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MODELLING THE GROWTH AD INTERACTIONS OF YOUNG RADIATA PINE WITH SOME IIMPORTANT WEED SPECIES

By

M. KIMBERLEY AND B. RICHARDSON

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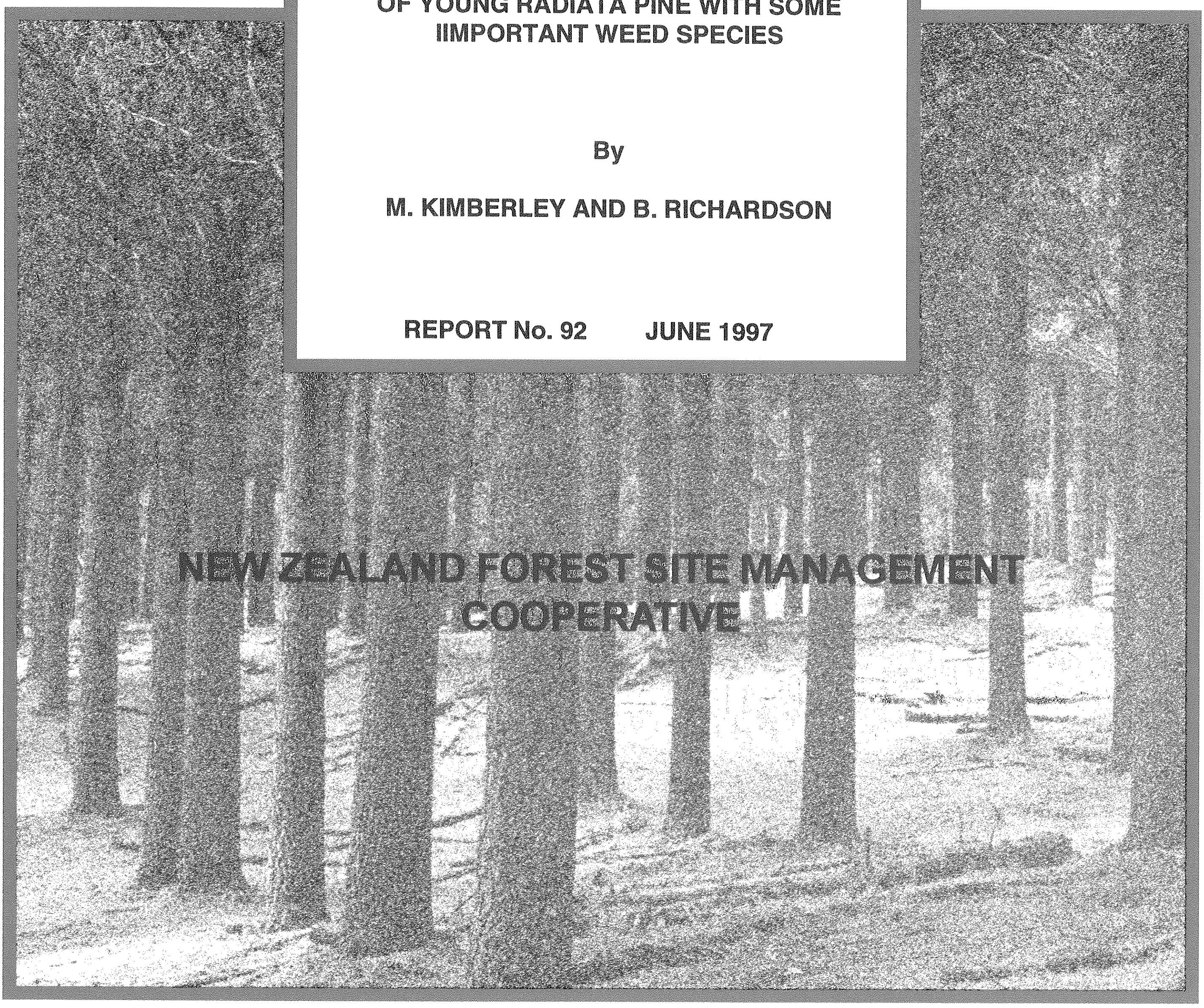

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MODELLING THE GROWTH AND INTERACTIONS OF YOUNG RADIATA PINE WITH SOME IMPORTANT WEED SPECIES

Mark Kimberley and Brian Richardson

New Zealand Forest Research Institute

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ABSTRACT

Investigations on the mechanisms of radiata pine growth suppression by some common forest weeds have demonstrated that light attenuation by weeds is a key growth-limiting factor on moist, moderately fertile Central North Island forest sites. Data from previous experiments were used to model the effect on radiata pine growth of a simple shade index, the height growth of the trees relative to neighbouring weeds. This analysis enabled a clearer definition of the effects of relative weed height on tree height and diameter growth. The model demonstrated that reductions in tree growth could be expressed as a function of this simple index of shading. However, the index was not independent of weed species or age. It is hypothesised that the species and age effects relate to the lack of a term in the model to describe weed density, and future studies will be used to test this hypothesis. The data showed that tree diameter growth was reduced by less than 10% when weeds were 50% tree height and by about 30% when the weeds were 75% tree height. Thus, an appropriate management intervention level to minimise tree growth losses would be when weeds exceed between 50-75% tree height.

