Do weeds respond to pest animal control?

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ABSTRACT

This descriptive study explored whether culling herbivorous mammals causes outbreaks of weed populations. Data were gathered by a questionnaire, by a literature search, from a database of herbivore diets, and by looking at the geographical overlap between goat and weed control in New Zealand. These anecdotal, quantitative, and experimental data gave 145 cases in which weed abundance was noted both before and after herbivore control. About three quarters of the records reported a weed increase. A CHAID analysis of the data found vegetation type and Conservancy to be useful predictors of weed increase after control, while type of animal controlled was not a good predictor. In particular, shrub and grass or herb species increased following goat, stock, or rabbit control in grassland and following goat control in damaged native forests or open sites. Very few reports were backed by experimental manipulation. Thus, the influence of animal control could not be isolated from other biological and physical variables. Nevertheless, the data suggested that the topic is worthy of further investigation to determine the magnitude and parameters of the problem. This will help conservation managers to design efficient conservation projects which both control pest animals, and minimise subsequent weed invasions.

Keywords: weeds, invasive plants, pest animals, plant–animal interactions, goat, rabbit, livestock, integrated management, monitoring, diet studies, New Zealand

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1. Introduction

This investigation was a first step in exploring the relationship between control of pest animals and weed abundance. We collated relevant existing data, observations and recollections. The investigation was prompted by the Environmental Weeds Research Plan (Timmins 1997), viz.:

> '4.2.1 (4) Quantify and forecast the relationship between weediness and management activities such as wild animal control … in native communities.
>
> '4.2.3 (9) Develop models of integrated management incorporating weed control with other practices such as animal control.'

1.1 BACKGROUND

The Department of Conservation (DOC) undertakes a lot of pest animal control. DOC's total budget for animal[1] control has averaged $25 million per year over the last four years. The majority of this is for possum (*Trichosurus vulpecula*) or goat (*Capra hircus*) control. DOC undertakes sustained control of goat and possum over approximately 2.4 million hectares and 1.1 million hectares respectively (Bill Fleury pers. comm.). Experience shows that there can be unanticipated effects following pest animal control with subsequent management needed to achieve the desired conservation outcomes (Veitch & Bell 1990). For example, on Tiritiri Matangi Island rank grass and bracken (*Pteridium esculentum*) increased after stock were removed, bringing a concomitant increase in the density of kiore (*Rattus exulans*) (Craig & Moller 1978). We now recognise the importance of removing pest animals in the right order. Another oft-quoted example is the explosion of boxthorn[2] following rabbit (*Oryctolagus cuniculus*) eradication on Motunau Island (Cox et al. 1967). This latter example suggests that weed control needs to be considered as part of the suite of management activities at a site where pest animals are controlled. But when, where, and by how much do weeds increase in abundance after pest animal control?

There is a wealth of literature documenting the recovery of native vegetation following the control of a variety of herbivores in mostly forest and grassland vegetation. A network of permanent plots throughout the country can be measured for this purpose (Bellingham et al. 2000). By contrast there has been limited study on the interaction between pest animals and weeds. There is only one study on the role of pest animals in facilitating the establishment and spread of weeds (Williams et al. 2000). Even less is known about the response of weeds to animal control, but it is logical to expect some response. This being the case, conservation planning should take account of the potential costs as well as the benefits of any proposed management action.

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1 Possum, goat, deer, thar, chamois, horse, some mustelid work, wasp, rabbit, and hare.

2 A glossary of exotic plant common and scientific names is given in Appendix 1.

1.2 OBJECTIVES

- Determine whether there is evidence—formal or anecdotal—of changes in weed abundance following mammalian herbivore control in New Zealand.
- Identify which vegetation classes or situations are vulnerable to weed invasion and/or expansion following pest herbivore control.
- Make recommendations for management, and for future research if it is needed.

We anticipated that a variety of outcomes were possible following the control of large populations of browsing animals. In situations where pest animals were browsing or damaging weeds, we expected the weeds to increase after animal removal. Such an increase would be most dramatic in disturbed, high light environments and where there is a high weed propagule pressure, e.g. close to towns. Where the herbivores were keeping the vegetation open then we expected that the light-demanding weeds would decrease in abundance after herbivore control, however, the observation of this effect was likely to be time-dependent.

1.3 DEFINITIONS

A **weed** is an exotic plant species that disrupts the structure and functioning of the indigenous communities it invades. The currently recognised weeds of conservation concern in New Zealand are listed as such on DOCs national weeds database (Bioweb Weeds). At the time of this study, 2001, the list of **environmental weeds** stood at 247 species.

A **pest animal** is an exotic animal species that disrupts the functioning of the indigenous communities it invades, or causes the decline of indigenous species.

2. The data

2.1 DATA COLLECTION

We decided to use existing data and observations as a first step in investigating this topic. This allowed us to explore the full variety of pest animals, weeds and vegetation classes. We anticipated this approach would give us a good indication of where best to put future research effort.

2.1.1 Email questionnaire

We emailed 255 DOC staff on three email discussion lists: Weeds, Pest animals, and Habitat monitoring. We asked four questions, for which mostly one-word answers were possible. We wanted to get lots of returns rather than just a few highly detailed replies. We did, however, invite respondents to contact us if they were prepared to give us more information. Our questions were:

- Have you seen changes in weeds following pest animal control work?
- If so, where?
- What pest animals were controlled?
- Which weed species changed in abundance?

We emailed similar questions to former staff of the New Zealand Wildlife Service and to researchers in Crown Research Institutes and universities. We asked more directed questions of people who had been involved in animal control at particular sites. We also talked to some overseas workers, in particular those who attended an International Island Eradications conference in Auckland 19–23 February 2001 (Veitch & Clout 2002).

2.1.2 Literature search

We searched the ecological literature for studies that examined vegetation change following animal control, and in particular for studies exploring whether weeds respond to animal control. We also gathered relevant anecdotal comments from a broader range of papers—those that had both animal control and invasive plants or weeds in their key words. Our literature search did not capture studies that monitored vegetation change after animal control in remote blocks of forest where invasive weeds are unlikely to be present at the moment. We make the cautionary note however, that even these parts of the country could become vulnerable to weed invasion in the future.

