Assessing the response of forest understoreys to feral goat control with and without possum control

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ABSTRACT

Goats (*Capra hircus*) are a common wild ungulate in New Zealand, inhabiting about 11% of the land area. Much of this land is managed by the Department of Conservation. Outcome objectives for sustained goat control operations on conservation land should relate directly to ecosystem health, which is the overall conservation objective, rather than goat population levels. In this study we developed and tested new sampling methods to assess more directly the response of forest understoreys to reductions in feral goat populations. We also attempted to separate goat from possum (*Trichosurus vulpecula*) impacts. The study included the establishment and remeasurement (after goat culling operations) of 274 forest understorey plots (5 m × 5 m) across one South Island and two North Island areas. The methods were successful in recognising recovery from goat impact, and in demonstrating the variable effects of different goat population levels on different groups of plants. Improvements in understorey condition following possum control were negligible in the absence of effective goat control, and were difficult to disentangle from goat-control effects where goat numbers were reduced. Possum impacts on understoreys need further study. The data collected provided a range of variables and indices with which to analyse goat impacts on forest understoreys. The choice of which variable or index a manager might use in any situation depends on the detail of information required and the specific conservation objectives desired for an area of natural estate.

Keywords: animal control, forest understoreys, goats, *Capra hircus,* impacts, monitoring techniques, possums, *Trichosurus vulpecula*, New Zealand

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1. Introduction

Methods to assess the response of forest understoreys to reduction in feral goat (*Capra hircus*) populations were developed and tested, and the outcomes from a range of goat-hunting intensities and different combinations of goat and possum (*Trichosurus vulpecula*) control were measured between January 1993 and April 1998. The study included the establishment and remeasurement of 274 forest understorey plots in 10 blocks across three areas (two in the North Island, one in the South Island), to test the methods developed, and to measure changes in forest understorey condition following a range of goat and possum control operations undertaken by three Department of Conservation (DOC) conservancies. This report describes the outcomes of the animal control operations that were monitored, the methods developed and their utility in assessing goat and possum impacts on forest understoreys.

2. Background

Goats are generalist browsers of trees and shrubs (Rudge 1990) with strong dietary preferences (Mitchell et al. 1987). They affect forests by browsing forest understoreys and reducing or eliminating palatable species. These often include canopy species, so their reduction may affect canopy regeneration (Atkinson 1964; Mitchell et al. 1987; Parkes 1993; McKelvey 1995). Feral goats inhabit about 11% of New Zealand, with two-thirds of their range on land managed by DOC. Currently DOC spends $5–6 million annually on goat control, acting in about 135 areas covering 1.5 million ha (S. Kelton, pers. comm.). While eradication has been successfully achieved in some past operations (Parkes 1993), virtually all areas are now managed on a sustained-control basis.

The Department of Conservation's managers are required to set outcome objectives for sustained goat control operations. These may either relate directly to the condition of the vegetation browsed by goats, or be indirect measurements of the status of biota that are dependent on healthy forests. The monitoring of changes in forest condition in response to known levels of goat control, at least in some areas, is crucial to determining the levels of control necessary to achieve these stated objectives. However, at the start of this study in 1993, managers rarely judged the success or failure of goat control actions by measuring such objectives, despite the availability of a robust technique for detailed monitoring of vegetation change in forest (20 m × 20 m permanent plots, Allen 1993). This may, in part, be due to the resources required to undertake such detailed monitoring on large plots. This project was, therefore, initiated to develop new efficient methods to monitor goat impacts on forest understoreys, and to investigate the response of forest understoreys to goat control.

The Department of Conservation funds separate research projects on the impacts of feral goats and possums on forest habitats. It also controls these pest species in many forests but, again, action priorities have been set separately for each species. It seems sensible to integrate both the research and management of all forest herbivore pests to maximise benefits from limited animal control-budgets. To do this DOC needs to understand the tactical and strategic consequences of single- and multi-species control campaigns. The last aim of this project is to address this issue by comparing forest understorey changes following different combinations of goat and possum control.

3. Objectives

- To design and test methods to efficiently measure reductions in goat impact on forest understoreys as a result of goat control operations
- To investigate benefits to forest understoreys of a range of goat-hunting intensities
- To investigate the relative benefits to forest health of combinations of goat and possum control

4. Methods

4.1 STUDY SITES AND ANIMAL CONTROL

Three areas were investigated to address the three objectives of this study. In one area (Tawarau Forest) forest understorey responses to different intensities of goat control were measured. In a second (Waitaanga Forest), understorey responses to different combinations of possum and goat control were measured. Forest understorey changes following goat and possum control were also investigated at a single site at Nydia Saddle, to increase the range of goat-controlled sites covered by this investigation.

4.1.1 Tawarau Forest

The Tawarau area includes the Tawarau Forest, Taumatatotara Forest, and adjacent unnamed conservation lands in north-western King Country (38°21' S, 154°50' E). These forests are within the Waitomo Ecological District (McEwen 1987), a karst landscape dominated by limestone features (Williams 1990). Topography is generally lightly to moderately dissected hill country between 200 and 400 m a.s.l. Forests are of one broad forest association, generally dominated by tawa[1] with occasional emergent rimu and miro (Nicholls 1979a). Other common canopy species include kamahi, hinau, rewarewa, pigeonwood, mahoe, tawheowheo, and mangeao. Goats have probably been present at Tawarau Forest since at least the 1940s and were largely uncontrolled prior to 1980 (K. Broome, pers. comm.).

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[1] Scientific names for plants mentioned in the text are listed in Appendix 1.

The effect of different goat-hunting histories and intensities were studied at Tawarau. Five forested blocks were investigated. One block of 5600 ha had received long-term annual goat hunting (T(LTG)), from 1981. Another of 4600 ha had been goat-hunted annually (T(G1P)) from 1992 to 1996. A 1600-ha part of the T(G1P) block had received extra goat hunting (T(G2P)) in 1993 and 1995. Two blocks adjacent to the hunted blocks were selected to sample a c. 6500 ha forested area where no goat hunting had occurred (T(NC), T(P)). Six goat-exclosure plots were built along transects in each block except in block T(LTG), providing a goat eradication treatment T(EX). Although not part of the original study design, aerial-1080 operations to control possums were undertaken in all sampled areas apart from the T(NC) block during winter 1994.

Vegetation was assessed initially in January–February 1993 (except the T(NC) block established in November 1993). All plots were remeasured in November 1996.

4.1.2 Waitaanga Forest

The effect on forest understoreys of different combinations of possum and goat control was investigated at Waitaanga Forest (38°54' S, 174°55' E). Waitaanga Forest lies within the North Taranaki Ecological District. Forests within all selected blocks are tawa-rimu associations (Nicholls 1979b), with the canopy dominated by tawa. Kamahi, hinau, mahoe, maire, pigeonwood, and rewarewa are also common canopy and subcanopy components, with rimu and northern rata present as occasional emergents. The substrate is composed of heavily dissected conglomerates, siltstones, and sandstones (New Zealand Geological Survey 1972), and all vegetation plots were established at 400–600 m a.s.l.

The Waitaanga study involved four experimental blocks. One block received possum control (W(P)), and a second received goat control (W(G)). A third block received both goat and possum control (W(GP)), while the remaining block received no animal control (W(NC)). Vegetation plots were established during December 1993 – February 1994 (except block W(NC) established in January 1995) before animal control began. Aerial-1080 possum control was undertaken and annual goat hunting initiated during winter 1995. Vegetation plots were remeasured during December 1997 – January 1998 in all blocks.

4.1.3 Nydia Saddle

A single study site (N(GP)) was selected in seral vegetation at Nydia Saddle, Marlborough Sounds (41°08' S, 173°47' E). The vegetation at the site was composed of c. 100 ha of mahoe-dominated forest on talus and scree slopes surrounded by mixed red and hard beech/hardwood forest. Other common canopy species within the mahoe forest include pigeonwood, kamahi, broadleaf, kaikomako, heketara, and *Pittosporum* species. Greywacke and argillites are the dominant rock type in the area (New Zealand Geological Survey 1972). The site was part of 10 200 ha receiving annual goat control in 1994–98 and aerial possum control in winter 1994. Vegetation plots were established between 380 and 550 m a.s.l. in April 1994, before animal control commenced, and were remeasured in March 1998.