INTRODUCTION

Weed control in newly established radiata pine (*Pinus radiata* D. Don) plantations usually results in increased tree growth (Richardson, 1993). This positive response can often be explained in terms of increased availability of water, nutrients or light, or improved environmental conditions (e.g. temperature). With the high cost of weed control, the highest priority should be given to operations that maximise tree productivity gains. Control should also be targeted against the most competitive species. Optimisation of weed control strategies can only be achieved through a thorough understanding of the nature of tree/weed interactions and the way they vary over different sites, climates and time.

A trial to investigate the mechanism of radiata pine growth suppression by some common forest weed species was reported by Richardson et al. (1993; *in press*). Results from this trial at Rotorua, on a moist moderately fertile site, suggested that tall, fast growing weed species reduced radiata pine growth by restricting light availability to tree crowns. Regression analyses indicated that the effect on crop growth of broom, buddleia, pampas, and gorse could be related to a simple shading index, i.e. relative height or weed height versus tree height. There appeared to be a relative weed/tree height ratio, below which there was a much reduced effect on tree growth.

The purpose of this study was to model the relative height growth of radiata pine and broom, gorse, buddleia, and pampas to enable a clearer identification of the effect of relative weed height on tree diameter or volume growth. Specific objectives were to:

1. Obtain estimates of radiata pine, buddleia, pampas, broom, and gorse height growth at regular time intervals so that an integrated shade index could be calculated over time.
2. Define the threshold of competition (relative height) below which crop growth losses are insignificant.
3. Test the hypothesis that reductions in tree growth could be explained by a simple index of shading that is independent of specific weed type.

METHODS

Experimental design and measurements

The experimental design and measurements from which the data set used in this study were derived have been described in detail elsewhere (Richardson et al., 1993). Briefly, tree seedlings were grown weed-free and with either *Cytisus scoparius* L. (broom); *Ulex europaeus* L. (gorse); *Buddleja davidii* Franchet (buddleia); and *Cortaderia selloana* (Schult) Asch. et Graeb. (pampas). Water and nutrient levels were varied by factorial irrigation and fertiliser treatment. The three replicates (randomised complete blocks) of each set of treatment combinations were installed at intervals of one year between 1990 and 1992. Plots were 5 x 5 m, containing 25 tree seedlings at 1 x 1 m spacing. Gorse, broom, buddleia, and pampas seedlings, germinated during or shortly after the winter of tree planting, were planted at 0.5 x 0.5 m spacing in the October following tree planting.

Only the nine trees in the centre of each plot were measured. Root collar diameter and height were measured at time of planting, monthly for the first 18 months, then at 3-monthly intervals thereafter. At approximately 3-4 monthly intervals, the heights of eight sample plants per subplot of broom, buddleia, pampas and gorse was recorded.

Obtaining three-monthly height and diameter values

It was decided to base the modelling process on 3-monthly growth data. Because weed and radiata growth measurements were not made at precisely 3-monthly intervals, the initial step was to estimate 3-monthly plot means. This was carried out for each of the 60 plots in the trial. For weed and radiata height measurements, cubic interpolation was used, while radiata diameters were obtained using a 12^{th} order spline function. The spline function smoothed out slight imperfections in the diameter data which were most likely the result of measurement errors.

Model fitting

A variety of non-linear regression models were tested for predicting the competition effects of the weeds on radiata diameter and height growth. Relative diameter and height growth, defined as the growth increment in each weed plot divided by the increment in the corresponding control plot, were used as dependent variables. The basic form of the equation chosen to model relative diameter growth against relative weed height was:

$$\text{relative diameter growth} = 1 - \left(1 - e^{a(\text{relht})}\right)^b$$

where,
$$\text{relative growth} = \frac{\text{diameter increment in trees subject to competition}}{\text{diameter increment in control trees}}$$

$$\text{relative height} = \frac{\text{height of weed}}{\text{height of tree}}$$

This equation is essentially the Chapman-Richards equation with an intercept of one and an asymptote of zero. The former ensures that, when there is no competition, there is no reduction in growth, while the later implies that growth ceases completely at a high level of competition. Relative height growth was modelled using the same equation.