2.1.3 Other information avenues

We compared two national lists:

- The 145 sites of sustained goat control listed in tables 4–17 in the National Feral Goat Control Plan 1995–2004 (Anon. 1997)
- The 308 sites where weed control is a priority (Owen 1998)

Sites occurring on both lists were of potential interest because they implied goat control in the presence of weeds of conservation concern. We asked DOC Conservancy Technical Support Officers if interactions between goat control and weeds had been noted at these sites. In the same vein, we contacted DOC staff working in 'mainland island' areas—not real islands, but places with high conservation value that are intensively managed. Usually a suite of management activities is conducted in concert and monitored (Saunders 2000). We also sought to gauge how often vegetation assessment is a part of a pest animal control by following-up on a discrete set of animal control operations—goat eradications on islands as listed in Veitch & Bell (1990) and updated by Ian McFadden (pers. comm. 2001).

Tackling the problem from another angle, we wanted to determine which environmental weed species (the 247 species referred to in Section 1.3) have been found in the diet of pest animals. We used the animal diet database developed by the School of Forestry at the University of Canterbury. This database contains published and unpublished information for 63 different animal populations, comprising 18 species of introduced herbivore (Hamish Cochrane pers. comm.). Records were only used for those populations where at least five stomach or faecal samples were analysed.

2.2 SORTING THE DATA

We set minimum requirements for acceptable data. Records where pest animal or location in New Zealand was not specified were excluded, because this suggested the observation was too vague. We also omitted international examples from our actual data analysis because, although the pest animals were often the same as in New Zealand, the vegetation classes and weed species differed markedly. The international examples are confined to the discussion section. We classified the records according to the class of data on which the observation was based: experimental data, formal data, or anecdotal information. **Experimental** data refers to data from controlled field experiments explicitly set up to test weed response to pest animal control. **Formal** data refers to relevant quantitative or qualitative data collected systematically, but not necessarily in relation to the animal–weed topic. This class also included data from studies that did not include an experimental control. **Anecdotal** information comprised personal recollections and observations. They came from responses to our questionnaire, as well as comments in published papers.

The records also had data fields for land status, pest animal, vegetation class, and growth form of the weeds. Each record was classified as either 'mainland' or 'island'. The island category included mainland island areas, on the grounds that these are islands of intense management activity, within a modified landscape. Each record was classified according to pest animal controlled: goat, pig (*Sus* spp.), possum, rabbit, rat (*Rattus* spp.), wallaby (*Macropus* spp.), stock—mostly sheep (*Ovis* spp.), but also cattle (*Bos* spp.). For vegetation class we used the definitions in Williams (1997): intact forest, damaged forest (and forest margins), scrub (and fernland), grassland (including tussockland and herbfield), openland (bare), and wetland. Each separate record referred to an animal control operation in one distinct vegetation class. When several pest animals were controlled we categorised the record according to the pest animal likely to have had the greatest effect on the weed species cited. This is consistent with normal practice to reduce the dimensions of the dataset (e.g. Westbrooke & Jones 2002). We classified weed species into the following growth forms: tree, shrub, vine, grass/herb. Some animal control programmes had several weeds of different growth form respond. We classified the record by the growth form likely to have the most ecological impact on the given vegetation type, based on past observation and experience (e.g. Williams 1997). While this meant that we lost some information, we felt that the alternative—entering a separate record for each different weed growth form—would have exaggerated the incidence of weed increase after animal control.

2.3 DATA LIMITATIONS

Questionnaires have some inherent problems. The return rate is usually much less than 100%. Furthermore, reporting is biased towards those who observed changes in weeds, usually an increase. We tried to overcome this by inviting people to reply, even if they had not noted any interactions. Another problem is ambiguity in the questions and the answers. When 'no weed response' was reported we did not know whether weeds were even present at or near the site prior to control. We suspect it also covers situations when people actually did not know, i.e. no monitoring was set up or they did not specifically check for weeds. Timing of the observation influences the response observed—unfortunately we did not ask how long after the animal control the weed assessment was made. We have no way of determining what proportion of the possible anecdotal observations we have captured. We assume that we have most, if not all, of the available experimental and formal data on the topic.

Because of these limitations, our data may over- or under-emphasise the real incidence of weed increase after animal control (i.e. type I or type II error). Both carry risk (Table 1). If we under-estimate (Quadrant 3), the risk is that weeds will get away and cost much more to control than had they been anticipated and controlled promptly. If we over-estimate (Quadrant 2), the risk is that too much time and resources could be invested in monitoring for weeds; resources that could be better spent elsewhere.

TABLE 1. REALITY VERSUS OBSERVATION—THE RISK OF OVER OR UNDER ESTIMATING THE INCIDENCE OF WEED INCREASE AFTER PEST ANIMAL CONTROL.

		REAL WORLD (Do weeds increase following pest animal control?)	
		YES	NO
RECORDS (Have weeds been observed to increase following pest animal control?)	YES	**Quadrant 1** Accurate data. We are reporting a real phenomenon.	**Quadrant 2** We are over-estimating the extent of the problem and risk wrongly investing resources.
	NO	**Quadrant 3** We are under-estimating the extent of the problem and risk being unprepared for dealing with an explosion of weeds.	**Quadrant 4** Accurate data. We are accurately reporting the real situation.

2.4 DATA ANALYSIS

Because the data were neither independently nor randomly sampled, descriptive statistics were used to analyse the data. To determine which variables were the best predictors of increased weed abundance, we used Chi-squared Automatic Interaction Detector analysis (CHAID; Kass 1980). We used the exhaustive CHAID algorithm as implemented in Answer Tree (SPSS 1998).

