Impacts of Himalayan thar (*Hemitragus jemlahicus*) on snow tussock grasslands in the Southern Alps

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Abstract

The national Himalayan Thar Control Plan set densities for thar (*Hemitragus jemlahicus*) above which the Department of Conservation would conduct extra hunting. This report compares measurements of plant condition on 117 permanent vegetation plots in eight study catchments with changes in thar densities in the study catchments over the last decade. There was a detectable and significant effect of thar on the basal area, density and height of snow tussocks (*Chionochloa pallens*, *C. flavescens*, and *C. rigida*). On average across the eight study catchments, for every increase of 1 thar/km^2 the basal area, height and density of all tussocks pooled declined significantly by 3.0%, 0.6% and 2.0%, respectively. We also detected a very small but marginally significant deleterious effect of hares on tussock condition indices. These relationships are reflected in the overall trends in tussock condition indices since 1990. Over all age classes of tussock there were no significant changes. However, when divided into age/state classes, there was a trend towards improved basal area and density (but not height) among 'mature' tussocks at the expense of 'juvenile' and 'senescent' classes. The frequency of occurrence on the vegetation plots of herbs known to be eaten by thar generally increased over the decade, but there was no change in species richness. We conclude that under the current range of thar densities (averaging between 0.8 and 12.3/km^2 across the study catchments), the improvements in vegetation condition consequent on the massive reduction in ungulate densities caused by commercial game meat harvests in the 1970s have not been reversed, but that the rate of the future improvements in vegetation condition and its final state will depend on the level at which thar densities are maintained. Lower thar densities would result in faster vegetation recovery.

1. Introduction

The Department of Conservation (DOC) intends to review the national Himalayan Thar Control Plan (DOC 1993) in 2004. Landcare Research has been commissioned to archive and analyse the data from 117 permanently marked vegetation plots established in eight alpine catchments since 1990 and remeasured up to three times by the summer of 2002/03. The aim was to assess whether thar densities over the last decade have had any effects on the condition of alpine vegetation, particularly snow tussocks (*Chionochloa* spp.).

2. Background

The national Himalayan Thar Control Plan (DOC 1993) set maximum densities for thar on public conservation lands that, when exceeded, would trigger extra hunting effort, with DOC either encouraging more recreational hunting, allowing more commercial harvesting, or imposing official culling. These trigger or intervention densities range from <1 to 2.5 thar/km^2 for different areas. The intervention densities were set conservatively to protect conservation values, but not so low as to be unachievable largely by recreational and commercial hunters, i.e. without too much government intervention. They were therefore generally set at <10% of the thar densities observed in the late 1960s, before commercial hunting removed most thar (Parkes & Tustin 1985), and for a total population of no more than 10 000 thar. This population could be maintained by an annual harvest of about 2000 animals (Parkes 1993), which was thought to be achievable by private hunters (Nugent 1992).

However, the targets set were not based on any data that directly related the densities to the impacts of thar, so the plan required that these intervention densities be tested and refined so that the plan could be reviewed.

The plan did not consider what plant species might be most useful as indicators of thar impacts, direct how impacts were to be assessed, or specify what state of vegetation should be considered 'ecologically acceptable'. In the absence of such guidelines we selected the community dominated by snow tussocks in which to measure impacts. Such communities are often the dominant vegetation type in the Southern Alps and in one study (Tustin & Parkes 1988) thar were shown to spend 39% of their time within such communities. We also chose the snow tussocks themselves as the main indicators of thar effects because they form a major component of the diet of thar (30% by dried weight) but only a minor part of the diet of other sympatric mammalian herbivores (2% for chamois (*Rupicapra rupicapra*), 0% for possums (*Trichosurus vulpecula*), but unknown for hares (*Lepus europaeus*) (for the Rangitata/Rakaia catchments in Parkes & Thomson 1995; J. Parkes, unpubl. data). Other plant species present within the snow tussock communities were also monitored to a lesser degree. While recognising that we cannot prescribe what vegetation condition might be considered 'ecologically acceptable', for the purposes of this report we assume that any trend towards more or bigger tussocks indicates improving vegetation condition and is therefore 'ecologically acceptable'.

3. Objectives

- Archive electronic data and hardcopies of the data in the National Vegetation Survey databank (NVS) located at Landcare Research, Lincoln, with a CD-ROM of the data updated and lodged in NVS and with the Department of Conservation, Hokitika.
- Assess condition and trend in vegetation condition against the trend in thar densities at each of the eight study sites.
- Assess condition and trend in vegetation condition against the actual thar densities at each plot (as indexed by faecal pellet counts), and between sites in relation to the intervention densities in the Thar Control Plan.
- Assess plant biodiversity data trends from Recce plot data.
- Assess uncertainties in the results and gaps in information not addressed by the current monitoring.