Browsing ungulates other than goats were absent from both Tawarau and Waitaanga (King 1990). Red deer (*Cervus elaphus*) were present in very low densities at Nydia Saddle where one deer was sighted but no adult-deer-sized faecal pellets were found during faecal-pellet searches (see Section 4.3.1). Deer were therefore thought to have had minimal impact on Nydia Saddle vegetation during the period of the study. Pigs (*Sus scrofa*) were present at low densities in all areas, and their effects were also likely to be minimal. A summary of the 11 treatments applied to the 10 study blocks within this study is presented in Table 1.

TABLE 1. ANIMAL CONTROL TREATMENTS AND THE NUMBER OF PERMANENT PLOTS (5 m × 5 m) MEASURED FOR EACH BLOCK AT THE THREE STUDY AREAS.

STUDY AREA	TREATMENT AND NUMBER OF PLOTS				
	NO CONTROL	GOAT CONTROL	POSSUM CONTROL	POSSUM AND GOAT CONTROL	GOAT EXCLOSURES
Tawarau	T(NC), 18		T(P), 18	T(LTG), 18 T(G1P), 18 T(G2P), 18	T(EX), 24
Waitaanga	W(NC), 32	W(G), 32	W(P), 32	W(GP), 32	
Nydia Saddle				N(GP), 32	

4.2 SAMPLING DESIGN

Forest understoreys are temporally and spatially variable (much more so than the canopy, Foré et al. 1997), responding to a matrix of resource gradients in light and soil nutrients. This makes it difficult to disentangle the effects of herbivores from other factors influencing plant population processes. However, a major component of this variation is explained by differences in light levels between treefall gaps and areas under tree canopies, particularly for shade-intolerant plant species (Whitmore 1989; Stewart et al. 1991; Defreitas & Enright 1995; Busing & White 1997; Valverde & Silvertown 1998). Goats also preferentially utilise gaps compared with areas under tree canopies (Rudge 1990). Therefore, we stratified our monitoring to sample both gaps and closed-canopy sites.

Vegetation plots were established along one or two permanently marked transects in each block in all three study areas. Two permanent plots (5 m × 5 m) were established wherever the transect encountered or passed near a treefall gap of 5 m × 5 m or larger. One plot was located in the centre of the treefall gap and the other under the forest canopy 20 m away. They were laid out using a compass and measuring tapes with the plot sides aligned with the four major compass directions. Plot corners were marked permanently with permolat on aluminium pegs. Between 18 and 32 plots were established in each treatment block (Table 1).

There was limited replication within this study. There was at least one goat-and-possum-control treatment in all three areas but the other treatments were restricted to one or two of the study areas (Table 1). The experimental designs at Tawarau (range of goat hunting intensities) and Waitaanga (different combinations of animal control) were not replicated. This means that effects of management operations on forest understoreys are confounded with other sources of variation. Therefore, the results of this study are directly applicable only to the study areas, with only general inferences able to be made about other areas.

4.3 OUTCOMES OF ANIMAL CONTROL

4.3.1 Animal abundance assessment

Permanent plots were divided into four quadrants (2.5 m × 2.5 m), each with their centre permanently marked with an aluminium peg. Relative goat and possum densities in each block were measured by recording the presence or absence of possum and goat faecal pellets within 1.14 m of each centre peg (Baddeley 1985) during vegetation plot measurement. This gave a total of 72–96 (Tawarau Forest) or 128 (Nydia Saddle) counts in each block from which goat and possum faecal-pellet frequency (percentage of 1.14-m radius plots on which faecal pellets were present) was calculated. At Waitaanga Forest additional pellet counts were made on 32 10-plot lines that ran north and south from even-numbered gap plots and odd-numbered canopy plots in each treatment block. These additional counts boosted the total number of pellet counts to 448 plots per block at Waitaanga.

In addition to the faecal-pellet counts, data from DOC goat hunting in and around the study areas were collated, to quantify total hunting effort (days hunting) and to calculate mean kill rates (goats killed per day hunted) as another index of goat density.

4.3.2 Understorey responses to animal control

Responses to animal control were monitored using seedling counts in all blocks. Within each quadrant, on 5 m × 5 m plots, all woody saplings, tree ferns, supplejack stems, and hen and chicken ferns in the 'browse tier' (0.3–2.0 m) were counted by species. Heights were measured to the top of trunks for tree-ferns, to the tip of the tallest stem for saplings, and to the top of the tallest frond for ground ferns. The presence and identity of other non-woody species was also recorded within this 'browse' tier.

Quadrant centre pegs were used as the centre of a circular 'ground tier' subplot of 49 cm radius (area = 0.75 m^2). All woody seedlings, tree ferns, and hen and chicken ferns less than 30 cm tall were counted by species and the presence of other non-woody species recorded.

The establishment of plots provides the opportunity to collect additional information that can aid interpretation of results and a general understanding of local forest processes. Such data include site information, forest tier cover scores, and tree diameters (Allen 1992, 1993). These data will allow further analysis in RECCE format (Hall 1992) and, although collected during this study, are not presented here.

All plant species were assigned to height, 'woodiness', and goat preference classes so that plants with similar characteristics could be grouped for further analysis. Plants were classed as tall (species that, in the absence of ungulates, usually attain a standing height of > 30 cm) or short, herbs (ferns, herbaceous dicotyledons, and all monocotyledons except supplejack) or woody species (all other vascular species), and were divided into three preference classes (low, moderate and high) based on published data on diet and dietary preferences for goats (Atkinson 1964; Mitchell et al. 1987; Parkes 1993) and deer (Nugent & Challies 1988; Nugent 1990; Nugent et al. 1997). For species with few published data on palatability to ungulates, preference class was determined by comparing their browse indices (see below) with species of similar habit for which there were published data (Appendix 2). Possum preference classes, where known (Fitzgerald 1976; Coleman et al. 1985; Nugent et al. 1997), are also listed in Appendix 2.

An interim analysis (Burns et al. 1995) indicated that between-plot variation in seedling numbers in the ground tier (seedlings < 0.3 m) with and without goats present was so high that it was not useful for assessing goat impact. Therefore, we limited our analyses of seedling counts to the browse tier (0.3–2.0 m). Repeated-measures analysis of variance was used to compare the mean changes in total seedling numbers and seedling numbers in high, moderate, and low goat-preference species in the browse tier between treatments, to test for differences in the understorey response to the different management regimes. Separate analyses of possum-palatable plant groups were not undertaken because of considerable overlap between goat- and possum-preferred species (Appendix 2).

4.4 COMPARING ASSESSMENT TECHNIQUES

A number of additional parameters were recorded in some or all study blocks, or derived from seedling count data, to compare the efficacy of seedling counts and pellet frequencies with other measures of goat abundance and impacts.

4.4.1 Browse indices

The percentages of shoots (woody species), fronds (ferns), or leaf blades (grasses and other monocotyledons with grass-like leaves) that had been browsed by ungulates were assessed for each species with foliage in the browse tier on all permanent plots, using a 5-point scale (Appendix 3). These browse scores were recorded during initial and final vegetation measurements at Waitaanga and Nydia Saddle, but only during the final vegetation measurement at Tawarau.

A browse index (BI) was calculated for individual and groups of species by determining the mean of individual species browse-scores across a group of plots. This provides an index of browsing pressure on individual or groups of species in relation to their availability (Rose & Burrows 1985). A detailed description of browse assessment and index calculation is given in Appendix 3.

4.4.2 Seedling height growth rates

At Tawarau and Waitaanga, high goat-preference seedlings 0.1–2.0 m tall within each plot were measured for height and then tagged using numbered aluminium labels attached with wire loops. Their distances and directions within plot quadrants relative to the centre pegs were recorded to aid re-location. Seedlings were initially measured for standing height in 1994 at Tawarau (389 seedlings) and in 1994 and 1995 at Waitaanga (624 seedlings). They were then remeasured in 1996 at Tawarau and 1998 at Waitaanga.

4.4.3 Seedling ratios

Seedling ratio methods were adapted from Wardle et al.'s (1971) susceptibility ratings, and provide a measure of the ability of a species to regenerate under present and recent-past browsing pressure. They can be derived from seedling count data or simple vegetation plots where only the presence or absence of target species are recorded in the ground and browse tiers. They therefore potentially provide a simple and quick alternative to seedling-count/plot methods for assessing herbivore impacts on forest understoreys. In this study, seedling ratios were derived from the seedling count data on plots of 5 m × 5 m. They were calculated by dividing the number of occurrences of tall species in the ground-tier plots by their number of occurrences in browse-tier plots. Seedling ratios were calculated for individual species and for the three goat-preference classes. Where no target species were encountered in the browse tier on all plots in one block, seedling ratios were taken as the total number of encounters in the ground tier.