CHAID is a procedure for predicting the outcome of a dependent categorical variable (in our case, weed increase) on the basis of a set of categorical predictor variables (in our case, data quality, animal pest combined class, vegetation class, conservancy, and mainland or island status). The dependent and predictor variables can be ordinal or nominal (as with our data). CHAID analysis cross–tabulates each predictor variable with the dependent variable then applies an algorithm to look at each pair of the predictor variable categories. A chi-squared test of independence was then applied to examine whether their behaviour was significantly different with respect to the dependent variable. Categories that were not significantly different were merged. The process was recursive (merged categories being tested against the remaining ones) until each predictor variable had been optimally merged. When all had been optimally merged, the variable that was most significantly associated with weed increase was chosen as the best predictor. The data could now be split into subsets according to the chosen predictor variable categories and the original algorithm reapplied to each subset, and the process repeated until a stopping criterion was met. The result of CHAID analysis is a tree diagram in which the 'root' of the tree is the whole dataset, and the subsets and sub-subsets the branches (Westbrooke & Jones 2002).

We also calculated 95% confidence limits on the responses we obtained reporting weed increases, decreases, or no change (but only increases in weed abundance are reported in the results). These limits were calculated as if the records were an independent and random sample, and we recognize that these assumptions were not valid. However, interpreted with caution, the calculated limits offer some, possibly underestimated, indication of the variation in response that might be expected.

3. Results and discussion

3.1 CHARACTERISTICS OF THE INFORMATION

Half of our 145 records came from the 59 people who responded to our internal DOC email. We obtained records from all 13 conservancies. A quarter came from the 14 external people that we talked with. The remaining quarter came from the 26 published papers, theses, and reports we reviewed. The majority of records (66%) were anecdotal but nearly a third (30%) were based on formal data. Just 4% of records were based on ecological experiments designed to look at changes in weeds following pest animal control. The type of information varied for each of the animals reported on (Table 2). For goat control, the

TABLE 2. NUMBER OF RECORDS CLASSIFIED BY TYPE OF INFORMATION.

PEST ANIMAL CONTROLLED	ANECDOTAL	FORMAL DATA COLLECTION	EXPERIMENTAL STUDIES	TOTAL	PERCENTAGE
Goat*	45	7		52	36
Pig		2		2	1
Possum	10	1		11	8
Rabbit†	22	16	5	43	30
Rat	3	3		6	4
Stock	12	16	1	29	20
Wallaby	1	1		2	1
Total	92	41	6	145	
Percentage	63	28	4		

* For 12 of these records other animals were controlled along with goats; they were mostly possums.

† Sheep were controlled along with rabbits for 8 of these records.

records were largely anecdotal (87%) with only limited formal work. Experimental studies have only been conducted with respect to rabbit or stock control, mostly in grassland. In addition, over half the records for stock control involved quantitative data collection and over a third for rabbit control did so (Table 2). It seems that formal assessment is more likely following animal eradication on islands than on the mainland—half the island records are based on formal data compared to a quarter of the mainland records.

The records cover most of the herbivorous pest animals that DOC controls but notable exceptions were deer (*Cervus* spp.), chamois (*Rupicarpra rupicapra*), and thar (*Hemitragus jemlahicus*). The bulk of the records were for goats (36%), rabbits (30%) or stock (20%) (Table 2). The records also cover the range of vegetation classes, although two are well represented: grassland, including tussockland and herbfield, and damaged forest and forest margins (Table 3). Most of the records were for mainland sites (72%) and the rest were from islands, including just one 'mainland island' area. This was surprising because weeds are an ecological threat at all but one of DOC's mainland island areas, all have pest animal control programmes, all are monitored including any biota likely to be affected by conservation management. The difficulty with gathering information from mainland island areas is that several pest animals and weeds are controlled concurrently. This makes it difficult to tie any particular weed response to any one management activity, such as the control of one pest animal (Saunders 2000).

3.2 ANALYSIS OF THE INFORMATION

Of the 145 records, three-quarters reported a weed increase after pest animal control (74% ± 7%). A decrease in weeds reported following pest animal control occurred in only three cases (Table 3). It is true that we cannot infer from these records the proportion of all animal control programmes that will result in a weed increase in the field. It may be much less than the three-quarters suggested by our data. However, had we included the 196 people who did not reply to our email questionnaire and scored them all as 'no weed changed observed', then one third of the records would still have reported a weed increase (32% ± 5%).

3.2.1 Which pest animals?

The pattern of an increase in weeds after animal control held across all the pest animals. Nearly all the rabbit records (91% ± 8.2%) reported a weed increase. Similarly a weed increase was reported for many of the stock (76% ± 15.9%) and goat (65% ± 13.6%) records (Table 3). For all the other animals the number of records was relatively low—too low to make any statements about what happens to weeds after their control. This was reflected in the CHAID analysis by pest animal, for which $P = 0.2615$ suggesting that, in our data at least, animal controlled is not a reliable predictor of weed increase.

3.2.2 Which vegetation classes?

The CHAID analysis showed vegetation to be a highly significant ($P < 0.00005$) predictor of weed increase after animal control (Fig. 1). This is likely to be related to the high proportion of weed increase records in grassland and the almost absence of weed increase in intact forest (Table 3). Taking the main pest animals in turn, for goat control, nearly half the weed response records were from damaged forest and margins. For open sites—like riverbeds or coastal cliffs—all the goat records reported a weed increase after control. By contrast, for scrub and intact forest there were more reports of no weed response (Table 3). For example, in a catchment of the Urutawa Conservation Area on the East Coast, several tall individuals and abundant seedlings of buddleia turned up in a goat exclosure on open shingle regularly washed by a stream. Yet buddleia did not invade the exclosure on the forested bench further downstream (Dave Wilson pers. comm.). Part of the explanation for this could relate to light levels and disturbance. At the open sites, released from browse pressure, weeds could take advantage of the high light environment whereas in the shaded forest conditions light levels were too low—and perhaps became more shaded after animal

