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WEED NUMBERS IN NEW ZEALAND'S FOREST AND SCRUB RESERVES

Summary: New Zealand's protected natural areas are being increasingly threatened by weeds as the natural landscape is fragmented and surrounding land use intensifies. To assist in designing management to reduce the threat, we attempted to determine the most important reserve characteristics influencing the presence of problem weeds in forest and scrub reserves. Data on 15 reserve characteristics were derived from surveys of 234 reserves.

From correlation analysis, analysis of variance and consideration of several multivariate models, it appears that the most important characteristics influencing the number of problem weeds in reserves are proximity to towns, distance from roads and railway lines, human use, reserve shape, and habitat diversity. These factors reflect principally increased proximity to source of propagules associated with intensifying land use, including urbanisation. Reserves with the most weeds are narrow remnants on fertile soils with clearings and a history of modification, and those close to towns or sites of high human activity. If these reserves are to continue to protect natural values, they will require regular attention to prevent the establishment of further weeds. Accidental spread of weeds and disturbance in reserves should be minimised.

Keywords: Weeds; introduced plants; problem plants; invasion; reserves; protected natural areas; forest and scrub reserves.

Introduction

In many parts of the world, invasion of natural communities by naturalised plants, especially woody species, constitutes a serious threat to the survival of these natural communities, although the threat is not fully acknowledged by conservationists (Heywood, 1989). In New Zealand there are almost as many naturalised plant species as indigenous ones (Webb, Sykes and Garnock-Jones, 1988). Several hundred new plant species are introduced into New Zealand each year, and many become naturalised, e.g., in metropolitan Auckland four new species are added to the naturalised flora every year (Esler and Astridge, 1987). Many of these are "problem weeds" in reserves; that is, they substantially change the indigenous vegetation of the sites they have occupied (Williams, 1984; Timmins and Williams, 1987). Further, increasingly the naturalised species are long-lived perennials rather than ruderals *(S.* Halloy, *pers. comm.).* Thus we can expect weeds to have a greater impact on native vegetation in the future.

The threat of these naturalised species invading protected natural areas is increasing with continued urbanisation and intensified agricultural use of the landscape and concommitant fragmentation of the natural landscape. Much modem ecological theory relates to the process of invasion (e.g., MacArthur, 1970), but such theory has thrown little light on what makes a community prone to invasion in the first place (Crawley, 1987; Quinn, Wilson and Mark, 1987). Among the most important factors identified in a wide range of ecosystems are: proximity to large sources of potential invaders, extent of openness, and frequency of disturbance (Crawley, 1987; Kruger *et al.,* 1989; Macdonald *et al.,* 1988; Usher, 1988). In addition, Simberloff (1989) emphasised that the opportunity for invaders to disperse to a site can be just as important to their successful invasion. For their part, problem weed species tend to have a rapid growth rate, a specialised dispersal mechanism, a rapid turnover, and a tolerance of a diverse range of environmental conditions (Timmins and Williams, 1987).

The numerous forest and scrub reserves in New Zealand provide an opportunity to attempt to determine the most important reserve characteristics influencing the presence of problem weeds in reserves. Such information could then be used to assist managers to develop better strategies to minimise the number of weeds in these types of reserves at least (Timmins and Williams, 1990).

Method

Eight lowland regions were studied. An outline of their biophysical features is given in Table 1. Only small and

Table 1: *Biophysical features of study areas. Ybl = yellow brown loams, Bgl = brown granular loams, Ybp = yellow brown pumice soils, Ybe = yellow brown earths, Yge = yellow grey earths. Source of biophysical information: Wards* (1976).