When the model was fitted separately to each 3-monthly growth period, it was clear that the influence of relative weed height on diameter growth increased with age (Figure 1). For diameter growth, this increase occurred for the first few periods, but stabilised after the 15-18 month period. To take account of this effect, an exponential term in stand age was incorporated into the model. There also appeared to be some differences between weed species (Figure), and it was necessary to allow for any fertiliser (frt) or irrigation(irr) effects. Indicator variables, taking values of 1 or 0 as appropriate to indicate the species or treatment, were therefore included in the model. The expanded model took the following form:

$$\text{relative growth} = 1 - \left(1 - e^{X}\right)^b$$

where,
$$X = (a_p \times \text{pampas} + a_{br} \times \text{broom} + a_{bd} \times \text{budd} + a_g \times \text{gorse} + a_{irr} \times \text{irr} + a_{frt} \times \text{frt}) \times (1 - c^{(\text{age}-d)}) \times \text{relht}, \quad \text{if age} > d$$

and,
$$X = 0, \quad \text{if age} \leq d$$

pampas, broom, budd and gorse are species indicator (0 or 1) variables

irr and frt are treatment indicator (0 or 1) variables

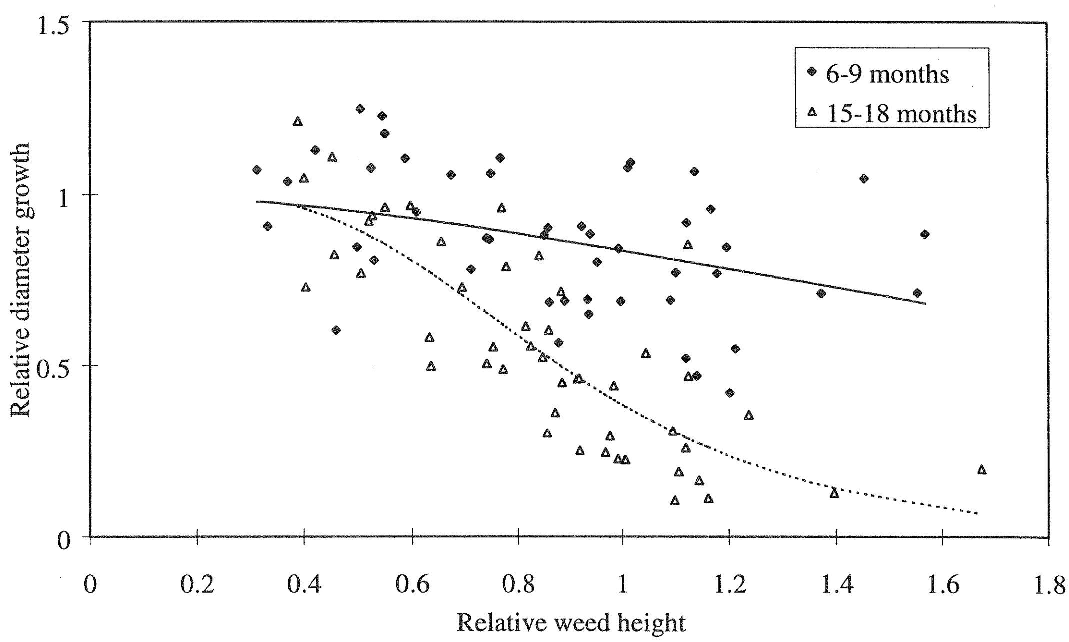

Figure 1 Relative diameter growth versus relative weed height for two selected 3-monthly periods.