4. Methods

4.1 Study catchments

Permanent vegetation plots were established in eight study catchments located in each of the management units where thar densities were set above zero in the national Himalayan Thar Control Plan, and where thar have been regularly counted (Fig. 1). The history of thar and surveys, and the aims of the thar control plan for each study catchment, are summarised in Appendix 1 and photographs of one plot from each study site are shown in Appendix 4. The individual plot grid references are noted in NVS (see Appendix 2 for file names) and archived at Landcare Research, Lincoln, and the boundaries of the study catchments surveyed for thar are noted on maps held at the relevant DOC conservancy.

4.1.1 Hooker – Tasman

The Hooker study site (NZMS 260, H36 780 210) is part of the Mt Cook range on the true left of the Hooker Valley in Mt Cook National Park, from Hooker Corner north to Mt Mabel. Thar and chamois were liberated near this site in 1904 and reached 'very high densities' within a few decades (Caughley 1970). Disease (Daniel & Christie 1963), official culling from the 1930s until the mid-1980s, and commercial harvesting from 1971 until 1983 (Parkes & Tustin 1985) had together reduced thar densities in the study area to near zero by 1984.

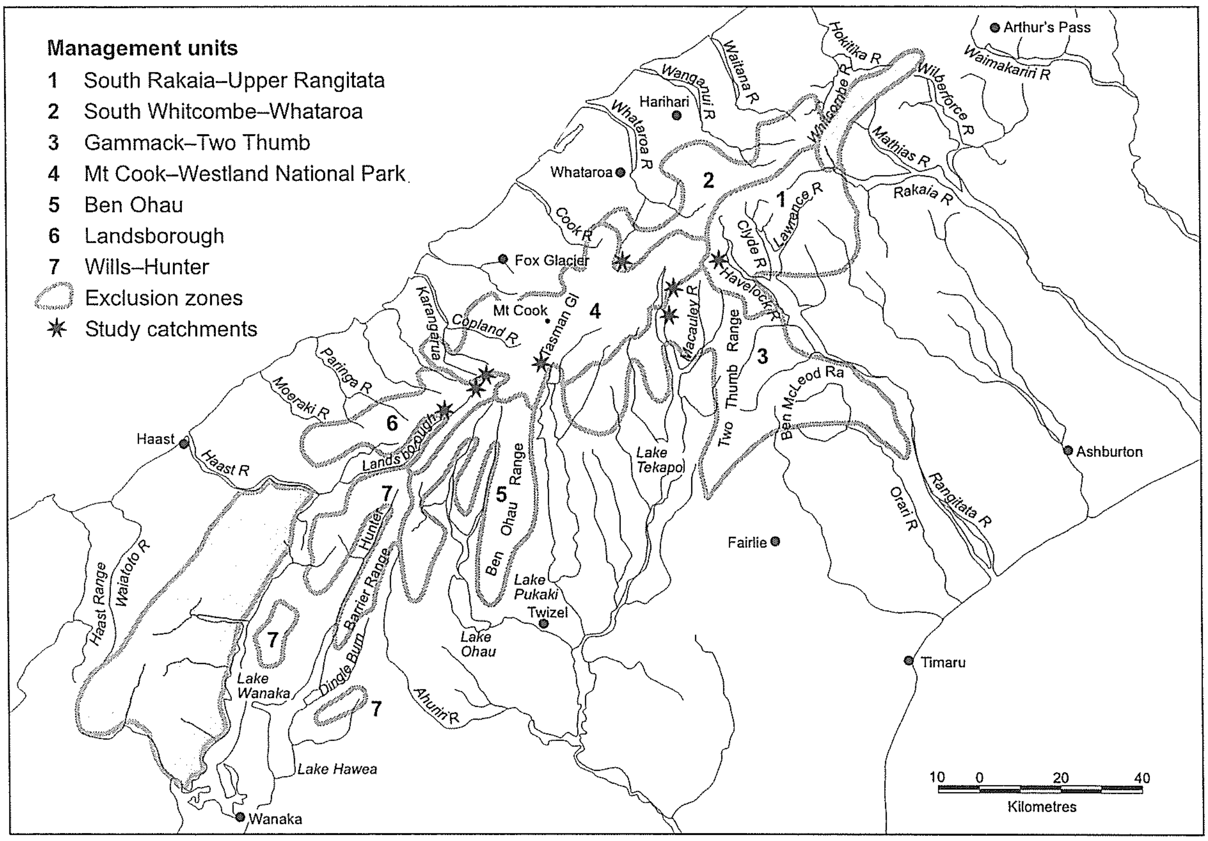

Figure 1. Management units from the thar plan and location of the eight study catchments used in this report.