Region	Mean temp. (°C)	Mean rainfall (m)	Soil group	No. of reserves in data set	Source of data on reserve characteristics
Auckland	14	1.2 - 1.6	Ybl, Bgl	27	Gardner, Court and Esler (1981)
Gisbome	14	1.2 - 2.4	Ybp, Ybe	20	Clarkson and Regnier (1989) Beadel and Shaw (1988)
Egmont	13	1.6 - 2.4	Ybe	34	Clarkson and Boase (1982)
East Taranaki	13	1.6 - 2.4	Ybl, Bgl	64	Bayfield *et al*. (1986)
Taumarunui	12	1.6 - 2.4	Ybe, Ybp	23	Fuller and Edwards (1989)
Wairarapa	12	1.2 - 1.6	Ybe, Yge	13	Wassilieff, Clark and Gabites (1986)
Wellington	12	1.2 - 1.6	Ybe	24	Wassilieff, Clark and Gabites (1986)
Marlborough Sounds	12	1.2 - 1.6	Ybe	29	Walls (1984)

medium-sized ≤500 ha) reserves of scrub and forest were used to minimise sources of variation in the data. Larger reserves, those with a significant proportion of grassland or wetland (i.e., greater than 10% in area), and island and coastal reserves, were omitted. Data for 234 reserves were derived from published biological surveys of scenic and allied reserves reports. Although surveyors differed between regions, the information was collected and recorded in a standard format devised by Kelly (1972). For each reserve the data comprised values for 15 reserve characteristics: 6 on a numeric scale, 9 using an ordinal scale.

Reserve Characteristics

Number of problem weed species

A list of 75 problem weed species[1] of forest and scrub reserves was compiled (see Appendix 1). The number of these listed species which were present in each reserve was recorded. The relative abundance of these species, which would have been a better measure of degree of impact of problem weeds in reserves, was not recorded in the original surveys and so could not be used. The number of weed species has been used as an index of invasion susceptibility by other workers (e.g., Macdonald, Powrie and Siegfried, 1986).

Number of native plant species

Naturally occurring native vascular plant species.

Size

Total area of reserve in hectares.

Shape

The perimeter (km) and area (ha) of each reserve were used to calculate a shape index using the following formula:

$$\frac{\text{perimeter}}{200\sqrt{\pi\ \text{area}}}$$ (B. D. Lloyd, *pers. comm.).*

[1]Formal and common names of naturalised plants follow Webb *et al*. (1988).

A circular reserve had a shape value of 1 and more linear-shaped reserves or those with indented perimeters had higher values (e.g., greater than 3). Unlike the simple area/perimeter (a/p ratio) used by Schonewald-Cox and Bayless (1986), this formula gave an index for shape that was independent of reserve size.

Surroundings

Six categories describing the human impact in the surrounding landscape, adapted from the classification of Godron and Forman (1983) were used:

(i) natural- reserve completely (≥ 90%) surrounded by native forest;
(ii) mostly forest - 60-89% of the surroundings in native forest;
(iii) mostly grassland - 60-89% of surroundings in modified grassland or scrub, with and without elements of native vegetation;
(iv) intensive farmland - 90% of surroundings in intensive farming, cropland or orchards;
(v) peri-urban - mixture of suburbia, agricultural and natural surroundings;
(vi) urban - reserve completely (≥ 90%) surrounded by houses, factories, playing fields etc.

Stream source

The catchments of streams which flowed through the reserves were classified in the same six categories used for surroundings.

Proximity to towns

Distance (km) to the nearest town of 5,000 or more inhabitants.

Distance from road/rail

Distance (km) from the nearest road or railway line. For the majority of reserves this was 0 km as most have road access.

Soil fertility

The four categories of increasing soil fertility used in the original surveys were adopted: low, low-medium, medium, moderate-high.

Scrubbiness

Five categories indicating the proportions by area of forest and scrub: 90% forest, 60-89% forest, 40-59% forest, 60-89% scrub, 90% scrub.

Fire history
Six categories describing fire history: no evidence of burning; minimal, moderate-extensive burning more than 25 years ago; minimal, moderate, extensive burning less than 25 years ago.

Clearings
Four categories describing the percentage of the area in naturalised, herbaceous vegetation: < 1%, 1-1.9%, 2.0-4.0%, 5.0-9.9%.

Stock use
Four categories indicating the degree of animal damage: none, low, medium, high. Values were determined largely from the occurrence of droppings, browse sign, and the original recorders' interpretation of vegetation structure.

Rubbish
Four categories indicating the amount of rubbish present: none, low, medium, high. No distinction was made in the survey data between organic and inorganic rubbish.