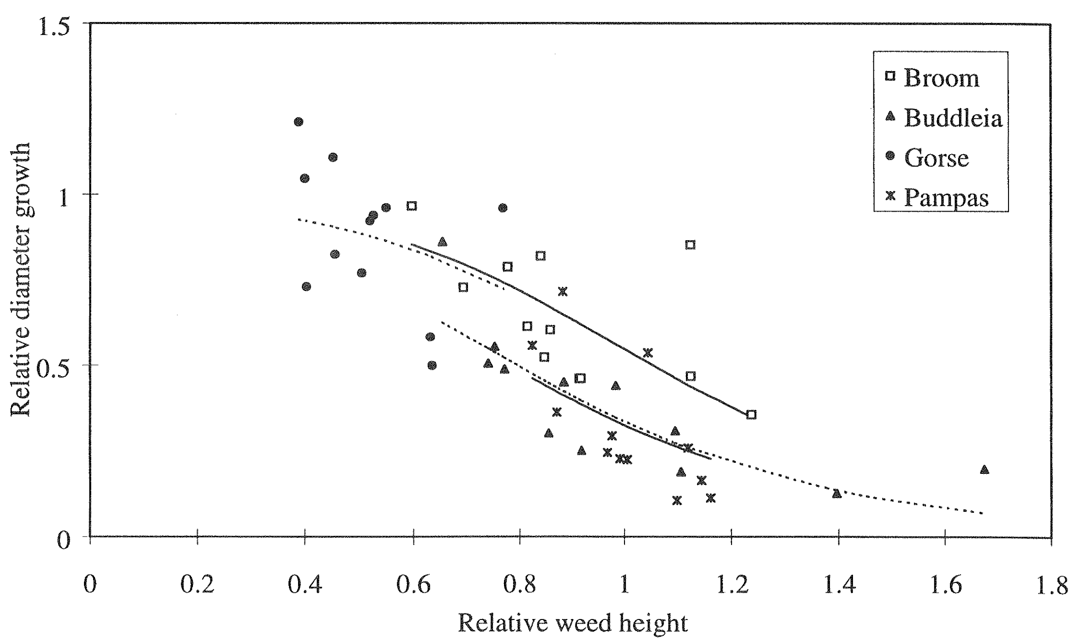

Figure 2 Relative diameter growth versus relative weed height and species during the 15-18 month period.

Statistical significance of model terms

The emphasis of this report is on the development of a model to help understand the nature of weed competition on radiata pine for this site. During the process of fitting the model, the statistical significance and standard error of each term included in the model was calculated. However, in order for these tests to be valid, the errors of each data point need to be independently distributed, and this is questionable for two reasons. Firstly, the 3-monthly increments cannot be regarded as statistically independent over time. Secondly, when calculating relative growth values for each weed species, a common control was used, again compromising the assumption of independence. Unfortunately, methods for fitting non-linear regression models with non-independent error terms are in their infancy. To confirm that the model terms are genuinely significant, we therefore fitted a repeated measures linear model. This linear model was much less useful for prediction purposes, but provided statistically valid tests. The dependent variables in this analysis were annual diameter and height increments. The independent terms tested in the model were: trial block, relative weed height, age, irrigation and fertiliser.

RESULTS

Three-monthly heights and diameters

The means of the three-monthly interpolated values for weed and radiata pine height (Tables 1 and 2, Figure 3) showed that all the weeds, with exception of gorse which did not grow well on this site, matched the height growth of the control radiata pine for the first two years. The effects of weeds on radiata pine diameter (Table 3, Figure 4) and height (Figure 5) were readily apparent. A marked seasonal pattern of growth for both weeds and radiata was also clearly apparent.

Table 1 Three-monthly mean heights of radiata pine growing alone or with various weed species.

Age (months)	Radiata pine height (m)				
	Weed-free	Broom	Buddleia	Gorse	Pampas
3	0.35	0.36	0.36	0.35	0.36
6	0.58	0.6	0.61	0.6	0.61
9	0.86	0.9	0.92	0.91	0.93
12	0.95	1.01	1.02	1.00	1.03
15	1.21	1.30	1.30	1.27	1.35
18	1.74	1.84	1.76	1.84	1.83
21	2.34	2.34	2.12	2.47	2.21
24	2.46	2.43	2.17	2.54	2.26
27	2.79	2.74	2.37	2.87	2.45
30	3.68	3.49	2.86	3.67	2.91
33	4.23	3.89	3.19	4.15	3.19

Table 2 Three-monthly mean weed heights.

Age (months)	Mean weed height (m)			
	Broom	Buddleia	Gorse	Pampas
3	0.15	0.1	0.05	0.2
6	0.40	0.41	0.26	0.51
9	0.94	1.12	0.46	1.25
12	1.01	1.19	0.52	1.49
15	1.05	1.21	0.51	1.29
18	1.79	1.84	1.09	1.91
21	2.65	2.54	1.86	2.71
24	2.63	2.58	1.86	2.3
27	2.63	2.51	1.95	2.16
30	2.89	2.69	2.28	2.45
33	3.31	3.01	2.7	2.75