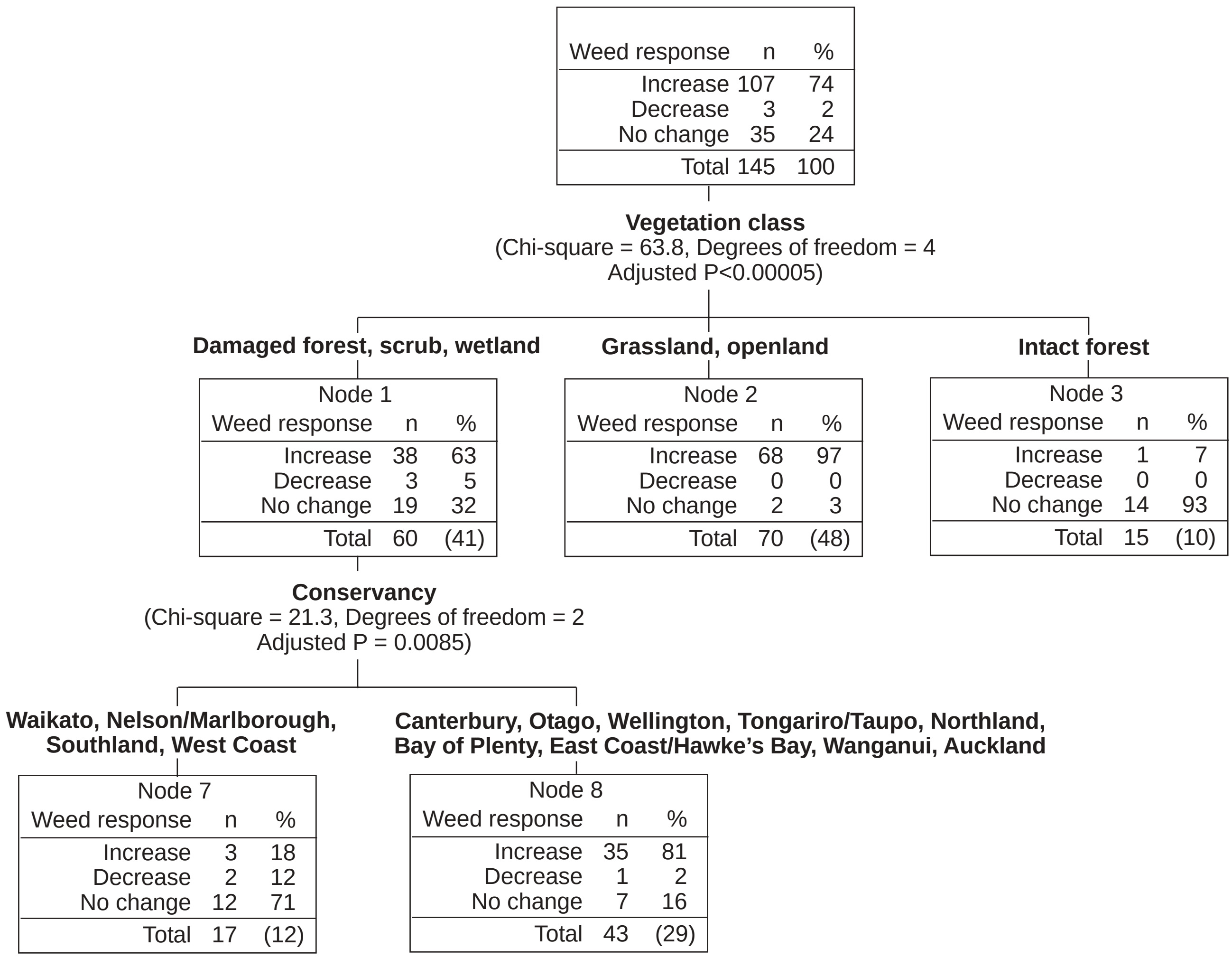

Figure 1. Decision tree from CHAID analysis of 145 records of weed response following pest animal control. Each box gives number and percentages of records for each level of response. The variable used for each split of the data is given with its statistics (chi-square value, degrees of freedom, *P*-value adjusted for multiple comparisons). The first data split is based on vegetation class; a subsidiary split is based on Conservancy.

TABLE 3. NUMBER OF RECORDS WHERE WEEDS SHOWED A GIVEN LEVEL* OF CHANGE IN ABUNDANCE FOLLOWING PEST ANIMAL CONTROL (LISTED BY VEGETATION CLASS).

VEGETATION CLASS	RABBIT†		RAT		STOCK		GOAT‡			POSSUM		WALLABY		PIG		TOTAL§			VEG. TYPE (%)			ALL RECORDS BY VEG. TYPE (%)
	INC	NIL	INC	NIL	INC	NIL	INC	NIL	DEC	INC	NIL	INC	NIL	INC	NIL	INC	NIL	DEC	INC	NIL	DEC	
Grassland	25	1	1	0	14	0	9	0	0	1	0	0	0	0	0	50	1	0	98	2	0	35
Openland	5	1	1	0	1	0	9	0	0	0	0	2	0	0	0	18	1	0	95	5	0	13
Intact forest	0	2	0	0	1	7	0	3	0	0	1	0	0	0	1	1	14	0	7	93	0	10
Wetland	2	0	0	0	1	0	0	1	0	0	0	0	0	0	0	3	1	0	75	25	0	3
Damaged forest and margins	3	0	1	0	4	0	14	7	3	5	4	0	0	0	0	27	11	3	66	27	7	26
Scrub	4	0	2	1	1	0	1	5	0	0	0	0	0	0	1	8	7	0	53	47	0	10
Total INC/NIL response	39	4	5	1	22	7	33	16	3	6	5	2	0	0	2	107	35	3	74	24	2	
Percentage	91	9	83	17	76	24	63	31	6	55	45	100	0	0	100							
Total records for pest animal	43		6		29		52			11		2		2								
% of all records represented by animal type	30		4		20		36			8		1		1								

* INC = increased; DEC = decreased; NIL = did not change

† Sheep were controlled along with rabbits for eight of the weed increase records.

