few variables showing significance. Vegetation densities, vegetation types and soil types were then tested as groups but none of the groups were significant at the 10% level. However, some of the individual components were thought to be significant based on examination of the correlation matrix.

The preferred individual-component model is as reported in Table 1. Based on the scientific data presented earlier, we can predict the expected signs for the explanatory variables, so we use one tail tests for the t-statistics. In general, the results 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 38% of the variability of the spread rate is explained by the model and there is some evidence of significant heteroskedasticity as depicted by the LM test value of 10.870.

At the mean values of the continuous explanatory variables, the base cases of the categorical variables and the zero values of the yes/no dummy variables, the results show that over the 10 year period 1989-1999, the average spread was 0.601 of a km.

The variable indicating NPWS treatment at the site had the expected negative sign with a coefficient estimate of -0.273 and a P-value of 0.088, statistically significant at 10% level. This implies that, for areas where treatment was done, the average spread was reduced by 0.273 of a km.

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 0.485 and a P-value of 0.026. This implies that, on the crown reserve land, the average spread of Broom was increased by 0.485 of a km over the 10 year period.

The estimated coefficient for the slope measurement at the site had a value of -0.897 and a P-value of 0.007. The coefficient for slope had the expected negative sign, implying that on steeper areas the spread was reduced by 0.897 of a km on average.

The estimated coefficient for sparse vegetation had the expected positive sign with a coefficient estimate of 0.533 and a P-value of 0.108, just outside the 10% level significance. But the positive sign implies that the spread increased by 0.533 of a km on areas with sparse vegetation compared to more dense vegetation cover. This agrees with the literature that Broom spreads more in open areas.

The variable indicating that the site had a subalpine vegetation type instead of a eucalypt type had the expected negative sign with a coefficient estimate of 0.326 and a P-value of 0.078. In areas with subalpine vegetation the spread of Broom was reduced by 0.326 of a km.

Finally, the variable indicating the site had a wetpeat soil type also had the expected negative sign with a coefficient estimate of 0.702 and a P-value of 0.009. This result agrees with the literature that Broom does not grow on soggy/very wet soil. The estimated coefficient implies that, on areas with wet peat soil the spread was reduced by 0.702 of a km on average.

Probit model

The Probit model explaining whether Broom has spread or not as the dependent variable was estimated in the same way as the OLS model. The number of positive observations was 26 meaning that the data set was evenly balanced. The final model incorporated five explanatory variables including the constant, NPWS treatment, Subalpine vegetation type, slope, and the presence of feral pigs. Again the overall level of explanation was quite low with only 24% of the variability of the dependent variable explained by the model. However the fraction of correct predictions was quite high at 0.673. The variables that were retained had the correct signs consistent with the literature and all variables were statistically different from zero at the 10% level of significance (see Table 2).

The benchmark coefficient (the constant term) implies that, over the 10 year period, the probability of broom spreading across all sites which have the benchmark characteristics, is approximately 14.5%. This figure was obtained from a set of normal distribution tables $F(1.063) = 0.145$.

The estimated coefficient for the variable indicating NPWS treatment at the site had the expected negative sign with a coefficient estimate of -0.881, statistically different from zero at the 10% level of significance. This estimate implies that, for areas where treatment was done, the probability of broom spreading is reduced by 18.9%.

The variable indicating that the site had subalpine vegetation instead of a eucalypt had the expected negative sign with a coefficient estimate of -1.398. In this case, the probability of broom spreading in subalpine vegetation is estimated to be reduced by 8.2%.

The estimated coefficient for the slope measurement at the site had a value of -3.118. The coefficient for slope had the expected negative sign, implying that on steeper areas the probability of broom spreading is reduced by a very small amount, something less than 1%.

For the new dummy variable where feral pigs were thought to be active at the site, this variable had a positive sign in line with the literature, with the estimated coefficient of 0.663, statistically different from zero at the 10% level of significance. This result implies that in areas where feral pigs are present, the probability of broom spreading is increased by 25.5%.

Multinomial logit model

We tried to apply the Multinomial logit model, to see whether we could distinguish the characteristics of those sites where the Broom density has changed. However, due to the small number of observations and the highly skewed nature of the dependent variable, we failed to obtain solutions to the model.

8. Discussion and Conclusion

In summary, the analysis shows that there are some significant results, which demonstrates that the Park activities, the effects of feral pigs and the influence of the environmental factors such as slope, subalpine vegetation, crown land and wet peat soil have an impact on the spread.

From the results we understand that the spread is greatest on crown land, where there is no treatment, on less steep slopes and where the natural vegetation is sparse. We also understand that the spread is least with treatment, on steep slopes, on areas with subalpine vegetation and on wet peat soil. The results also show us which factors are most important. Following their statistical levels in the right order the most important factors are slope, wet peat soil, crown land, subalpine vegetation and treatment. The probit model shows the risk of feral pigs in spreading broom is increased by 25.5%.

It would be nice to say how much of the spread could be reduced by \$1. But we couldn't do that, all we could do is to say whether the control was effective or not. On average the treatment stops the spread by 0.273 of a kilometre and with treatment the probability is reduced by 18.9%.

Given the low level of variation explained by the OLS and Probit models and the lack of solutions from the Multinomial Logit model, we first need to increase the size of the sample to cover the whole area of the broom infestation and redo the analysis. We would be hopeful that the results will show some improvement in statistical properties and in the inclusion of other significant variables.

The next step, which depends on the results of the revised analysis, will then be 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 can be improved to fit the case of Barrington Tops National Park.

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Table 1. Summary of the OLS results

Variable	Estimated coefficient	Standard error	t-statistic	P-value
Constant	0.601	0.194	3.102	0.002
NPWS Treatment	-0.273	0.199	-1.372	0.088
Crown land	0.485	0.242	2.004	0.026
Slope	-0.897	0.351	-2.560	0.007
Sparse natural Vegetation	0.533	0.425	1.253	0.108*
Subalpine Vegetation	-0.326	0.226	-1.446	0.078
Wet peat soil	-0.702	0.284	-2.469	0.009

* Statistically insignificant at 10% level ($\alpha = 0.10$)

$R^2 = 0.383$ LM het test = 10.870

Table 2. The Probit model results

Parameter	Estimate	Standard error	t-statistics	P-value	Probabilities
Constant	1.063	0.677	1.571	0.058	0.145
NPWS Treatment	-0.881	0.555	-1.588	0.056	0.189
Subalpine vegetation	-1.398	0.603	-2.319	0.010	0.082
Slope	-3.118	1.261	-2.473	0.007	0.001
Pig activity	0.663	0.468	1.417	0.078	0.255

$\alpha = 0.10$, Kullback-Leibler R-sq = 0.237

Number of positive observation = 26

Fraction of correct Predictions = 0.673