The 17.5-km^2 study site extends from newly deposited moraines at about 800 m a.s.l. through a band of subalpine shrub up to 1300 m a.s.l., then through snow-tussock (*Chionochloa pallens* and *C. crassiuscula*) grassland and herbfields up to the limit of vegetation at about 1850 m a.s.l. to the top of the range at 2000 m a.s.l. The nine permanent vegetation-plots were established in 1992 on colluvial side-slopes above the Hooker Glacier. All were in sites dominated by *C. pallens* with *C. crassiuscula* co-dominant on seven of the plots. Six plots were in grassland habitats and three in sites with a higher shrub component. The plots were remeasured in 1995 and 2001.

The thar control plan aims for zero thar within this management unit (mostly within national parks where the Act specifies such an aim) and determines that DOC will intervene with official control if thar densities exceed 1/km^2, i.e. they will attempt to keep thar at the lowest practicable level.

4.1.2 FitzGerald – Godley

The 8-km^2 FitzGerald study site (NZMS 260, I35, 090 445) is in the headwaters of the Godley River in Mt Cook National Park and extends from about 1100 to 2400 m a.s.l. Thar colonised this area in the late 1940s and reached very high densities before the commercial harvesting of the 1970s (Caughley 1970). The thar plan aims to achieve zero thar within this management unit.

Fifteen plots were established in 1999 on both sides of the FitzGerald Stream above the glacial lakes. These were remeasured in 2003. *Chionochloa pallens* was co-dominant with *C. crassiuscula* (present in varying amounts) on nine plots and co-dominant with *C. flavescens* on a further three plots (*C. crassiuscula* was also present on one of these plots). Two plots were purely *C. pallens* and one plot purely *C. flavescens*.

4.1.3 Townsend – Landsborough

The 5-km^2 Townsend study site (NZMS 260, H36, 610 115) is on the true right bank of the Landsborough River about 1–2 km upstream from the Arbor Rift plots. The study site extends from about 900 to 1800 m a.s.l. Thar colonised the Landsborough in the late 1940s (Caughley 1970) and were at high densities when commercial harvesting began in the 1970s. The thar plan aims to have no more than 1.5 thar/km^2 in the area.

Fifteen plots were established in 1999 and remeasured in 2003. *Chionochloa pallens* was the dominant snow tussock on seven plots. It was co-dominant with *C. crassiuscula* on four plots, with *C. flavescens* on one plot, with *C. oreophila* on two plots, and with *C. elata* on one plot.

4.1.4 Whymper – Whataroa

The 24-km^2 Whymper study site (NZMS 260, I35, 970 470) is located below the Whymper glacier at the headwaters of the Whataroa River in Westland and extends from about 600 to 2300 m a.s.l. The lower slopes are forested or covered in subalpine shrubland. Thar colonised the area in the 1960s (Caughley 1970) and probably did not reach maximum densities before the start of commercial harvesting in the early 1970s. The thar plan aims to have no more than 2 thar/km^2 in the area.

Twelve plots were established in March 1993, remeasured in January 1997 with 11 plots remeasured in January 2002. Eight plots were sited on the true left of the Whataroa River and four in the tributary creek below Mt Barrowman. *Chionochloa pallens* was the dominant snow tussock in nine plots with *C. pallens* and *C. crassiuscula* co-dominant in the remaining three plots.

4.1.5 Carneys Creek – Rangitata

Carneys Creek (NZMS 260, I35, 210 430) is a tributary of the Havelock branch of the Rangitata River. Thar reached Carneys Creek in 1939 when 10 were shot during a chamois-culling operation (Davidson 1965). Breeding populations probably established in the catchment in the late 1940s (Caughley 1970), reaching high densities in the early 1960s despite some government and recreational hunting (Tustin & Challies 1978). No hunting was allowed between mid-1964 and early 1966 and the first survey of thar numbers was made in 1965 when 37.4 thar/km^2 were counted (Tustin & Challies 1978). Recreational hunting, official control (from helicopters since 1967–1968), and then commercial meat hunting between 1970 and 1975 reduced the population to only 2.5/km^2 by 1977 (Tustin & Challies 1978). The thar plan aims to have no more than 2.5 thar/km^2 in the area.

The 19-km^2 catchment extends from about 760 to 2150 m a.s.l. It has extensive bluff systems, screes and avalanche chutes. Subalpine shrubland and forest cover some lower parts of the catchment, but snow tussock (*Chionochloa pallens*) and herbfields are the dominant vegetation. Detailed descriptions of the catchment are given in Forsyth (1997).