‡ For 12 of the records of an increase in weed abundance, other animals were controlled along with goats; mostly possums. For 2 of the nil records, either possums or pigs were controlled along with the goats. The total number of goat records includes 3 records of a decrease in weeds after goat control in damaged forest; this is reflected in the percentages.

§ Number of records of where weeds showed a decrease given for goats only; for all other pest animals, weeds either showed no response or an increase.

control—for light-demanding weeds at least to expand. This supports our earlier contention that the light environment will have an effect on weed response.

For rabbits, nearly two thirds of reported weed increases occurred in grasslands. Similarly for stock, over half the records of a weed increase were also from grasslands with most of these relating to sheep exclusion (Table 3). Native grasslands, being of low stature, are more vulnerable to woody weed invasion. Also if these grasslands occur near pasture the latter will be a source of exotic grasses and herbs.

3.2.3 Location, and vulnerable sites

Conservancy turned out to be a useful predictor of weed increase. It was used as the first variable to split the data in the CHAID analysis (P = 0.0029). Even as a second order variable Conservancy had a significant P-value (Fig. 1). This may actually relate to vegetation type, e.g. the bulk of the Canterbury records were for a weed increase after stock or rabbit control in grassland (Section 3.2.2). It is also possible that Conservancy was linked to proximity to towns, a proven predictor of weed propagule pressure (Sullivan et al. 2001). In fact, very few (10%) of the control operations in any Conservancy were conducted close to towns.

At some sites weeds have wreaked havoc after animal control. This is of particular concern where threatened species are involved. At Moeatoa on the west coast of the North Island, following goat control, weeds such as tall fescue and other introduced grasses increased and crowded out the threatened forget-me-not *Myosotis petiolata* var. *pansa* (Alastair Fairweather; Pim DeMonchy pers. comm.). Similarly, at Whitirea Scientific Reserve, an ephemeral wetland south of Wanganui, rush species and pasture grasses, e.g. strawberry clover and Yorkshire fog, smothered a small patch of *Sebaea ovata*, a threatened gentian that was fenced to exclude rabbits (LaCock & Ogle 1999).

The impact of any increase in weeds after animal control may depend on the occurrence of disturbance at the site. For example, in Te Urewera National Park, if buddleia colonises young alluvial sites regularly disturbed by flood events, it will displace the native plant communities and their dependent invertebrate fauna that would normally colonise these sites (Chris Ward pers. comm.; Smale 1990). By contrast, if buddleia colonises stable sites, it is unlikely to be a problem. At these sites succession is likely to follow the same path as it would, had the native tutu (*Coriaria arborea*) colonised the site.

3.2.4 What type of weeds?

Shrubs and grasses or herbs were the weed growth forms most often reported as increasing after animal control (Table 4). For goat control, shrubs comprised over half of the records of weed increase. Similarly, for rabbit and stock control, shrubs and trees together made up over half of the weed increases. The rest were grasses or herbs with several being recognised as environmental weeds, e.g. hawkweeds. Table 5 lists some of these environmental weeds observed to increase after animal control. Only those weed species thought to pose an ecological threat in each vegetation class have been included. It appears that while some species overlap, the weed species vary considerably with pest animal controlled and with vegetation class. This meant we could not test for a relationship between weed species, weed increase, and other variables.

However, of those records where an increase was observed, 98% involved light-demanding species. This is not really surprising because 91% of the DOC weeds are light-demanding (Bioweb Weeds). This counters our original suggestion that light-demanding weeds might decrease in abundance after herbivore control. Rather, it seems these species may well take advantage of the high light levels created by the past browsing of the pest animals.

TABLE 4. NUMBER OF RECORDS WHERE WEEDS INCREASED AFTER PEST ANIMAL CONTROL, LISTED BY GROWTH FORM.

WEED GROWTH FORM	GOAT*	RABBIT†	STOCK	POSSUM	RAT	WALLABY	TOTAL
Grass/herb	10	16	10				36
Shrub	21	11	7	3	3	1	46
Tree	3	12	4		1	1	21
Vine	2		1	3	1		7
TOTAL	36	39	22	6	5	2	110

* For 12 of these records other animals were controlled along with goats; they were mostly possums.

† Sheep were controlled along with rabbits for eight of these records.

TABLE 5. EXAMPLES OF INVASIVE WEED SPECIES* THAT INCREASED FOLLOWING PEST ANIMAL CONTROL OR EXCLUSION, GROUPED BY VEGETATION CLASS.

VEGETATION CLASS	PEST ANIMAL CONTROLLED	WEED SPECIES WHICH INCREASED IN ABUNDANCE
Intact forest	Stock	Chinese privet
Damaged forest and forest margins	Goat	Old man's beard, Japanese honeysuckle, wandering Jew, mistflower, woolly nightshade, pampas grass, purple guava, African olive, Mysore thorn
	Possum	Banana passionfruit, Darwin's barberry, hakea, mile-a-minute vine
	Stock	Old man's beard, banana passionfruit, privets, elder, wandering Jew, spindle tree
Scrub and fernland	Rabbit	Hawthorn, barberry, kangaroo acacia
Tussockland, grassland, and herbfield	Rabbit	Gorse, broom, boxthorn, pines, sweet brier, hawkweeds, bone-seed
	Stock	Pines, larch, spruce, Spanish heath, broom, gorse, hawkweeds
	Goat	Gorse, Himalayan honeysuckle, broom, blackberry, Chinese privet, buffalo grass, African feather grass, periwinkle
Openland (bare)	Goat	Old man's beard, gorse, buddleia, pampas grass, Mexican daisy, kikuyu grass, Japanese honeysuckle, willow
	Rabbit	Broom, boxthorn, willow, thyme
Wetland	Rabbit	Pasture grass and rush species
	Stock	Pampas grass, blackberry, Japanese honeysuckle

* A glossary of exotic plant common and scientific names is given in Appendix 1.