Seedling ratios assume that frequencies of occurrence of species in the ground tier are largely unaffected by herbivores. This assumption is tested by regressing the mean number of species found in the ground tier of the permanent plots for each block against block goat-faecal-pellet frequencies. This result was compared with that for browse-tier vegetation. Ratios of about or below 1.0 are indicative of low browser impacts and rise above 1.0 as impacts increase.

4.4.4 Utility of assessment techniques

Block means for browse-tier seedling counts, seedling ratios, and browse indices were calculated for a range of species groups for initial and final vegetation measurements at Waitaanga and Nydia Saddle, but only during the final vegetation measurement at Tawarau (N = 17 block measurements). Vegetation assessments at Tawarau in 1993 and 1994 were excluded because of insufficient time for the vegetation to adjust to goat hunting, which commenced in 1992. Simple linear regression was used to describe and compare the relationships between block means for these assessment techniques and goat abundance (pellet frequencies). Data was often ln- or square-root-transformed to provide the best straight line fit. Because of possible correlation between initial and final measures on the same plots, regression P-values may overstate the significance of any relationships.

4.4.5 Efficiency of assessment techniques

To compare the efficiency of the assessment techniques trialed during the study, the sample size required to produce an estimate of the population mean with a standard error of 10% of the mean was calculated from data collected during the study. Data from pre-hunting vegetation and animal abundance assessments at Waitaanga were aggregated into groups of 10 adjacent plots to simulate a likely sampling strategy of randomly located 10-plot transects, and variances were calculated from group means. Sample sizes were then derived from these variances. Total time resources (hours) required to attain this level of precision was then calculated by multiplying this sample size by the mean time to measure one sampling unit. Direct time measurements were recorded at Tawarau for measuring seedling counts for all species, and for high preference species only, in the ground and browse tiers on 25-m^2 plots (N = 81), and for scoring browse in both tiers on 25-m^2 plots (N = 54) at Waitaanga. Based on extensive field experience (P.J.S) an estimate of 1 min per 1.14-m radius plot was used to calculate pellet-count transect times. Other plot times were estimated by scaling down these measured times by the relative area, number of tiers, and number of species targetted. Total time required to complete the whole survey for each technique was also estimated by assuming an average time of 1 min to travel between plots on a transect, and 1 h to travel to and between transects, with 8 h total field time per day. Time estimates are for one observer working alone.

Efficiency of using small plots (6.25 m^2), compared with large plots (25 m^2), for various assessment techniques was assessed by calculating means from the north-western quadrant of each plot (5 m × 5 m) to simulate measurement of small plots, and using data from whole plots for large plots. The presence or absence of species occurring in the ground tier on these plots was measured on one 0.49-m-radius subplot on small plots and four 0.49-m-radius subplots on large plots.

5. Results

5.1 OUTCOMES OF ANIMAL CONTROL

5.1.1 Animal abundance

Goat and possum faecal-pellet frequencies at Tawarau and Nydia Saddle confirm that animal control reduced goat and possum population sizes in all controlled blocks in those two areas, and the exclosures effectively excluded goats (Table 2). Relatively low pellet frequencies in all hunted blocks at Tawarau in 1993 suggest that goat hunting had already reduced goat densities before the initial vegetation assessment. Goat hunting once a year (T(G1P) block) was sufficient to reduce goat densities to very low levels within 2 years, therefore the extra hunting (T(G2P) block) was not necessary. These two blocks, therefore, effectively received the same treatment.

Goat-pellet frequencies after control remained similar to those before control at Waitaanga with the exception that they increased threefold during the study in the no-control block (W(NC)) (Table 2).

No clear pattern between goat-hunting effort and reduction in goat densities was apparent within the three study areas (Tables 2 and 3). Less than one hunting day per 100 ha per year was sufficient to reduce goat kill rates to one per day over 4 years at Nydia Saddle, while a mean of 1.5 hunted days per 100 ha per year over 3 years had little impact on goat densities at Waitaanga. Higher hunting intensities (2.0–4.7 d/100 ha) were used at Tawarau, and resulted in very low goat densities in all hunted blocks there.

Possum-pellet frequencies declined in all blocks where possums were controlled (Table 2). As these data were collected 2–3 years after possum control, the initial possum population reduction would have been greater than indicated in Table 2. Possum kill at Waitaanga in 1995 was estimated at 93% from leghold trap-catch data (L. Stanley, pers. comm.).

TABLE 2. GOAT AND POSSUM FAECAL-PELLET FREQUENCIES (% OF 1.14-m RADIUS SEARCHES) IN DIFFERENT SAMPLING BLOCKS AT (A) TAWARAU FOREST, (B) NYDIA SADDLE, AND (C) WAITAANGA FOREST.

Note: Data for Waitaanga Forest are from 448 searches on plots of 5 m × 5 m and additional pellet-count lines combined, while all other data are from searches on plots only.

A. TAWARAU FOREST

BLOCK	GOAT			POSSUM		
	1993	1994	1996	1993	1994	1996
T(P)	15.3	6.9	16.7	30.6	6.9	2.8
T(NC)	40.3	19.4	30.6	50	41.7	51.3
T(G1P)	15.3	1.4	0	40.3	15.3	2.8
T(G2P)	2.8	1.4	0	38.8	19.4	11.1
T(LTG)	9.7	0	0	54.2	37.5	15.3
T(EX)	20.8	0	0	40.2	26.8	20.8

B. NYDIA SADDLE

BLOCK	GOAT		POSSUM	
	1994	1998	1994	1998
N(GP)	42.2	3.1	35.9	10.2

C. WAITAANGA FOREST

BLOCK	GOAT		POSSUM	
	1993/94	1997/98	1993/94	1997/98
W(P)	27.9	34.2	72.0	20.4
W(GP)	21.1	15	68.0	25.6
W(G)	13.3	17.6	70.5	55.6
W(NC)	4.7	18.3	69.4	55.0

5.1.2 Understorey response to animal control

Tawarau Forest and Nydia Saddle: Changes in seedling counts were analysed with blocks as treatments except for the T(G1P) and T(G2P) blocks, which were combined into one goat and possum control block (T(GP) because goat and possum population densities were similar in these two blocks during the study.

Total, high-preference, and moderate-preference seedling densities in the browse tier differed between initial and final vegetation measurements but low-preference seedling densities remained constant (Table 4). Goat-palatable (high- and moderate-preference) seedling counts also differed significantly

TABLE 3. GOAT KILL RATES (NUMBER OF GOATS KILLED PER DAY SPENT HUNTING) AND MEAN ANNUAL HUNTING EFFORT FOR THE THREE STUDY AREAS.
Note: numbers in brackets are total days hunted. Data for Waitaanga are for both goat-hunted blocks combined. Data for the T(G1P) (goat hunted once annually) block at Tawarau are for hunting in that block and the initial hunting in the T(G2P) (extra hunting) block combined, while kill data for the T(G2P) block are for the extra hunting only, but the mean effort data given are for total annual effort for each block for years that hunting was undertaken. T(LTG) = long-term goat hunting block.

TIME PERIOD	TAWARAU FOREST			WAITAANGA FOREST	NYDIA SADDLE
	T(LTG)	T(GIP)	T(G2P)	W(G), W(GP)	N(GP)
1992/93	1.8	7.5			
1993/94	1.1	5.0	1.0		
1994/95	0.7	2.5			2.6
1995/96	0.7	1.72	0.0	5.2 (64)	2.4
1996/97				7.6 (21)	1.3
1997/98				3.8 (112)	1.0
MEAN 1995–98				4.4 (67)	
MEAN EFFORT (DAYS/100 ha/YEAR	2.0	3.2	4.7	1.5	0.9

TABLE 4. PROBABILITIES OF SIGNIFICANT DIFFERENCES BETWEEN DIFFERENT SOURCES OF VARIATION IDENTIFIED FROM REPEATED-MEASURES ANALYSIS OF VARIANCE OF BROWSE-TIER SEEDLING COUNTS AT TAWARAU FOREST AND NYDIA SADDLE.
Note: GC = comparisons between canopy and gap plots, Hunt = comparisons between animal control treatments, Time = changes between initial and final measurements.