Human use
Four categories reflecting the amount of recreational human use such as walking: none, low, medium, high.

Statistical Analyses

Before analysing the data the values of four of the variables were transformed to a more normal distribution. The square root transformation $(X + 0.5)$ (Bartlett, 1936) was applied to the data on number of weeds. Logarithmic transformations were applied to the three variables: area, distance from road/rail, and proximity to town (Zar, 1984).

Correlation analysis using Pearson correlation coefficients was made by region to indicate which of the variables, other than nominal variables, were likely to be most useful to predict number of weeds in a multiple variable model. Analysis of Variance (ANOVA) was used to test whether there were differences between the number of weeds in different categories of the nominal variables surroundings and stream source. Tukey's studentized range test was used for multiple comparison tests of the differences among the means.

In order to assess the relative importance of the explanatory variables, modelling was undertaken using the SAS procedure GLM (SAS Institute, 1985, p. 435). The procedure uses the method of least-squares to fit general linear models such as ANOVA, multiple regression and homogeneity-of-slopes models including variable interactions. The method is useful for developing causal hypotheses but does not involve testing.

The models were run on the total data set: i.e., all regions combined, with region included as a variable, as the regional data sets were too small for modelling by themselves.

Results

Taking the results of all the regions, the number of problem weed species was significantly ($p < 0.05$) correlated with eight of the reserve characteristics: proximity to towns, distance from road/rail, shape, presence of rubbish, human use, soil fertility, fire history, and clearings (Table 2). When the data for all regions were analysed together seven of the reserve characteristics were significantly correlated with number of weeds: the same first five above plus scrubbiness and reserve size (Table 2). Analysis of variance showed a significant difference in the mean number of weeds in different categories of surroundings

Table 2: *Correlation of 12 reserve characteristics with number of problem weed species. * = correlation coefficient significant at* $p < 0.05$. *** = correlation coefficient significant at* $p < 0.01$. *ns = not significant.*

Table 2: *Correlation of 12 reserve characteristics with number of problem weed species. * = correlation coefficient significant at* $p < 0.05$, *** = correlation coefficient significant at* $p < 0.01$, *ns = not significant.*

Reserve characteristic	Region: Auckland	Gisborne	Egmont	East Taranaki	Taumarunui	Wairarapa	Wellington	Marlborough Sounds	All Regions
Proximity to towns	-0.65**	-0.56**	-0.62**		-0.62**			-0.58**	-0.56**
Road/rail			-0.36*	-0.28*	-0.69**			-0.61**	-0.37**
Shape	+0.48**							+0.46**	+0.26**
Rubbish		+0.44*	+0.56**						+0.35**
Human use			+0.42**		+0.48*			+0.47**	+0.39**
Soil fertility			+0.40*			+0.72**			ns
Fire		+0.69**							ns
Clearings			+0.45**						+0.16*
Scrubbiness									+0.13*
Area									-0.39*
Stock use									-0.19**
Number of natives									ns

Table 3: *Number of problem* weed *species by category of surroundings and* stream source *for all regions combined. Means with the* same *letter are not significantly different, at* p < *0.05, according to Tukey's studentized* range *test.*

Surrounding/stream source category	Mean no.of problem weed species			
	Surroundings		Stream source	
Urban	12.5	a	13.0	a
Peri -urban	11.0	a b	12.0	a
Intensive farmland	7.3	a b	7.6	b
Mostly grassland	7.3	a b	7.7	b
Mostly forest	5.3	b		
Natural	5.5	b	6.4	b
No. of streams			7.2	b

($F = 9.68$, $p < 0.0001$). Tukey's groupings showed some overlap between surroundings categories with respect to number of weeds (Table 3). A significant difference was also found between the mean number of weeds in different categories of stream catchment ($F = 4.90$, $P < 0.0003$). Tukey's studentized range test recognised two significantly different groups, i.e., urban or rural origins (Table 3).

Correlations between the reserve characteristics for all regions combined are given in Table 4. The correlation analysis by region showed fewer correlations, for example, Auckland data (Table 4). These correlation data, and those of Table 2, guided selection of the reserve characteristics for multivariable model analysis.