3.2.5 Time since animal control

While we did not explicitly ask about the timing of assessment in relation to the animal control, we expected that time since animal control would have a bearing on whether weeds were observed. Weeds may increase with a big bang straight after animal control, and then subside over time, or alternatively there may be a time lag in the response of weeds or native plants because of factors such as climate. We do not have any New Zealand examples of this because our records tend to be one-off observations. However, the phenomenon is well illustrated by an international example. On Santa Cruz Island, California the vegetation cover decreased after eradication of sheep because of a five-year drought. Yet once it rained, exotic annual grasses quickly blanketed the island (Rob Klinger pers. comm.). This example also shows another time effect—that woody weed species may not increase immediately after animal control. On Santa Cruz the establishment of exotic grasses and herbs after animal control actually delayed the establishment of woody weeds.

Another aspect of time is natural succession. At Mapara, where blackberry and Japanese honeysuckle appeared to increase in open areas along rivers following goat control, DOC staff expect succession towards native canopy species to take care of the weeds (Ian Flux pers. comm.). In some circumstances however, the invasion by weeds allowed by pest animal control merely facilitates the invasion of further weeds. Round Island, Mauritius, provides an international example of this sequence. Following the eradication of goats there in 1978 and rabbits in 1986, one weed species after another dominated the plant succession (David Bullock pers. comm.; North et al. 1994). Relying on natural succession to eliminate weeds requires three prerequisites: an adequate seed-source of native species; native vegetation taller or more competitive than the weeds, and conservation values safe from immediate threat, i.e. not compromised by the time taken for natural succession to oust the weeds (Williams 1997).

3.3 GOAT CONTROL

As at July 2001, goats had been successfully eradicated from 16 of New Zealand's offshore islands (Veitch & Bell 1990; Ian McFadden pers. comm.). For 12 of these islands we were able to secure relevant post-control information from referenced reports or other sources. Of these, only three islands were formally monitored for vegetation change in relation to the goat eradication. On another four islands, people had recorded, or could recollect their observations about vegetation change following goat removal. Exotic species increased on five islands (pasture grasses in three cases), no response was reported on one; and on the remaining island weed species both increased and decreased. For the remaining four eradication operations, we could not find any information. Two of them pre-dated DOC and its forerunner New Zealand Wildlife Service. The other two operations apparently did not include any post goat control monitoring or observations of any kind. In summary, formal monitoring was established for only three of the 16 eradications.

When we looked for convergence between mainland goat operations and sites with weed problems we found 29 (20%) of the sustained goat control projects were conducted within or near protected areas where weed control is either undertaken or identified as a priority (Anon. 1997; Owen 1998). These sites were in six different DOC conservancies: Bay of Plenty, East Coast/Hawke's Bay, Tongariro/Taupo, Wellington, Otago, and Southland. Apparently, none of the goat control operations at these sites included formal post-control vegetation monitoring. The results reported here come entirely from the recollections of the staff involved with pest animal or weed control. Just one person reported a weed increase. Overwhelmingly, staff could not recall any change in weed abundance following goat control. They gave two reasons for this. First, goats had been at low levels for many years—perhaps too low for their control to have an observable effect on weeds. Second, weeds were absent in the areas where goats were actually controlled. The other difficulty in investigating the link between goat control and weed increase is that often different personnel are involved in the two control activities (animals or weeds) and neither group may have thought about the connection between the abundance of the two types of pest.

3.4 DO PEST ANIMALS EAT WEEDS?

We used diet composition studies to assess if pest animals browse weeds. We found that weed species turned up in approximately 40% of the 63 introduced herbivore diet studies examined (Cochrane & Norton 2000). There were 37 species involved, or 43 taxa if weeds identified only to the genus level are included. Possum had the greatest number of weed species in their diet (23), followed by deer (all deer species combined) with 12 weeds. No other pest animal had more than 6 weed species. Only 9 weed species were recorded at an abundance of more than 10% of animal diet by volume and these were primarily in possum diet. Appendix 2 lists the specific weed taxa recorded in the diet of introduced herbivores. In summary, for goat diet most species recorded are not considered environmental weeds, e.g. hooked dock, Scotch thistle. The same can be said for stock and rabbit diet of which the only environmental weeds are the hawkweed king devil and sweet brier respectively. The data are obviously influenced by the amount of diet studies that have been undertaken for each animal, with the most studies undertaken on possum diet. More studies of pest animal diet could usefully be conducted, given the inconsistency between weeds reported to have increased following animal control in our records and the weeds found in animal diet.

Diet studies can identify weed species that may not be detected by vegetation monitoring prior to control. Not doing such assessments can be catastrophic. For example, after the eradication of feral goats and pigs from Sarigan Island (Commonwealth of the Northern Mariana Islands) there was a rapid expansion of a smothering vine *Operculina ventricosa*. This vine, which local people on the island actually fed to their domestic goats, had been suppressed to such a low level that that it wasn't detected in the pre-control vegetation survey (Arriola 2000).

4. Conclusions

4.1 SUMMARY OF FINDINGS

Our data support the contention that weeds increase after pest animals are controlled. In particular, weedy shrubs, grasses and herbs increase following goat, livestock or rabbit control in grassland and following goat control in damaged forests or open sites. While most of the records were anecdotal, the more formal studies also supported this finding. An examination of the international literature, including a review of the topic by Zavaleta et al. (2001), also revealed several striking examples of weeds increasing after pest animal control.

4.2 IMPLICATIONS FOR MANAGEMENT

Taking these data together suggests that weeds should be considered when pest animals are controlled. This has management implications because the cost of deferred weed control is so great (Harris et al. 2001). If only a third of all animal control operations results in an increase in weeds then it would be wise to remember weeds when doing pest animal control.

In fact, there are already some examples of animal–weed integrated management in DOC. For example, on Raoul Island managers identified the weed species likely to become more abundant after rat eradication (Veitch 1994; West 1996). Subsequently they narrowed down the problem weeds to just one—grape—and it was controlled prior to rat removal. Raoul Island managers remain alert should there be a flush of grape seedlings from the seedbank (Mike Ambrose pers. comm.). In Nelson–Marlborough Conservancy DOC staff have set up monitoring to detect changes in weeds following goat control in a relatively open area with existing weed species (Gregg Napp pers. comm.). In Waikato, monitoring staff have noted the presence of weed species where goats are to be controlled and where a threatened plant occurs (Elizabeth Grove pers. comm.).