SOURCE OF VARIATION	TOTAL SEEDLINGS	SEEDLINGS OF DIFFERENT GOAT-PREFERENCE CLASS		
		HIGH	MODERATE	LOW
Between factor levels				
GC	0.011	0.070	< 0.001	0.876
Hunt	< 0.001	0.002	< 0.001	0.920
GC × Hunt	0.818	0.807	0.061	0.909
Between repeated measurements				
Time	< 0.001	0.006	< 0.001	0.335
Time × GC	0.001	0.001	< 0.001	0.917
Time × Hunt	0.004	0.019	< 0.001	0.864
Time × GC × Hunt	0.097	0.053	0.061	0.912

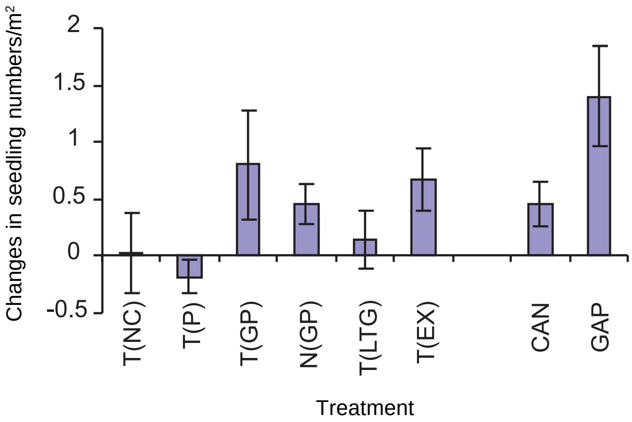


Figure 1. Changes in numbers of high- and moderate- goat-preference seedlings per square metre (± 95% C.I.) between initial and final measurements on plots subject to no control (T(NC)), possum control (T(P)), goat and possum control at Tawarau (H(GP)) and Nydia Saddle (N(GP)), exclosures (T(EX)), and long-term goat hunting (T(LTG)). GAP = all gap plots and CAN = all canopy plots in goat-controlled treatments. Means where 95% confidence intervals (error bars) do not overlap are significantly different.

between gap and canopy plots, and between hunting treatments (Table 4, Fig. 1). For high- and moderate-preference species, densities increased markedly in all short-term goat-hunted blocks and on exclosure plots, remained unchanged in the long-term goat-hunted (T(LTG)) and no control (T(NC)) blocks and de-creased in the possum only control block (Fig. 1). Seedling count changes were greater on gaps than canopy plots (Fig.1).

Waitaanga Forest: The animal abundance data suggest that while possum numbers were reduced where poisoned, goat hunting failed to reduce goat numbers at Waitaanga. Seedling densities also remained largely unchanged during the study. Although there was a small decrease in the density of high-preference species (0.052 ± 0.034 C.I. seedlings per square metre) between vegetation measurements, no significant changes for high- or moderate-preference species were recorded between treatments or between canopy and gap plots (Table 5). Only low-preference species differed significantly between different combinations of animal control, with seedling densities increasing in the possum-control block and decreasing in the no-animal-control block (Fig. 2).

5.2 COMPARING UNDERSTOREY ASSESSMENT TECHNIQUES

5.2.1 Utility of assessment techniques

Browse indices: Browse indices appeared to be good predictors of relative goat abundance (pellet frequency). Of several species groups tested, the browse index for all goat-palatable herbs (high- and moderate-goat-preference

TABLE 5. PROBABILITIES OF SIGNIFICANT DIFFERENCES BETWEEN DIFFERENT SOURCES OF VARIATION IDENTIFIED FROM REPEATED MEASURES ANALYSIS OF VARIANCE OF BROWSE-TIER SEEDLING COUNTS AT WAITAANGA.

Note: GC = comparisons between canopy and gap plots, Hunt = comparisons between animal control treatments, Time = changes between initial and final measurements.

SOURCE OF VARIATION	TOTAL SEEDLINGS	SEEDLINGS OF DIFFERENT GOAT-PREFERENCE CLASS		
		HIGH	MODERATE	LOW
Between factor levels				
GC	< 0.001	0.074	< 0.001	0.746
Hunt	0.03	0.112	0.368	0.042
GC × Hunt	0.809	0.515	0.349	0.571
Between repeated measurements				
Time	0.465	0.006	0.309	0.787
Time × GC	0.07	0.122	0.411	0.347
Time × Hunt	0.002	0.126	0.196	0.001
Time × GC × Hunt	0.208	0.118	0.247	0.952

species combined) provided the best index of goat abundance, explaining 88% of the variation in pellet frequency (Table 6; Fig. 3). The browse index for all palatable plants was close behind, explaining 80% of between-block variation in pellet frequencies (Table 6). Rates of browse on woody species were generally less useful for predicting goat abundance than browse on herbaceous species or all plant types combined (Table 6).

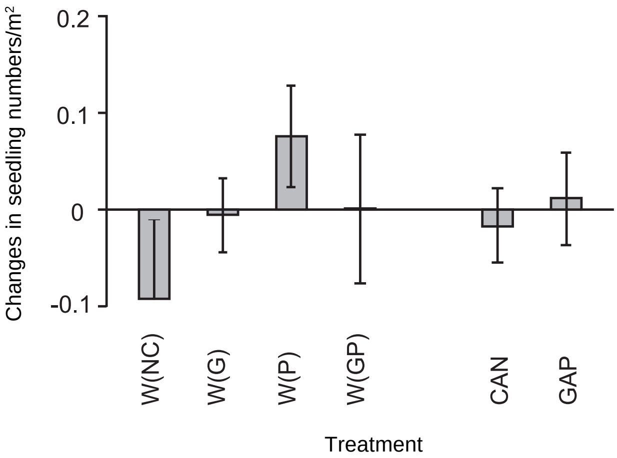


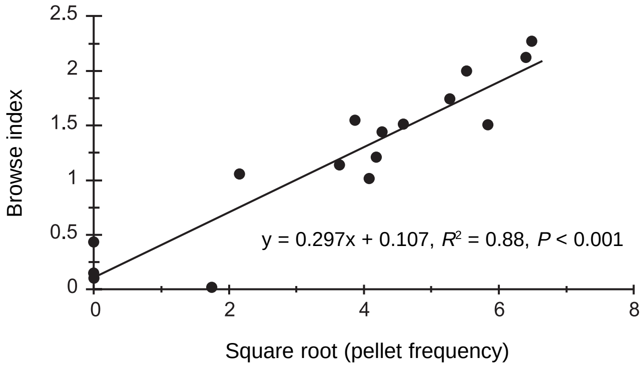
Figure 2. Changes in numbers of low-goat-preference woody seedlings per square metre (± 95% C.I.) between initial and final measurement on plots at Waitaanga subject to no animal control (W(NC)), possum control (W(P)), goat and possum control (W(GP)), and goat control (W(G)). GAP = all gap plots and CAN = all canopy plots. Means where 95% confidence intervals (error bars) do not overlap are significantly different.

Low levels of goat browse (browse indices of 0.1–0.3) were recorded in all blocks with low goat densities, including within exclosure plots 4 years after they were established. This indicated that some non-goat-induced damage to plants was consistently scored as goat browse. Browse indices ranged from 0.5–2.6 in blocks where goats were not hunted.

TABLE 6. COEFFICIENT OF VARIATION (R^2) VALUES FOR LINEAR REGRESSIONS BETWEEN BROWSE INDICES FOR A RANGE OF PLANT TYPES AND GOAT DENSITIES (SQUARE ROOT(PELLET FREQUENCIES)).

PREFERENCE CLASS	PLANT TYPE		
	ALL	WOODY	HERBACEOUS
High	0.84	0.54	0.85
Moderate	0.69	0.49	0.79
High+moderate	0.80	0.54	0.88
Low	0.51	0.57	0.50
All	0.73	0.57	0.77

Figure 3. Browse index for all goat-palatable herbs versus goat pellet frequency in different treatment blocks across the three study areas. The regression function and statistics are given.