Single factor analysis of variance showed region explains 26.9% of the variation in number of problem weed species ($p < 0.0001$). Tukey's studentized range test showed that while some regions differ significantly ($p < 0.05$) in number of weeds, others have similar numbers (Table 5).

Results from the initial model, using all variables, and from a final refined model are given in Table 6. The final model excluded area and 7 of the categorial variables: fire history, soil fertility, stock use, clearings, scrubbiness, stream source, and human use. Area was not significant in some of the previous models. Fire history and soil fertility were not significantly correlated with number of weeds in all regions combined and stock use and clearings only weakly so (Table 2). Scrubbiness was not significantly correlated in anyone region (Table 2). Stream catchment, although significant, explained only a fraction of the variation in number of weeds ($r^2 = 0.097$, $F = 4.90$, $p < 0.0003$). Human use was highly correlated with proximity to towns (Table 4). None of these variables were significant in the initial model (Table 6).

The best model tried employed three interactions: rubbish with increasing proximity to towns, rubbish with region (Gisborne and Egmont) and surroundings with region (Auckland and Egmont; Table 6). In other words, the influence of the first variable on number of weeds increased in response to change in the second variable as indicated. This model explained nearly 70% of the variation in number of weeds and eight variables were significant: the three interactions plus shape, proximity to towns, distance from road/rail, number of native plant species, and region.

Discussion

The way reserve characteristics might influence, both independently and in concert, the number of weeds in reserves, is discussed.

Table 4: *Correlations between 13 reserve characteristic variables for all regions combined and Auckland data only. Upper triangle of table represents all regions combined. lower triangle refers to Auckland data only. Town = proximity to town, RoadR = distance from road or railway lines, Trash = rubbish. Use = human use, Fert = soil fertility. Fire = fire history, Clear = clearings, Scrub = scrubbiness, Native = number of native plant species, Weeds = number of problem weed species.* * = p < *0.05*, ** = p < *0.1*

	Variables												
	Town	RoadR	Shape	Trash	Use	Fert	Fire	Clear	Scrub	Area	Stock	Native	Weeds
Town	•	+0.22**		-0.49**	-0.44**		-0.31**		-0.28**		+0.23**		-0.568**
RoadR		•		-0.23**	-0.14*	+0.14*				+0.16*			-0.37**
Shape			•	+0.16*									+0.26**
Trash				•	+0.38**						-0.20**		+0.35**
Use	-0.50**			+0.47*	•							+0.16*	+0.39**
Fert						•	-0.17**	+0.19**		-0.19**		-0.37**	
Fire						-0.57**	•	-0.27**	+0.37**	+0.32**			
Clear								•		-0.20**	+0.23**	-0.22**	+0.16*
Scrub					-0.54**		+0.41*		•			-0.18**	+0.13*
Area	+0.42*					-0.49**				•	+0.19**	+0.56**	-0.39**
Stock										+0.54**	•	+0.17**	-0.19**
Native						-0.61**	+0.54**	-0.45*		+0.74**		•	
Weeds	-0.80**		+0.48**										•

Table 5: *Number of problem weed species by region. Means with the same letter are not significantly different* ($p < 0.05$) *according to Tukey's studentized range test.*

Region	Mean no. of problem weed species			
Auckland	8.3	a	b	
Gisborne	10.5	a		
Egmont	10.4	a		
East Taranaki	4.9		b	c
Taumarunui	8.2		b	c
Wairarapa	4.6			c
Wellington	10.5	a		
Marlborough Sounds	6.4		b	c

Proximity to Towns

Those reserves close to towns have more weeds than those further away. Proximity to towns was significant ($p < 0.0$ I) in all the models in which it was included and appears to be one of the most important influences on number of weeds in reserves (Table 2). Towns are the initial source of most problem weeds, as many are first introduced as garden plants (Esler, 1987). In our data, about 85% of the problem weeds present in Auckland and Egmont regions respectively, were present in reserves within 1 km of towns. In Auckland there were 10 species which did not occur further than 1 km from towns, and in Egmont, eight species. Most of these are either bird dispersed, e.g., Japanese honeysuckle *(Lonicera japonica)* and Mexican devil *(Eupatorium adenophorum),* or spread in garden rubbish, e.g., Italian arum *(Arum italicum)* and wandering Jew *(Tradescantia fluminensis).*