5. Future research directions

5.1 GOING BEYOND ANECDOTAL INFORMATION

The current study looked at whether or not weeds respond after animal control. But the real issue is determining the magnitude of any increase in weed abundance and whether such an increase threatens the recovery of the native community. Further, the myriad factors involved in the interaction between animal control and weed increase need to be teased out before we can intelligently inform conservation practice. This requires more rigorous study. Prior to animal control, sites should be surveyed for weed species and signs of browse. This would identify sites needing ongoing monitoring and management. The following situations would be the most profitable to monitor. They are the ones our records have shown to be most vulnerable to weed invasion.

- Dry ecosystems previously used for pastoral purposes, e.g. control of rabbits and removal of grazing animals in the high country
- Disturbed high light environments with large goat numbers, e.g. rocky stream beds following goat control
- Reserves near towns and cities, with pest animals and abundant weeds (several species, large infestations)
- Animal eradications on islands, e.g. rat eradication on Raoul Island.

Such monitoring data could inform management at the sites as well as contribute to a wider research study.

5.2 FUTURE GOAT CONTROL RESEARCH

Goat control operations are an obvious candidate for a co-ordinated study. Goat control is a high priority for DOC, second only to possum control. Sustained control of goats occurs in 145 ecological areas (Anon. 1997). Thirteen new goat control programmes, covering approximately 330 000 ha of benefit area, have been funded through the biodiversity budget since 2000 (Keith Briden pers. comm.). To date, minimal experimental data have been collected in relation to goat control—there were no experimental studies included in our records. From the anecdotal records collected in this study we anticipate that many goat control operations will see a change in weeds. The rest of our discussion on future research focuses on goats.

5.2.1 Study sites and duration

Our records showed that the vegetation classes most vulnerable to weed increases after goat control are damaged forest, open land, or grassland. Within these vegetation classes factors such as proximity to settlements, disturbance history, likelihood of the weeds being replaced by natives, and the presence of threatened plants, make weed invasion more of an issue at some places. These will offer sites most suitable for further study. By contrast, sites where native plants will ultimately out-compete weeds are less suitable.

It can take some time for weeds to respond to animal control. Also, there is considerable variation in the time it takes to resolve the net ecological impact of weed changes. Sometimes there is a delay in woody weeds taking off. At other times and places a flush of weeds is soon replaced by native species. For these reasons, any future studies will need to be long-term and should avoid the temptation of jumping to a conclusion too soon.

5.2.2 Questions for further investigation

Future research on this issue must address these questions:

- Are weed species present at many of the sites where goat control occurs?
- Do goats change the physical characteristics of native communities to make them more vulnerable to weed invasion?
- Do goats eat weed species? Do they do so selectively?
- Do goats eat a sufficient quantity of weed biomass or seed to make a difference to vegetation composition when they are controlled? What is the potential viability of seed consumed?
- Do weeds become a management issue following goat control?

5.2.3 The importance of an experimental control

Several processes impinge on changes in weeds at a site: climate, vegetation composition, availability of weed propagules, and the history and current occurrence of disturbance. To separate the effect of animal control from other factors, any future study must include experimental controls: areas without goats (i.e. never had goats) and areas without goat control (i.e. goats still present), as well as goat control to varying levels (e.g. low density, zero-density). If detailed information is collected for the various factors then their relative importance can be evaluated. Even so, it is the nature of ecological studies that we cannot always provide for adequate controls or replication. For example, at Flat-Top Hill in Central Otago, exotic plants increased in the four years after sheep and rabbit grazing stopped. However, during this same period, the rainfall in the growing season was higher and temperatures lower than usual. Therefore, the relative importance of weather and cessation of grazing could not be separated (Walker 2000). In some situations, time series studies can be used to address these difficulties.

5.3 CO-ORDINATED EXPERIMENTS

Ideally future studies will deliver generalisations across the broad spectrum of conservation land. This will be challenging given sites vary in pest animal density, presence of other pest animals, browsing pressure and duration, length of time since the animals were removed, and the type of impact wrought by the pest animal, e.g. browsing, trampling, seed predation or dispersal. Sites also vary with respect to vegetation, its composition and structure, available seed sources, and longevity of growth forms present as well as other environmental conditions. What is required is a co-ordinated suite of projects—this should be an essential part of the experimental design.

If future experimental studies substantiate the findings of this current largely anecdotal study, the next step could be an adaptive experimental management approach, i.e. monitoring the effectiveness of changes to management so that subsequent improvements to management can be made. This sort of experiment would be appropriate if DOC Conservancy and Area staff at one locality, or in different parts of the country, had different approaches to weed management in conjunction with pest animal control. An adaptive management project would test the efficacy of the different management approaches. A current DOC project ('Optimising possum control by adaptive management' S&R Investigation no. 2398) is doing this for possum and could provide a model for a future project to investigate appropriate weed management following pest animal control.