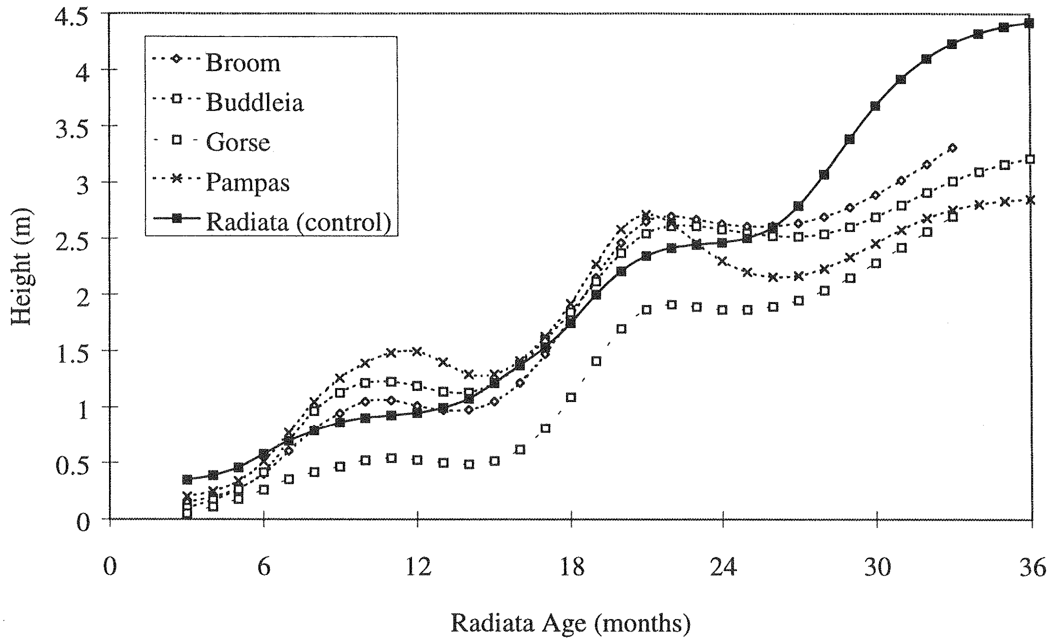

Figure 3 Height of weeds and radiata pine. Values obtained by interpolating the measurement data.

Table 3 Three-monthly mean diameters of radiata pine growing alone or with various weed species.

Age (months)	Radiata pine root collar diameter (mm)				
	Weed-free	**Broom**	**Buddleia**	**Gorse**	**Pampas**
3	6.5	6.5	6.4	6.4	6.5
6	11.2	11.4	11.3	11.5	11.6
9	19.1	18.7	16.9	19.3	17.7
12	23.8	23.6	20.3	24.7	20.9
15	31.3	29.7	24.2	31.2	24.1
18	40.7	35.7	27.7	39.4	26.9
21	51.5	41.0	31.1	47.8	30.3
24	55.8	43.2	32.5	51.6	31.2
27	60.8	46.7	35.1	55.9	33.0
30	67.9	50.4	38.5	61.4	35.9
33	74.5	54.2	42.2	66.2	39.8

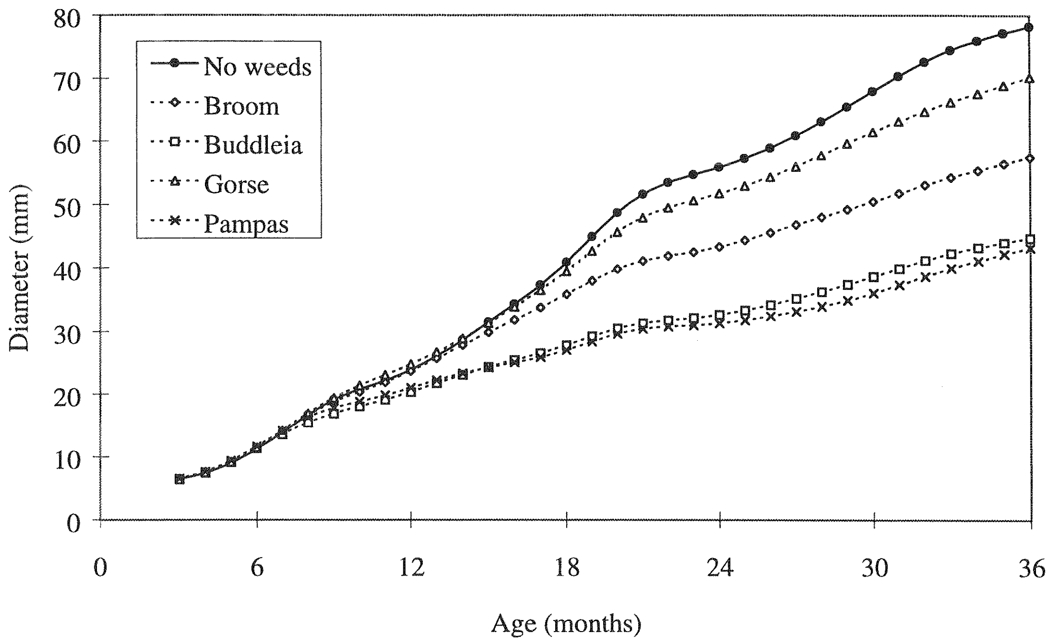

Figure 4 Root collar diameter of radiata pine growing alone or with various weed species. Values obtained by interpolating the measurement data.