The relationship between proximity to towns and number of weeds was not as strong in East Taranaki, Wairarapa and Wellington (Table 2). In the first two, towns arc few and most reserves are a long way from towns. Apparently there is a steep decline in number of weeds with distance from towns; one can imagine that birds, wind, and people will disperse weed seeds or fragments only so far, and beyond a certain distance there is a limited effect of the increasing distance from towns. Also, some weeds will not have had time to spread from their points of introduction to distant reserves.

Reserves near towns tend to be more intensively used than those further away. Proximity to towns was inversely correlated with human use, rubbish, fire history and scrubbiness and positively correlated with road/rail and stock use (Table 4).

Rubbish

The influence of presence of rubbish on numbers of weeds in reserves depends on proximity to towns and on the region (Table 6). Some weeds are moved about almost solely by dumping of garden rubbish: e.g., yellow wild ginger *(Hedychium flavescens)* and wandering Jew *(Tradescantia fluminensis)* which are seedless, and German ivy *(Senecio mikanioides)* which sets non-viable seed (Esler, 1988). Once dumped, these weeds spread by vegetative reproduction.

Human Use

In Egmont, Taumarunui, Marlborough Sounds, and the regions combined, as human use increases, number of weeds increases ($r^2 = 0.390$, $p < 0.01$; Table 2). It is human misuse, such as dumping garden rubbish and destructive recreational use which encourages weeds (Bagnall, 1981; Esler, 1988; Healy, 1969). This result is consistent with Macdonald *et al.* (1989). They found a significant correlation ($p < 0.05$) between number of introduced species and annual visitor numbers for 11 of 13 biome groupings of continental nature reserves in southern Africa and North America. Visitors accounted for between 38 and 81 % of the variance in number of weeds.

Surroundings

The significant association between surroundings and number of problem weed species (Table 3) appeared to be additional to the effect of proximity to town, and varied with region (Table 6). While urban reserves are synonymous with those close to towns, reserves further away may be surrounded by cropland, farmland or native forest. Each of these differ in the probability that influences such as stock, fire damage, sharp boundary with adjacent land use, intensive recreational use, or dumped garden refuse, will be present. Degree of weed

Table 6: *Two models of number of problem weed species in reserves. Model types: ANOCO = analysis of covariance. HS = homogeneity of slopes model. Variables: Reg = region, Surr = surroundings, Trash = rubbish, Town = proximity to towns, RoadR = distance to road/rail, Native = number of native plant species, Area = area of reserve. Shape = shape of reserve, Town X Trash = interaction of rubbish with proximity to towns.* * = $p < 0.05$. ** = $P < 0.01$

Model type	Variables used	r^2	Significant reserve characteristics
ANOCO	all variables including Reg	0.613	Shape*, Town**, RoadR**, Native*, Reg**
HS	4 continuous (not Area) + Reg + 3 interactions	0.699	Shape**, Town*, RoadR**, Native*, Reg**, Town X Trash*, Reg X Trash**, Reg X Surr*

invasion in reserves may increase as land use intensifies but perhaps more important, surroundings influence the range and availability of weed propagules. In our data, two weeds widely used as farm shelter were associated with reserves in rural surroundings: hawthorn *(Crataegus monogyna)* and pampas grass *(Cortaderia selloana)*. By contrast, wild ginger was more prominent in urban reserves.

Road/Rail

Reserves close to roads or railway lines have more weeds (Tables 2, 6), presumably because these routes provide vectors such as seed-bearing vehicle tyres or gravel. Roads and railway lines also improve access and consequently human use, and abuse, of reserves.