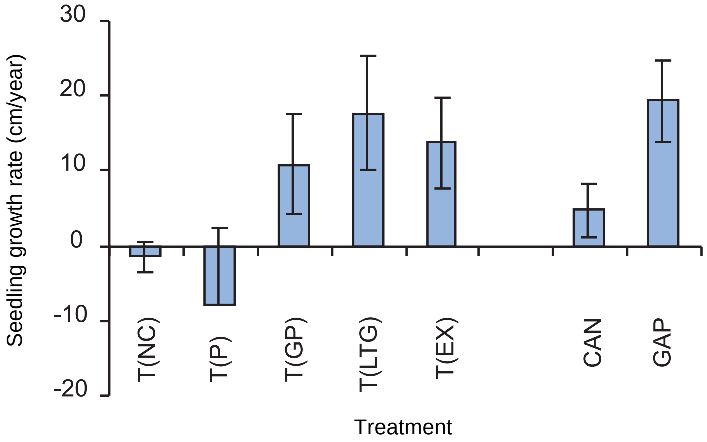


Figure 4. High-goat-preference-seedling height growth rate (cm/yr) at Tawarau for plots subject to no animal control (T(NC)), possum control (T(P)), goat and possum control (T(GP)), long-term goat hunting (T(LTG)) and exclosures (T(EX)). GAP = all gap plots and CAN = all canopy plots in goat-controlled treatments. Means where 95% confidence intervals (error bars) do not overlap are significantly different.

Seedling-height growth rates: Positive height growth of high-goat-preference seedlings was recorded during the study at Tawarau on goat-hunted, exclosure, and long-term-hunted plots, but no seedling height growth was observed within non-goat-hunted blocks (Fig. 4). Growth rate of seedlings on canopy plots was lower than on gap plots where goat numbers were reduced (Fig. 4). These results are similar to those for seedling counts (Fig. 1) with the exception that growth rates in the T(LTG) block were positive while seedling counts remained unchanged there.

Mean height of tagged high-goat-preference seedlings at Waitaanga either remained unchanged or declined in all blocks during the study.

Seedling ratios: Mean number of species per plot in the ground-tier vegetation on plots of 5 m × 5 m was unrelated to goat faecal-pellet frequency ($R^2 = 0.03$, $P > 0.05$) while mean number of species in the browse tier was strongly correlated with pellet frequency ($R^2 = 0.77$, $P < 0.001$). This confirms that frequencies of occurrence of species in the ground tier are unaffected by goat browsing while those in the browse tier are and, therefore, that seedling ratios potentially provide a meaningful measure of goat impact on browse-tier vegetation.

Seedling ratios for low-, moderate- and high-goat-preference plants were all significantly correlated with pellet frequency (Fig. 5). They indicate that moderate- and high-preference species were adversely affected by the presence of goats with seedling ratios rising from c. 1 (little goat impact) when pellet frequency was low to c. 2–3 (high goat impact) when pellet frequency was high. Over the same range of goat abundance, seedling ratios for low-preference species remained close to 1, indicating they were little affected by the presence of goats. Seedling ratios for all goat-palatable (moderate and high preference) species were more closely correlated to pellet frequency (ln(seedling ratio) = 0.022(pellet frequency) – 0.06; $R^2 = 0.78$, $P < 0.001$) than were any of the three individual species groups in Fig. 5. The contrast in response to increasing goat abundance of seedling ratios for low palatable species and for all palatable species is consistent with patterns of seedling numbers recorded during the study (palatable species responded to effective goat hunting while low-preference species did not). The validity of using a value of 1.0 as a low-impact baseline seedling ratio for palatable species is supported by these results.

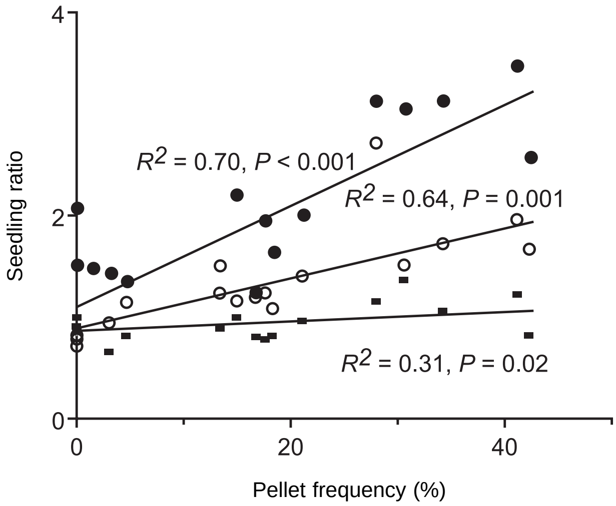


Figure 5. The relationship between seedling ratios and goat pellet frequency for tall species of high (solid circles), moderate (open circles), and low (squares) goat preference, in different treatment blocks across the three study areas. Regression statistics for each group are given.

Seedling counts:

Although densities of goat-palatable seedlings changed significantly in response to reductions in goat numbers (Section 5.1.2), large variances in seedling densities between blocks with similar pellet frequencies meant that seedling densities were not as closely correlated to pellet frequency, as were seedling ratios. Pellet frequencies explained only 38% of the observed variation in densities of goat-palatable seedlings during the study (Fig. 6).

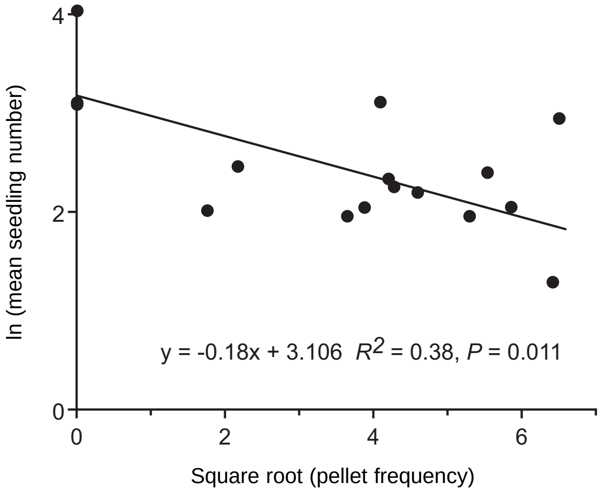


Figure 6. The relationship between the mean number of goat-palatable seedlings and goat pellet frequency, in the browse tier in different treatment blocks across the three study areas. The regression function and statistics are given.

5.2.2 Efficiency of assessment techniques

The number of 10-plot transects required to obtain standard errors of the mean that were equal to 10% of the mean, and the total on-plot time to measure those plots, for a range of assessment techniques are given in Table 7. Counting

TABLE 7. NUMBER OF 10-PLOT TRANSECTS AND TOTAL TIME REQUIRED TO OBTAIN STANDARD ERRORS THAT WERE WITHIN 10% OF THE MEAN FOR A RANGE OF ASSESSMENT TECHNIQUES.

Estimates of the time to measure a single plot, total on-plot time, and total time including time to travel to and between transects are also given. Number-of-transect estimates include plots for which target species were absent. Large plots are 25 m^2 and small plots are 6.25 m^2. All data are from Waitaanga Forest before hunting was initiated.

PLOT TYPE	NUMBER OF TRANSECTS	TIME/PLOT (min)	TOTAL ON-PLOT TIME (h)	TOTAL TIME (h)
Browse indices				
All palatable herbs (large plots)	9	5	7.5	21
All palatable herbs (small plots)	19	2	6.3	33
High-preference herbs (large plots)	11	5	9.2	25
High-preference herbs (small plots)	22	2	7.3	40
Goat pellet frequency (4.08-m^2 plots)	30	1	5	46
Seedling ratios				
All palatable species (large plots)	11	11	20.2	38
All palatable species (small plots)	12	3	6	23
High-preference species (large plots)	16	5.5	14.7	38
High-preference species (small plots)	18	2	6	31
Browse tier seedling counts				
All palatable species (large plots)	29	16	77.3	127
All palatable species (small plots)	43	3	12.5	82
High-preference species (large plots)	100	10.5	175	334
High-preference species (small plots)	229	2	76.3	393

seedlings in both the ground- and browse-tiers on plots (5 m × 5 m) took a mean of 41 ± 2.9 (95% CI) min for all species and 11 ± 1.1 min for just high-goat-preference species. Scoring browse on all species in both tiers took 18.9 ± 1.7 min. All other vegetation-plot-assessment times were derived from these baseline times.

Recording browse on large plots was an efficient means of gathering data on goat abundance with only 7.5–9.2 h of on-plot time, and 21–25 h of total survey time required to obtain estimates with standard errors of 10% of the mean for a range of browse indices. Approximately twice as many transects were required to measure browse on small plots to the same level of precision as for large plots, resulting in total time estimates for small plots being about 60% greater than for large plots.