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Appendix 1

GLOSSARY OF EXOTIC PLANT COMMON AND SCIENTIFIC NAMES

COMMON NAME	SCIENTIFIC NAME
African feather grass	*Pennisetum macrourum*
African olive	*Olea africana*
Banana passionfruit	*Passiflora mollissima*
Barberry	*Berberis glaucocarpa*
Bone-seed	*Chrysanthemoides*
Boxthorn	*Lycium ferocissimum*
Buffalo grass	*Stenotaphrum secundatum*
Chinese privet	*Ligustrum sinense*
Darwin's barberry	*Berberis darwinii*
Elder	*Sambuscus nigra*
Gorse	*Ulex europaeus*
Purple guava	*Psidium cattleianum*
Hakea	*Hakea* spp.
Hawkweed	*Hieracium* spp.
Hawthorn	*Crataegus monogyna*
Kangaroo acacia	*Racosperma paradoxum*
Kikuyu grass	*Pennisetum clandestinum*
Larch	*Larix decidua*
Mexican daisy	*Egigeron karvinskianus*
Mile-a-minute vine	*Dipogon lignosus*
Mist flower	*Ageratina adenophora*
Mysore thorn	*Caesalpinia decapetala*
Pampas grass	*Cortaderia selloana*
Periwinkle	*Vinca major*
Pine	*Pinus* spp.
Privet	*Ligustrum* spp.
Rush	*Juncus* spp.
Spanish heath	*Erica luscitanica*
Spindle tree	*Euonymus europaeus*
Sweet brier	*Rosa rubiginosa*
Spruce	*Picea* spp.
Thyme	*Thymus vulgaris*
Wandering Jew	*Tradescantia flumensis*
Willow	*Salix* spp.
Woolly nightshade	*Solanum mauritianum*
Apricot	*Prunus armeniaca*
Black nightshade	*Solanum nigrum*
Blackberry	*Rubus fruticosus*
Boxthorn	*Lycium ferocissimum*
Broad-leaved dock	*Rumex obtusifolius*
Broom	*Cytisus scoparius*
Browntop	*Agrostis capillaris*
Buddleia	*Buddleja davidii*
Californian thistle	*Cirsium arvense*
Cocksfoot	*Dactylis glomerata*

Glossary (Continued from previous page)

COMMON NAME	SCIENTIFIC NAME
Douglas fir	*Pseudotsuga menziesii*
Elderberry	*Sambucus nigra*
Field hawkweed	*Hieracium murorum*
Floating sweetgrass	*Glyceria fluitans*
Gorse	*Ulex europaeus*
Grape	*Vitis vinifera*
Hawkweeds	*Hieracium* spp.
Hawthorn	*Crataegus monogyna*
Heather	*Calluna vulgaris*
Himalayan honeysuckle	*Leycestria formosa*
Hooked dock	*Rumex brownie*
Japanese honeysuckle	*Leycestria japonica*
Kangaroo acacia	*Acacia paradoxum*
King devil	*Hieracium praeltum*
Lotus	*Lotus pedunculatus*
Mercer grass	*Paspalum distichum*
Mouse-ear hawkweed	*Hieracium pilosella*
Orange hawkweed	*Hieracium aurantiacum*
Perennial ryegrass	*Lolium perenne*
Radiata pine	*Pinus radiate*
Ragwort	*Senecio jacobaea*
Scotch thistle	*Cirsium vulgare*
Scotts pine	*Pinus sylvestris*
Sheep's sorrel	*Rumex acetosella*
Slender birdsfoot trefoil	*Lotus augustissimus*
Small-flowered nightshade	*Solanum americanum*
St John's wort	*Hypericum perforatum*
Strawberry clover	*Trifolium fragiferum*
Sweet brier	*Rosa rubiginosa*
Sweet vernal	*Anthoxanthum odoratum*
Tall fescue	*Schedonorus phoenix*
Walnut	*Juglans regia*
Yorkshire fog	*Holcus lanatus*

Appendix 2

WEED TAXA RECORDED IN THE DIET OF INTRODUCED HERBIVORES

The percentage contribution of each weed to the animal's diet is given in brackets where it exceeds 1% of total volume. The author, study and location is also indicated (refer to the numbered references on next page).

WEED TAXA	ANIMALS RECORDED IN AND ABUNDANCE	REFERENCES
Apricot	possum	
Black nightshade	possum	10
Blackberry	fallow deer (*Cervus dama*), sambar deer (*Cervus unicolor*) (1.8), sheep, possum (1.8–10.9)	4, 5, 12, 15, 19, 21, 22, 25
Boxthorn	possum	5
Broad-leaved dock	possum	
Broom	sambar deer, possum (7.2, 17.3)	4, 15, 22, 25
Browntop	sheep, wallaby (3.2), possum (1.8, 1.2), rabbit (4.1)	4, 7, 9, 20
Californian thistle	possum (7.0)	4, 23
Cocksfoot	sheep, wallaby (6.7), possum (1.8–30.2)	4, 7, 18
Douglas fir	possum (2.3)	25
Elderberry	possum (9.3, 14.5)	4, 15
Field hawkweed	thar, chamois	
Floating sweetgrass	sambar deer (29.0)	8
Gorse	fallow deer, sambar deer, possum	3, 4, 5, 12, 15, 22, 25
Hawthorn	possum (1.16)	4
Heather	hare (*Lepus* spp.)	6
Hawkweed (murorum)	chamois	
Himalayan honeysuckle	fallow deer (4.1)	12
Hooked dock	goat	
King devil hawkweed	thar, chamois, sheep, possum (3.17)	Unpub. data, 7, 18
Lotus	goat (2.2, 2.9), fallow deer (3.6), sambar deer, wallaby, possum	3, 11, 12, 17, 22, 24
Mercer grass	wallaby	
Mouse-ear hawkweed	thar, chamois, sheep, possum	Unpub. data, 7
Orange hawkweed	white-tailed deer (*Odocoileus virginianus*)	
Perennial ryegrass	wallaby, possum (1.8–39.5)	4, 18
Radiata pine	wallaby, possum (24.4)	5, 24, 25
Ragwort	possum	14
Scotch thistle	goat (1.4, 1.8, 4.3), wallaby	2, 16, 17, 24, 26
Sheep's sorrel	possum, sheep, chamois	
Slender birdsfoot trefoil	wallaby	
Small-flowered nightshade	goat	
St John's wort	chamois	Unpub. data
Sweet brier	possum (17.3), hare, rabbit	1, 4, 20
Sweet vernal	wallaby (7.12), possum (0.24), rabbit (8.23)	4, 9, 20
Tall fescue	sambar deer (18.0)	8
Tuber ladder fern	goat	28
Variegated thistle	possum	4
Walnut	possum	

For details of numbered References to this table: See facing page >>

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