Shape

Shape was a significant *(p < 0.05)* variable in all the models in which it was used. As reserve perimeter to area ratio increases, i.e., as reserves have more edge, the number of weeds increases. Edges are primary entry places for weeds; they tend to be open, have higher light levels, and allow the passage of vectors carrying weed propagules. They favour the establishment of species which enjoy these conditions, which many of the problem weed species in reserves do (Timmins and Williams, 1987). Narrow reserves are effectively all edge; some reserves in the Auckland region resembling the shape of a Maltese cross have many weeds. Although reserves near towns often have higher perimeter to area ratios, the influence of shape on weeds in reserves is in addition to the effect of proximity to towns (Table 6); they are not correlated (Table 4).

Size

The results for area were ambiguous. Area was correlated with number of weeds (Table 2) and was a significant variable in explaining the variation in number of problem weed species in reserves in some of the models. This is consistent with popular expectation and some overseas results (Macdonald *et al.,* 1988; Usher, 1988) which suggest that smaller reserves are effectively all edge and thus more prone to weed invasion. Of course some larger reserves actually comprise several discrete parcels, i.e., they too have a lot of edge.

By contrast, in other models, including the final one, area was not a significant variable. Small reserves may have weeds throughout but larger reserves may have as many or more weeds because they tend to have a greater range of habitats available for weed invasion. This idea is equivalent to the Quinn *et al.* (1987) finding that habitat diversity, rather than island area *per se,* is the determinant of species richness in the Lake Manapouri islands. Reserve size was not found to be a significant factor in determining weed invasions in southern African reserves (Macdonald *et al.,* 1986).

Number of Native Plant Species

This variable explained a significant amount of the variation in number of weeds in all the models it was used, although it is probable that the relationship is not direct as number of native plant species and reserve size are highly correlated (Table 4). Macdonald *et al.* (1989) also found that reserves with more native plant species tended to have higher numbers of introduced plant species. They suggested this could be a result of increased habitat diversity, but not size of reserve.

Soil Fertility

Soil fertility was not used in the final model but it was significantly correlated with number of weeds in Egmont ($r^2 = 0.395$, $P < 0.05$) and Wairarapa ($r^2 = 0.718$, $P <$ 0.0 I). A partial explanation for the relationship could be that many fertile sites are regularly flooded by rivers which deposit nutrients, silt, and weed propagules. Also, a few weeds tend to be more frequent in reserves of high soil fertility, e.g., montbretia *(Crocosmia* x *crocosmiiflora)* and wandering Jew *(Tradescantia fluminensis)*.

History of Human Use

In preparing the data set, several reserves in each region stood out as having a particularly high number of weeds. Often they were close to towns, roads or railway lines. Invariably, however, they were on or adjacent to a site of past or current high human use such as an old homestead, pa site, sawmill or mining enterprise, cemetery, rubbish tip, railway wasteland, camping ground, golf course or school. These activities provide a source of weed propagules (e.g., the gardens of old homesteads), sites for weed establishment (e.g., railway

Table 7: *Variability in road/rail data by region.*

Region	Distance from road/rail		
	Range	$\bar{x}$	% of reserves 0 km from road or rail
Auckland	0 - 0.5	0.019	96
Gisborne	0 - 0.1	0.005	95
Egmont	0 - 1.2	0.147	55
East Taranaki	0 - 4.0	0.250	81
Taumarunui	0 - 4.0	0.683	56
Wairarapa	0 - 2.0	0.215	76
Wellington	0 - 0.5	0.033	92
Marlborough Sounds	0 - 7.0	1.155	48

wasteland), or increased probability of use of the reserve (e.g., camping grounds). The activities are often associated with towns (>5000 population) and are further explanation of the effect of proximity to towns in the models where this is significant. It appears from informal exploration of the data that these past and present human activities are important influences on the degree of weed invasion in reserves and they may actually dilute the significance of proximity to towns in the models.