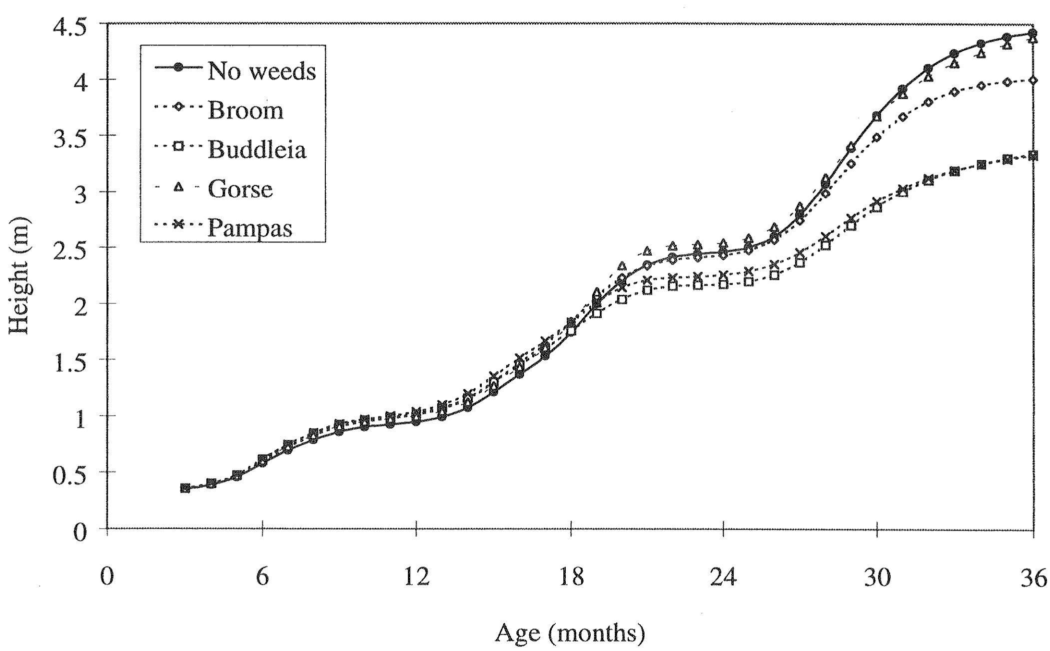

Figure 5 Height of radiata growing alone or with various weed species. Values obtained by interpolating the measurement data.

Competition model predictions

The coefficients for the diameter and height models are given in Table 4. The influence of age is described by the two coefficients c and d, and these require some explanation. It should be remembered that this age effect is additional to the influence of weed height. It accounts for the fact that at a young age, weed height had less influence than at older ages (Figure 1). The coefficient, d, can be thought of as a threshold parameter. It is the age, in months, at which measurable competition begins. The coefficient, c, describes how the age effect stabilises over time.

Table 4 Regression model coefficient estimates and their standard errors.

Coefficient	Relative diameter growth		Relative height growth	
	estimate	s.e.	estimate	s.e.
a_p	-2.52	0.27	-2.19	0.43
a_{br}	-2.02	0.26	-1.27	0.37
a_{bd}	-2.39	0.27	-1.93	0.39
a_g	-2.10	0.34	-1.43	0.47
a_{irr}	-0.02	0.08	-0.12	0.10
a_{frt}	-0.32	0.08	-0.59	0.11
c	0.560	0.143	0.861	0.049
d	9.46	0.50	12.03	1.62
b	6.94	1.82	6.26	2.06
R^2	57		56	

These effects are best understood by examining the model predictions of relative diameter and height growth. Predictions are tabulated for relative weed heights of 0.5 and 1.0 (i.e., 50% and 100% radiata height (Table 5). Note that, for example, a prediction of 0.8 implies a growth rate equal to 80% of the competition-free level. The reduction in relative diameter growth with age stabilises after about 18 months, but continues much longer for relative height growth.

Table 5 Regression predictions showing the influence of age on relative growth.

Age (months)	Relative diameter growth		Relative height growth	
	relative weed height = 0.5	relative weed height = 1	relative weed height = 0.5	relative weed height = 1
6	1.00	1.00	1.00	1.00
12	0.97	0.69	1.00	1.00
18	0.92	0.48	0.99	0.89
24	0.91	0.47	0.97	0.71
30	0.91	0.47	0.95	0.63
36	0.91	0.47	0.94	0.60

A noticeable reduction in growth occurs when weeds are about half the height of the radiata pine (when there is a 9% reduction in diameter growth) and the effect increases rapidly in severity at weed heights greater than this (Table 6). There were some species differences, with pampas and buddleia having greater competitive effects than gorse or broom (Table 7). Application of fertiliser resulted in reduced diameter and height growth while irrigation had little effect (Table 8).