Broadly similar on-plot times were required to measure goat faecal-pellet frequencies and seedling ratios on small plots as for browse indices (5–9 h), but the larger number of transects needed to measure pellet frequencies means that a greater total time commitment would be necessary to measure them compared with seedling ratios and browse indices. Seedling ratios on large plots took about three times longer to measure than on small plots, although a similar number of transects were required for both plot sizes. Therefore, measuring seedling ratios on small plots is likely to be more efficient than measuring them on large plots (Table 7).

The large variance in the number of browse-tier seedlings on plots meant that large numbers of transects needed to be measured to reduce the standard error to 10% of the mean, particularly for high-preference species. Consequently, the times required to measure them were greater than for other assessment techniques. Counting seedlings on small plots required substantially less time than counts on large plots for all species and all palatable species (Table 7).

6. Conclusions

6.1 OUTCOMES OF ANIMAL CONTROL

6.1.1 Goat control

Reduction in goat numbers at Tawarau and Nydia Saddle resulted in significant changes to understorey conditions that reflect goat impacts. Densities of goat-palatable seedlings increased in those areas where goat numbers were substantially reduced but not where goat numbers remained stable. This result was replicated in four blocks/two areas for sites where goat numbers were reduced during the study, and in five blocks/two areas for sites where goat numbers were not reduced. Therefore, we can confidently predict that goat-palatable seedling densities will increase across a wide range of sites when goat densities are reduced from high to low levels. These responses to goat removal are likely to be greater, or at least occur more rapidly, in canopy gaps than under intact canopies, reflecting enhanced potential for seedling establishment or growth within the high-light environment of gaps.

In the block where goats had been maintained at low levels for 10 years (T(LTG)) prior to this study, seedling counts remained static during the study, but growth rates for goat-palatable species were positive. This suggests that net seedling recruitment in response to goat control in this area had stabilised by the start of this study, perhaps due to light levels becoming limiting for small seedlings, but that goat impacts remained low, allowing positive growth of the seedlings already established. This conclusion is supported by a seedling ratio value of 0.84 for goat-palatable species in the T(LTG) block at the end of the study (i.e. below 1.0, the level at which this study indicates goat impacts are negligible). Mean growth rates were below 20 cm per year in all blocks, which suggests that sustained goat control for at least a decade may be necessary to allow a cohort of goat-palatable seedlings to establish and attain sizes where they are no longer threatened by goat browsing.

We were unable to determine definitive levels of hunting effort required to permit substantial understorey recovery, because of variation in the hunting data. As little as 1 hunting day per 100 ha per year can substantially reduce goat populations in at least some areas (e.g. Nydia Saddle), but more intensive hunting may be required if high-density goat populations are to be reduced rapidly. Additional hunting above 3 hunting days per 100 ha per year may not be very productive as very few goats were killed during the extra hunting efforts applied to the T(G2P) block at Tawarau.

The goat-kill, browse, and faecal-pellet data do suggest that substantial understorey recovery is achieved by reducing goats to levels where kill rates are about or below one per day, browsed indices are below c. 0.4, or pellet frequencies are below c. 4%.

Interpretation of the recovery of seedling populations following reduction of goat numbers in this study is confounded by the fact that in all study sites where goat populations were reduced, possums were also controlled. We conclude that understorey recovery was largely a result of reductions in goat rather than possum numbers because (1) forest understoreys showed no recovery in the two blocks where possum numbers were reduced in the absence of goat control, (2) seedling counts and seedling ratios remained largely unchanged in the T(LTG) block at Tawarau despite goat populations remaining low and possum control being conducted during the study, and (3) the dramatic recovery of seedling populations that is often seen inside exclosures that exclude ungulates but not possums (e.g. Allen et al. 1984).

6.1.2 Possum control

Despite reductions in possum abundance, and some improvement in foliage cover indices in possum-preferred trees at Waitaanga (P. Sweetapple, unpubl. data), there was no consistent recovery of forest understoreys in this study attributable to possum control. Although significant increases in low-goat-preference seedling densities were recorded in the possum control block at Waitaanga, there were no similar significant improvements in forest understoreys in either the goat- and possum-control block at Waitaanga or the possum-control block at Tawarau, both of which also had static goat densities and reduced possum densities during the study (Table 1). The failure of goat hunting to reduce goat densities at Waitaanga reduced our ability to fully determine the impact of possums on understoreys. Any potential benefits to understoreys of possum control may have been masked by heavy goat impacts at those sites where possums were controlled. We conclude that forest understoreys do not benefit from possum control in the presence of uncontrolled goat (and, probably, other ungulate) populations.

The lack of demonstrable benefits to forest understoreys following possum control in this study is supported by the findings of Nugent et al. (1997) who found, with the exception of haumakaroa, that possums had no measurable impact on forest floor seedlings; although, again, the presence of ruminants (in this case deer) may have masked possum impacts on seedling populations. Conversely, recent work at Pureora demonstrates that fuchsia and wineberry will regenerate on some disturbed sites when possums are reduced to very low densities, but only those from which deer are excluded, such as raised root plates, or within inpenetrable windfall debris (P. Sweetapple, unpubl. data). The benefits to forest understoreys of possum control in conjunction with ruminant control requires further investigation.

If possum control does not greatly benefit forest understoreys, then the short-term management of possums and ungulates, and the benefits of management operations against these pests, can be considered independently. However, regardless of the impact of possums on forest understoreys, the long-term maintenance of forest structures will require a combination of pest control aimed at possums, to prevent continued decline of existing possum-preferred canopies (see Payton (2000) for a review), and forest ruminants, to ensure sufficient regeneration of canopy species. Therefore, the long-term management of indigenous forest will require the integration of possum- and ruminant-control strategies. Such integration will improve outcomes of pest control (Parkes 1996).

6.2 FOREST UNDERSTOREY ASSESSMENT TECHNIQUES

6.2.1 Sampling strategies

The methods developed in this study were based on (1) collecting data on small (5 m × 5 m) rather than large (20 m × 20 m) plots; (2) stratifying plots to account for a major factor in variation of understorey plant composition and abundance (i.e. intact canopies v. canopy gaps); and (3) considering results for only a subset of the species present in plots, e.g. considering only the browse tier or considering only goat-palatable species. These design features have been successful in recognising recovery from goat impact and in demonstrating the variable effects of different goat-population levels on different groups of plants, and variable plant responses in different micro-sites.

The advantages of using these smaller permanent plots are that, for the same effort applied to larger plots (approximately one day is required for two people to measure a plot of 20 m × 20 m including travel; L. Burrows pers. comm.), a greater geographic spread of sampling will be achieved, and plots are more likely to fit within homogeneous patches within the forest mosaic, particularly canopy gaps. Our data also indicate that seedling counts and seedling ratios are more efficiently measured on very small (2.5 m × 2.5 m) rather than (5 m × 5 m) plots. The greater response to goat control of seedlings in gap plots demonstrates that the strategy of stratifying sampling between gaps and canopies could be useful for reducing residual variation between sampling points. A disadvantage of this approach is that gaps are relatively short-lived features, necessitating periodic selection of new sample plots, and that the subjective sampling required to target gaps may bias interpretation of overall forest change.

Increases in seedling density were predominantly of high- and moderate-goat preference species, while low-preference species were little affected by the goat control operations, indicating that uncontrolled goat populations have little impact on the latter. Therefore, monitoring just goat-palatable species in the browse tier will be a more cost-effective means of measuring changes in goat impacts than monitoring all or low-preference species, at least in the short to medium term. There may be some value in monitoring low-goat-preference species in the long term as these are likely to slowly change in abundance or distribution due to changes in competition from other species where there are long-term changes in goat browsing pressure.

6.2.2 Browse indices

Browse indices for goat-palatable plants and goat faecal-pellet frequency are indices of goat activity, or relative abundance, which are strongly correlated. As pellet frequency is an accepted measure of animal abundance (Baddeley 1985), these browse indices can also be used to confidently measure relative goat densities, at least over the range of goat densities observed in this study.

Browse indices have several measured or potential advantages over pellet counts. The accuracy of pellet counts is compromised by temporal variations in pellet recruitment rates (Nugent et al. 1997) and observer bias (W. Fraser pers. comm.), which could be major contributors to the discrepancies observed between browse indices and pellet frequencies in this study. Browse indices may be subject to smaller observer biases because seedlings taller than 30 cm are easier to locate on plots than goat faecal pellets, particularly in deep litter or heavily vegetated plots. Field workers dislike the tedious nature of pellet counts. Browse indices also require less effort to measure to a common level of precision than goat pellet frequency; therefore, they provide a cost-effective alternative to pellet counts for estimating relative goat abundance. They can also be measured in conjunction with understorey-condition plots with little additional effort.