Data Difficulties

Several of the reserve characteristics were only weakly, or not at all, associated with number of weeds. We suggest that in part this probably reflected inadequate data. In the field we have observed that clearings often facilitate entry of weeds into reserves by increasing the amount of edge and by providing suitable habitat for weed establishment. Despite this observation, clearings was only weakly correlated with number of weeds (Table 2) and was not included in the final model. This was because the survey data did not distinguish between mown grass, bare ground, grazed or ungrazed areas, clearings created for roads or power lines, or clearings with seral vegetation. These types of clearings differ in the opportunities they provide for weed invasion. Also, many weeds establish in partial shade or in very small gaps of a scale that would not have been recorded in the reserve survey.

The surveys did not distinguish those kinds of rubbish which would be likely to contain weed propagules (e.g., garden refuse) from those that would not (e.g., bottles), and it is likely that the relationship between rubbish and number of weeds would have been stronger had this distinction been made.

Fire history was not significant in any of the models tried (Table 6) although it was significantly positively correlated with number of weeds in Gisborne. In the surveys fire impact was recorded as more than or less than 25 years ago, as was appropriate in describing vegetation seral stages, yet weed invasion is most likely to occur in the first few years after a fire when fresh sites are available.

Presence of stock and animal damage was recorded but potential for weed invasion varies with number of stock units, seasonality and frequency of grazing in reserves as well as time since last grazed, and this detail was not reported in the survey data. Similarly, detail on the extent and species of weed infestations upstream from reserves was not available in the survey reports. It is likely that with these data, stream source would have been a significant variable in the models because other studies have shown that streams spread weeds (e.g., West, 1986).

Most reserves in our data set are close or adjacent to roads (Table 7) so it was not possible to fully test the relationship between distance from road/rail and number of weeds in reserves. In Egmont, East Taranaki, Taumarunui and Marlborough Sounds, only about half the reserves were on a road or railway line (Table 5) and it was in these regions that there was a significant correlation between road/rail and number of weeds (Table 2). The data on soil fertility presented a similar difficulty; for most regions more than 60% of the reserves had the same rating. The lack of spread of data was even a difficulty for the proximity to town variable in a couple of regions. In Wairarapa, for example, there were no reserves adjacent to towns, all being at least 15 km away.

The number of weed species in reserves as analysed here is only one measure of the extent of vegetation modification by weeds. Because weed invasions are likely to increase, partly for the reasons outlined above, e.g., increased human use of reserves, future surveys should collect more comprehensive information on the abundance of weeds and their relationship to the native vegetation.

Conclusions

These results suggest the most important influence on the extent of weeds in reserves is degree of human impact including proximity to towns, human use, presence of rubbish and distance from road or railway line. Some physical features, such as shape and habitat diversity, also influence number of weeds. Reserves close to towns tend to have more weeds than those at a distance because they are close to sources of propagules and, more importantly, likely to be subject to high levels of human use and abuse. This result is consistent with the MacArthur and Wilson (1967) theory of island biogeography but in contrast to several rigorous tests of it which have been applied to weed dispersal (e.g., Quinn *et al.,* 1987). A more widely accepted theory is that irrespective of their isolation or size, reserves should be designed to minimise the effect of reserve edges (e.g., Schonewald-Cox and Bayless, 1986). Our results suggest that the shape of reserves, while less important than proximity to towns, is indeed a significant factor in determining the degree of weed invasion.

In their analyses of 41 southern African nature reserves Macdonald *et al.* (1986) found that the only reserve characteristic which gave rise to significantly different numbers of introduced vascular plants was the annual number of visitors to the reserve. Subsequently they suggested that the increase in weeds was either a direct result of visitors importing plant propagules, or the result of habitat modification such as roads, campgrounds, trampling or accidental fires (Macdonald *et al.,* 1989), emphasising, as in this study, the importance of human impact in determining the extent of weed invasion in reserves.

Reserves near towns require regular attention to prevent the establishment of weeds. This is especially necessary if the reserves are narrow, close to railway lines or roads, highly modified and on fertile soils. Accidental spread of weeds into and through reserves can be reduced by restricting roading, controlling visitor movements, and preventing spread of propagules through dumping of garden rubbish. Disturbance such as camping and grazing should be minimized. According to Macdonald *et al*. (1989) plant introductions into reserves are likely to occur with increasing frequency unless improved preventative measures are implemented. This study provides a basis to determine which measures are likely to be most effective. The management implications of the study are discussed in detail in Timmins and Williams (1990). Reserve managers have tended to be more aware of animal pests as a problem in reserves than of plant weeds; this will need to be rectified in the future (Machlis and Tichnell, 1985, cited by Macdonald *et al.,* 1989).