Table 6 Regression predictions showing the influence of weed height on radiata pine diameter and height growth at age 2 years.

Relative weed height	Relative diameter growth	Relative height growth
0	1	1
0.25	1.00	1.00
0.5	0.91	0.97
0.75	0.71	0.87
1	0.47	0.71
1.25	0.29	0.54
1.5	0.17	0.39

Table 7 Regression predictions showing the influence of weed species on relative growth of radiata pine.

Weed species	Relative diameter growth		Relative height growth	
	relative weed height = 0.5	**relative weed height = 1**	**relative weed height = 0.5**	**relative weed height = 1**
Pampas	0.88	0.39	0.93	0.55
Broom	0.94	0.56	0.99	0.84
Buddleia	0.90	0.43	0.95	0.63
Gorse	0.93	0.53	0.98	0.80

Table 8 Regression predictions showing the influences of irrigation and fertiliser on relative growth.

Treatment	Relative diameter growth		Relative height growth	
	relative weed height = 0.5	**relative weed height = 1**	**relative weed height = 0.5**	**relative weed height = 1**
Unfertilised	0.93	0.53	0.98	0.80
Fertilised	0.89	0.42	0.95	0.61
Unirrigated	0.91	0.48	0.97	0.73
Irrigated	0.91	0.47	0.96	0.69

Statistical significance of model terms

Statistical tests for the terms in the competition model showed that relative weed height, age, weed species and fertiliser were all highly significant but that irrigation had no significant effect. As noted earlier, however, these tests should be treated with caution owing to a lack of statistical independence among the data points.

A more rigorous repeated measures linear model indicated that the following terms were statistically significant for both diameter and height increments: year (age), relative weed height, weed species and fertiliser. There were also significant year x relative height, and fertiliser x relative height interactions. Irrigation was not statistically significant. There were significant block effects, but these are catered for in the competition model by using relative growth increments (i.e., each growth increment is divided by the corresponding control plot increment). The linear models provided confirmation for the significance of the terms in the non-linear competition models.

DISCUSSION

The model described in this report gives a detailed insight into how weed competition influences growth rates of young radiata pine on moist, moderately fertile Central North Island forest sites. It supports the idea that for these sites, shading is the main competition factor. Irrigation had no effect proving that competition for water is not important. Fertiliser had a significant, but negative effect on growth. Increased weed foliage resulting in greater shading is the most likely explanation for the negative influence of fertiliser Richardson et al., *in press*).

However, the use of relative weed height as a simple index of shading competition was not entirely successful. Competition was found to increase with age (Table 6). This was probably because the weeds did not initially achieve complete site cover. Because of this, an index based purely on weed height could not adequately represent their shading characteristics. However, once complete weed cover was achieved (about 12-18 months), relative height was a good index for diameter growth. The influence of weed competition on height growth appears to be more complex. At a given relative weed height, the growth reduction became more severe with age for at least the first three years, long after full weed cover was achieved, suggesting that the competition effect is cumulative. However, overall, height growth is much less reduced than diameter growth for a given level of competition.

There were also some significant differences between species. The most likely reason for this is that a simple relative height index does not totally account for foliage density effects. For example, many broom plants died because of infection with pathogens (Richardson *et al.*, *in press*) but surviving, tolerant plants grew well. So, although broom performed well in terms of relative height growth, the plots were not fully occupied by broom foliage and light attenuation was less than it might otherwise have been. it is also possible that there are some inherent differences between species in terms of their effects on light attenuation.

By incorporating age, species and fertiliser into the model, it was possible to obtain good predictions using relative weed height as the basic competition index, although an index reflecting the shading properties of the weeds more directly might have resulted in a simpler model. Despite this, we believe that the model can be used to predict weed competition on similar sites. For example, Figures 6 and 7, show that the effect of pampas competition on diameter and height growth is adequately predicted by the model. They also show how the model can be used to predict future growth (to age five years) assuming pampas height has stabilised at three metres. By assuming zero weed height for the first 12 months, and the previous year's height following this, the effect of controlling pampas for one year is also predicted.