A 'mean browse index' method has been used in the past to correlate deer browse with faecal-pellet counts, with mixed success (Rose & Burrows 1985; Fraser & Speedy 1997). These inconsistent results may be due to this index being dependent on species richness as well as animal density. The browse index used in the current study is independent of species richness.

6.2.3 Seedling-height growth rates

Seedling growth rates of high-goat-preference species also responded to changes in goat densities with positive height gains seen, particularly in gap plots, where goat densities were reduced; but no or negative height gains recorded where goat hunting was either not undertaken or failed to reduce goat numbers. The advantages of this method are that it provides another direct measure of understorey demographics, and that it is useful for assessing ongoing understorey improvements in long-term hunted areas once seedling counts and seedling ratios have stabilised. Browse data should be collected together with growth-rate data to allow better interpretation of growth rates, particularly where growth rates are small or negative.

Although the time required to measure seedling heights was not recorded, they are likely to require greater labour resources to collect than simply counting or recording the presence of target species, because each tagged individual must be searched for regardless of its height or whether it is still present, its tag number checked, and its height measured and recorded. Other disadvantages of this method are that new seedlings must be tagged to replace those that die or grow taller than 2 m, and that two initial surveys are required to, firstly, establish a tagged population and, secondly, remeasure it before a height growth index of goat impacts can be calculated. This index also needs to be compared with data from similar sites where goat impacts are known to be negligible in order to evaluate the level of goat impact.

6.2.4 Seedling ratios

Seedling ratios assume that browsing animals impact forest understoreys whenever seedling frequencies in the browse tier are lower than in the ground tier (i.e. > 1.0). While this may not always be true, especially for individual species with intermittent regeneration strategies, we present strong evidence (Section 5.2.1) that, at least for groups of species, this assumption is robust enough for seedling ratios to provide a useful index of overall goat impact on understoreys. The seedling ratio for all palatable species was the most strongly correlated to goat abundance across a range of sites, forest types, and wide range of goat densities; therefore, it provides a robust index of goat impact.

In contrast to seedling counts and growth rates, seedling ratios do not need to be compared with those from a low-goat-impact standard to evaluate impact levels, because seedling ratios across a range of different areas and species groups tend toward or a little below 1.0 as goat impacts are reduced. Seedling ratios are more cost-effective than counting seedlings as a technique to measure overall goat impacts on forest understoreys, and can be applied to tall herbaceous species for which individual plants cannot be counted, as well as to tall woody species.

Seedling ratios therefore offer considerable potential as a robust and efficient tool for monitoring goat impacts and outcomes of goat control operations. Their utility might be increased by recording the presence of target species in a greater range of height classes (e.g. 1.0–2.0 m and 2.0–4.0 m) so that the recruitment of seedlings and saplings into the upper browse tier and taller height classes can be monitored. The efficacy of this modification warrants investigation.

6.2.5 Seedling counts

Seedling counts on fixed-area plots provide an absolute measure of forest understorey condition on a species-by-species basis. Counts of seedlings in the ground tier (0–0.3 m) were shown to be unresponsive to changes in goat densities in an earlier report (Burns et al. 1995) and were not analysed here, but counts of browse-tier seedlings (0.3–2.0 m) were responsive to animal control. However, there are no baseline levels of seedling density that are commensurate with low goat impacts because natural seedling densities vary considerably between species and from site to site. Therefore, in order to gauge the level of goat impact within any management unit using seedling counts, data must be compared with those from exclosure plots or similar areas where browsing ungulates are absent. This natural variation in seedling densities also means that more plots must be measured to obtain population estimates of high precision than for some of the other indices of vegetation condition investigated (Table 7).

6.2.6 Choice of monitoring method

The data collected have provided a range of variables and indices with which to analyse goat impacts on forest understoreys. The choice of which variable or index a manager might use in any situation depends on the specific conservation objectives set for an area of natural estate, and the level of detail desired. Three potential conservation objectives relevant to goats are:

- To reduce (or eliminate) the amount of native plant biomass being consumed by goats (and therefore make it available to indigenous consumers)
- To maintain (or improve) forest structure by ensuring that tree mortality is balanced by recruitment of seedlings to the canopy
- To maintain (or improve) biodiversity by ensuring that goat-palatable plant species retain viable populations

Our results suggest that the extent of biomass loss, assuming this is proportional to goat density, would be best monitored using browse indices on palatable species as indices of relative animal abundance, or more directly using seedling counts. Goat impacts on forest regeneration would be usefully monitored using seedling densities, growth rates of tagged canopy seedlings, or seedling ratios on small (5 m × 5 m or smaller) plots. Where detailed information on individual species is required, seedling densities or growth rates of tagged seedlings should be measured, but these should be complemented by paired monitoring in exclosures or similar sites with low goat densities. Where only a general assessment of understorey condition is required, measuring seedling ratios of palatable species will be more cost-effective. Goat impacts on biodiversity could be usefully monitored by following species richness in the browse tier (mean number of species per plot), or measuring seedling ratios.

The monitoring techniques described and tested in this study are specifically designed to provide cost-effective tools to monitor short- to medium-term outcomes of animal control operations on forest understoreys. They do not eliminate the need to periodically conduct detailed forest-overstorey assessments to determine long-term trends in forest structure. These types of measurement (stem counts, basal area measurements, overstorey cover scores) can be conducted on the understorey plots, if a permanent plot design of 5 m × 5 m or similar is chosen for short-term monitoring, although these small plots may not be the most appropriate plot size for describing forest overstorey structure.

The diets of a range of forest ruminants, including goats, in New Zealand forests are broadly similar (Mitchell et al. 1987; Nugent & Challies 1988; Nugent 1990; Nugent et al. 1997; Yockney & Hickling 2000); therefore, their impacts on forest understoreys are likely to be similar. The techniques used to successfully monitor goat impacts on forest understoreys in this study are therefore likely to also be useful for monitoring impacts of these other forest understorey browsers. Further research into the use of seedling ratios to monitor impacts of a range of browsing ungulates is currently being undertaken.

7. Recommendations

Monitoring protocols for assessing forest understorey condition should concentrate on seedlings of goat-palatable species on small plots (5 m × 5 m or smaller rather than 20 m × 20 m) to provide cost-effective means of measuring current goat impacts in forests, and recovery following goat control. Seedling densities in the browse tier (0.3–2.0 m) or growth rates should be measured in treatment blocks and on exclosure plots only if detailed data on the condition of individual species are required. Seedling ratios (recording presence and absence of species in the ground and browse tiers) should be calculated when only an efficient index of overall goat impacts is required. Browse on palatable species in the browse tier should also be recorded on all plot types to provide an index of goat abundance, and to aid data interpretation.

Responses of forest understoreys to possum control should be further investigated by comparing seedling population structures on gap and canopy plots in treatment areas where browsing ungulate and possum densities are low, with treatments where possum densities are high but browsing ungulate numbers are low. This design will enable responses to possum control in the absence of browsing ungulates to be assessed.

Managers of indigenous forest must recognise the need to integrate both possum and goat control strategies to provide long-term maintenance of natural forest structures. Whereas possum control may need to be continuously maintained to prevent decline in canopy condition of species vulnerable to possums, goat control may need only be applied intermittently to allow periodic recruitment of goat-palatable canopy and subcanopy species. The frequency and duration of goat control operations necessary to maintain long-term canopy structures needs to be investigated.

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Appendix 1

SCIENTIFIC AND COMMON NAMES OF PLANTS

Common name	Scientific name
broadleaf	*Griselinia littoralis*
fuchsia	*Fuchsia excorticata*
hard beech	*Nothofagus truncata*
haumakaroa	*Raukaua simplex*
heketara	*Olearia rani*
hen and chicken fern	*Asplenium bulbiferum*
hinau	*Elaeocarpus dentatus*
kaikomako	*Pennantia corymbosa*
kamahi	*Weinmannia racemosa*
kiekie	*Freycinetia baueriana*
mahoe	*Melicytus ramiflorus*
maire	*Nestegis cunninghamii/lanceolata/montana*
mangeao	*Litsea calicaris*
miro	*Prumnopitys ferruginea*
northern rata	*Metrosideros robusta*
pigeonwood	*Hedycarya arborea*
red beech	*Nothofagus fusca*
rewarewa	*Knightia excelsa*
rimu	*Dacrydium cupressinum*
supplejack	*Ripogonum scandens*
tawa	*Beilschmiedia tawa*
tawheowheo	*Quintinia serrata*
tree ferns	*Cyathea* & *Dicksonia* spp.
wineberry	*Aristotelia serrata*

Appendix 2

COMMON BROWSE TIER SPECIES

All plant species occurring on 10 or more plots during initial vegetation measurements in the three study areas (274 plots of 5 m × 5 m) are listed. Plants are listed by type (herbaceous or woody), goat preference class (High/Moderate/Low), and height class (Tall/Short). Possum preference classes, where known, are also given. Browse index (BI), seedling ratio (SR), and number of plots each species occurred on (N) for the initial vegetation assessment at Waitaanga and Nydia Saddle and non-goat hunted blocks at Tawarau, combined, are also given.