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Appendix overleaf

Appendix I. *List of problem weeds in forest and scrub reserves used in this study, compiled from observation and lists of problem weeds in protected natural areas (Timmins and Williams, 1987; Williams and Timmins,1990).*

Common name	Formal name	Common name	Formal name
apple of Sodom	*Solanum hermani*	Jerusalem cherry	*Solanum pseudocapsicum*
arum lily	*Zantedeschia aethiopica*	kikuyu grass	*Pennisetum clandestinum*
asparagus, climbing	*Asparagus scandens*	larch, European	*Larix decidua*
banana passionfruit	*Passiflora mollissima*	larch, Japanese	*Larix kaempferi*
barberry	*Berberis glaucocarpa*	Lawson cypress	*Chamaecyparis lawsoniana*
barberry, Darwin's	*Berberis darwinii*	macrocarpa	*Cupressus macrocarpa*
blackberry	*Rubusfruticosus* agg. (and others)	Mexican devil	*Ageratina adenophora*
boxthorn	*Lycium ferocissimum*	mist flower	*Ageratina riparia*
broom	*Cytisus scoparius*	montbretia	*Crocosmia* x *crocosmiiflora*
brush wattle	*Albizia lophantha*	Montpellier broom	*Teline monspessulana*
buddleia	*Buddleja davidii*	Mysore thorn	*Caesalpinia decapetala*
burdock	*Arctium* spp.	oak	*Quercus robur*
Cape ivy	*Senecio angulatus*	old man's beard	*Clematis vitalba*
cherry laurel	*Prunus laurocerasus*	pampas grass,	*Cortaderia selloana*
Chilean flame creeper	*Tropaeolum speciousum*	pampas grass, purple	*Cortaderia jubata*
cotoneaster	*Cotoneaster* sp.	periwinkle	*Vinca major*
Douglas fir	*Pseudotsuga menziesii*	pine, Corsican	*Pinus nigra* subsp. *laricio*
elaeagnus	*Elaeagnus* x *reflexa*	pine, lodgepole	*Pinus contorta*
elder	*Sambucus nigra*	pine, maritime	*Pinus pinaster*
elm	*Ulmus* x *hollandica*	pine, radiata	*Pinus radiata*
evergreen buckthorn	*Rhamnus alaternus*	privet	*Ligustrum ovalifolium*
German ivy	*Senecio mikanioides*	privet	*Ligustrum vulgare*
gorse	*Ulex europaeus*	privet, Chinese	*Ligustrum sinense*
green wattle	*Acacia decurrens*	privet, tree	*Ligustrum lucidum*
hakea, prickly	*Hakea sericea*	robinia	*Robinia pseudacacia*
hakea, willow-leaved	*Hakea salicifolia*	selaginella	*Selaginella kraussiana*
hawthorn	*Crataegus monogyna*	smilax	*Asparagus asparagoides*
hemlock	*Conium maculatum*	Spanish heath	*Erica lusitanica*
Himalaya honeysuckle	*Leycesteria formosa*	stinking iris	*Iris foetidissima*
holly	*llex aquifolium*	sycamore	*Acer pseudoplatanus*
inkweed	*Phytolacca octandra*	thorn apple	*Datura stramonium*
Italian arum	*Anm italicum*	tree lucerne	*Chamaecytisus palmensis*
Italian buckthorn	*Nhamnus almernus*	wandering Jew	*Tradescantia fluminensis*
ivy	*Hedera helix*	wattle, silver	*Racosperma dealbatum*
Japanese bamboo	*Arundinaria japonica*	wild cherry	*Prunus avium*
Japanese honeysuckle	*Lonicera japonica*	wild ginger (yellow)	*Hedychium flavescens*
		wild ginger (kakili)	*Hedychium gardnerianum*
		woolly nightshade	*Solanum mauritianum*