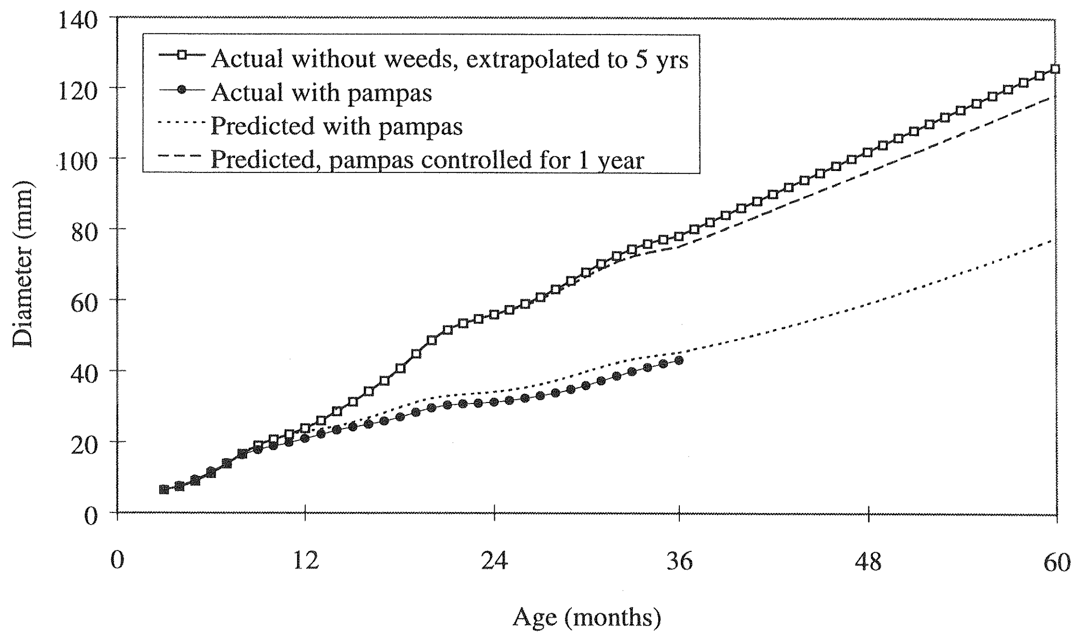

Figure 6 Actual and predicted radiata diameter in control and pampas competition plots.

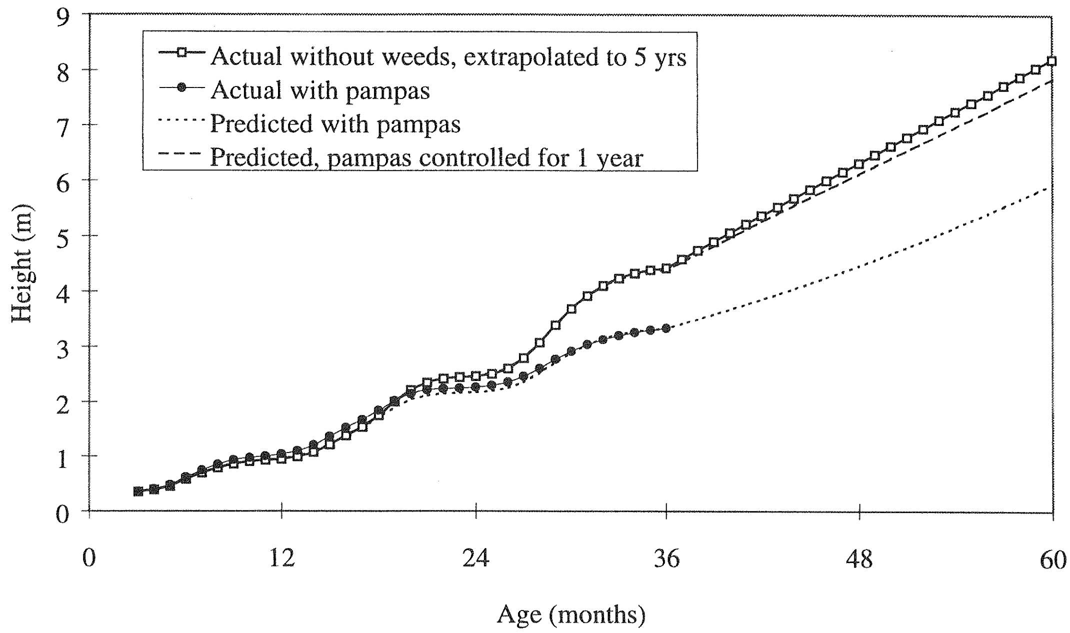

Figure 7 Actual and predicted radiata height in control and pampas competition plots.

The model helps define the relative weed height threshold at which weed competition begins to significantly reduce growth. This appears to be somewhere between 50% and 75% radiata height. At 50%, diameter growth is predicted to be reduced by less than 10% and height growth is unaffected (Table 6). However, when the weeds are 75% radiata height, diameter growth is seriously reduced by about 30%, and there is a greater than 10% reduction in height growth.

Since this study was initiated, a new competition index has been derived that appears to be very sensitive to shading effects and has shown promise in both field studies at FRI and in a forest environment. This type of analysis will be repeated with the new dataset. The new dataset will also allow validation of the approach described above.

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