SPECIES	GOAT PREFERENCE CLASS	POSSUM PREFERENCE CLASS	HEIGHT CLASS (TALL/SHORT)	BI	SR	N
HERBACEOUS SPECIES						
Asplenium bulbiferum	H	M	T	1.28	1.25	47
Astelia spp.	H	L	T	1.42	3.28	51
Freycinetia baueriana	H	L	T	2.48	0.67	83
Asplenium flaccidum	M	M	T	0.5	12.3	55
Asplenium hookerianum	M		S			22
Asplenium oblongifolium	M		T	0.25	3.75	11
Asplenium polyodon	M		T	0.33	5.67	7
Blechnum novae-zelandiae	M		T	0.94	0.94	15
Blechnum chambersii	M		S			44
Collospermum hastatum	M	L	T	0.5		12
Collospermum microspermum	M	L	T	2.4		17
Dicksonia squarrosa	M	L	T	1.26	0.64	177
Diplazium australe	M		T			10
Lastreopsis hispida	M		T	0.45		16
Leptopteris hymenophylloides	M	L	T	0.83	0.81	40
Phymatosorus spp.	M	M	S	0.6	4.4	29
Uncinia uncinata	M	L	T	0.7	1.1	93
Uncinia spp.	M	L	S	0.52		216
Blechnum discolor	L	L	T	0.61	0.55	153
Blechnum filiforme	L		T	0	7	54
Blechnum fluviatile	L	L	S	0.44	0.87	48
Cardamine debilis agg.	L	H	S			21
Cardiomanes reniforme	L		S			25
Corybas spp.	L		S			61
Cyathea dealbata	L	L	T	0.2	0.1	93
Cyathea smithii	L	L	T	0.35	0.26	158
Dianella nigra	L		T			15
Gahnia spp.	L	L	T	0.5	0.29	14
Grammitis billardieri	L		S			19
Histiopteris incisa	L	L	T	0.1	0.45	38
Hydrocotyle spp.	L	H	S			23
Hymenophyllum spp.	L	L	S			137

Appendix 2 continued.

SPECIES	GOAT PREFERENCE CLASS	POSSUM PREFERENCE CLASS	HEIGHT CLASS (TALL/SHORT)	BI	SR	N
Lindsaea trichomanoides	L		S			12
Lygodium articulatum	L		T	0.25	1.25	17
Microlaena avenacea	L	L	T	0.79	0.95	141
Paesia scaberula	L		T	0.13	1.13	12
Ranunculus reflexus	L		S			18
Urtica incisa	L		S			25
WOODY SPECIES						
Alseuosmia macrophylla	H		T	1.75	1.57	64
Coprosma grandifolia	H	M	T	0.91	4	75
Coprosma lucida	H	M	T	0.88	4.13	47
Griselinia littoralis	H	L	T	2	21.5	38
Melicytus ramiflorus	H	H	T	1.92	4.88	63
Olearia rani	H	M	T	2.5	0.7	26
Pseudopanax crassifolius	H	M	T	2.07	1.13	89
Ripogonum scandens	H	H	T	1.54	1.86	129
Weinmannia racemosa	H	H	T	0.89	4.68	145
Carpodetus serratus	M	L	T	0.96	1.12	66
Clematis spp.	M	L	T	0.37	2.42	55
Coprosma rhamnoides	M	M	T	1.43	0.29	36
Elaeocarpus dentatus	M	L	T	0.94	2.21	90
Geniostoma rupestre	M	M	T	0.5	2.64	69
Hedycarya arborea	M	L	T	1.4	3.79	179
Metrosideros fulgens	M	H	T	0.56	1.53	154
Myrsine australis	M	M	T	1.5	12.6	61
Rubus cissoides	M	M	T	1.08	0.96	60
Beilschmiedia tawa	L	M	T	0.86	0.57	151
Dacrydium cupressinum	L	L	T	1.25	4.75	42
Knightia excelsa	L	L	T	0.13	0.88	47
Laurelia novae-zelandiae	L	L	T	0.75	7.08	85
Leucopogon fasciculatus	L	L	T	1.33	0.33	38
Metrosideros diffusa	L		T	0.38	2.34	156
Metrosideros perforata	L		T	0.29	2.56	108
Nestegis spp.	L	L	T	0.56	1.31	24
Parsonsia spp.	L	H	T	0.17	2	32
Podocarpus hallii	L	M–H	T	1.08	0.2	24
Prumnopitys ferruginea	L	L	T	0.17	10.5	89
Pseudowintera axillaris	L	L	T	0.4	1.06	61
Quintinia serrata	L	L	T	1.5	1.9	43

Appendix 3

BROWSE INDICES

Browse indices are a measure of ungulate browsing intensity on vegetation within their reach, and are derived from the summation of browse scores on individual plants. They can be used as an index of ungulate density. The procedure used to assess goat browse in this study is described below.

Browse scores

A browse score was given for each species with foliage present in the browse tier (0.3–2.0 m above ground level) in each quadrant on the permanent (5 m × 5 m) plots. Each browse score gives an assessment of the total amount of ungulate browse on all individuals present of the species being scored, and was assessed on a 5-point scale as follows:

Browse score	Description
0	no ungulate browse observed
1	1–25% of stems with some browse observed
2	26–50% of stems with some browse observed
3	51–75% of stems with some browse observed
4	76–100% of stems with some browse observed

A stem is defined as any stem or shoot that was accessible to ungulates. Unbrowsed stems less than 2 cm long were ignored. On strongly divaricating plants, interior stems not accessible to ungulates were also ignored. For ferns, stems were defined as whole fronds, while each leaf-blade of grasses and plants with grass-like foliage (e.g. kiekie, *Astelia* spp., *Cordyline* spp.) were treated as individual stems. Epicormic shoots on the boles of trees and foliage on plants taller than 2 m but hanging down into the browse tier were also included.

Only recent browse was assessed, with old browse, defined by the browsed stem having died back to the point where the next stem arises, being ignored.

Identifying ungulate browse

Ungulate browse on woody vegetation is usually characterised by truncated stems, rather than torn or missing foliage on otherwise intact stems that is typical of possum-browsing damage. Occasionally stem-mining insects can cause damage to fine stems that resembles light ungulate browse (e.g. frequently seen on tawa seedlings in some years). In these cases ungulate and insect browse may be difficult to distinguish. Ungulates browse ferns by heavily truncating fronds but leaving the pinnae behind the point of truncation intact. Fronds that have heavily damaged pinnae but a relatively intact rachis (main stem) are indicative of insects or possum browse. Ungulate browse on grass-like leaf blades is distinguished from insect browse by the rough, jagged ends to the truncated leaf blades. Insects leave smooth, often curving, browsed edges on leaves of both woody and grass-like plants.

Fern fronds are sometimes damaged by wind, falling litter, or other causes, leaving damage sign similar to ungulate browse. Sometimes the dead and dried remains of the damaged frond tips are still attached to the remains of the frond, indicating that it was not browsed, but in other cases the following rule was used. Isolated, individual truncated fronds were ignored while two or more adjacent truncated fronts were scored as ungulate browse.

Calculating browse indices

A whole-plot browse score for each species present on each plot was derived from browse scores in the four quadrants by converting quadrant browse scores and cover classes to percentages (mid-point of each class), then calculating a weighted-average percent-browse, and finally converting this percentage back to a 5-class browse score (0–4 above).

Browse indices were calculated from these whole-plot browse scores for individual species as follows:

$$BI = \frac{\text{sum of all browse scores over a group of plots}}{\text{total number of browse scores}}$$

Indices can be calculated for all species present on plots combined, or for subsets of species of particular interest.