Twenty plots were established throughout the catchment in January 1992, 18 of which were remeasured in March 1997 and again in January–February 2002. One of the plots was washed away by a nearby creek and the other was judged to be too steep by the survey team, and these were not measured after 1992. *Chionochloa pallens* was the dominant snow tussock in ten plots. It was co-dominant with *C. crassiuscula* in five plots with *C. flavescens* in two plots and with *C. oreophila* in one plot. *Chionochloa flavescens* was dominant in one plot.

4.1.6 North Branch – Godley

The North Branch (NZMS 260, I36, 100 310) is a tributary of the Godley River. Thar had not reached this area by 1939 (Caughley 1967), but breeding populations colonised the catchment in the late 1940s (Caughley 1970). They had reached high densities by the early 1970s (Tustin 1980), with 111 being counted in one aerial survey in 1972 (Parkes undated). As elsewhere, control and then commercial harvesting (at least 1000 were known to have been shot on Lilybank Station between 1974 and 1978) had reduced the population to c. 20–25 animals by 1976 (Tustin & Parkes 1988). The thar control plan aims to have no more than 2 thar/km^2 in the area.

The catchment extends from about 800 m a.s.l. to 2200 m a.s.l. at the ridge tops. The lower part of the catchment is steep and dissected by bluffs, rocky outcrops, avalanche chutes and screes. The upper part of the catchment (less favoured by thar) opens out into areas of wider grasslands with less steep slopes.

Thar were counted on both sides of the catchment over an area of 20 km^2. The vegetation plots are sited on the true left of the catchment within the system of bluffs. A brief description of four of the major vegetation associations in the catchment (short tussock grassland, tall snow tussock, matagouri shrub, and short podocarp shrub) and the proportion of time thar spent feeding in each association are given in Tustin & Parkes (1988).

Fifteen plots were established in February 1990 (Rose & Allen 1990) and a further six plots in February 1992. Sixteen plots were remeasured in February 1996 (10 established in 1990 and 6 in 1992) and 19 were remeasured in February 2001 (13 established in 1990 and 6 in 1992). The sixteen plots measured in all years were used in the analysis. *Chionochloa rigida* was the main snow tussock and dominant plant on eleven of the plots. Two plots also contained *C. flavescens* and *C. pallens* was identified (in some years) on three plots. Nine plots were entirely dominated by tussocks, five were in areas with matagouri shrub, and two were in areas with podocarp shrub.

4.1.7 Zora – Landsborough

The 6-km^2 Zora study site (NZMS 260, H36 / H37, 545 100) is above Zora Canyon on the true right of Zora Creek, which flows into the Landsborough River in South Westland. The study site extends from 900 to 2200 m a.s.l. Thar colonised the Landsborough in the late

1940s (Caughley 1970) and were at high densities when commercial harvesting began in the 1970s. The thar plan aims to have no more than 1.5 thar/km^2 in the area.

Fifteen plots were established in 1999 and remeasured in 2003. Eleven plots were in areas co-dominated by *Chionochloa pallens* and *C. crassiuscula* and one in an area co-dominated by *C. pallens* and *C. flavescens*. Two plots were purely *C. flavescens* and one plot purely *C. pallens*.

4.1.8 Arbor Rift – Landsborough

The 4.5-km^2 Arbor Rift study site (NZMS 260, H37, 590 105) is on the true right bank in the headwaters of the Landsborough River in South Westland and extends from about 600 to 2020 m a.s.l. Thar colonised the Landsborough in the late 1940s (Caughley 1970) and were at high densities when commercial harvesting began in the 1970s. The thar plan aims to have no more than 1.5 thar/km^2 in the area.

Nine plots were established in February 1992 with a further eight established in February 1994. All seventeen plots were remeasured in February 1997 and in early March 2002. *Chionochloa pallens* is the dominant snow tussock on four plots and is co-dominant with *C. crassiuscula* (present in varying amounts) on ten plots and with *C. flavescens* on three plots.

4.2 Estimating animal densities

Thar and other ungulates were counted in each study catchment periodically in late February/early March, i.e. before the start of the thar rut when adult males disperse into female ranges. The study catchments were closed to recreational hunting for several weeks prior to each count. Counts were made (usually by two observers) from fixed viewing points during the late afternoon/evening and (for some catchments) during the early morning, using 20x spotting scopes and 8–10x binoculars (see Challies 1992). The fixed viewing sites gave complementary and overlapping fields of view. The observers at each site recorded the size, location and composition of each group of thar seen, and they were in radio contact with each other. This allowed some assessment to be made of potential double counting. Thar do not move over large areas at this time of year (Tustin & Parkes 1988), so we think the risks are low that thar are double counted between days during the census period. However, the count is technically a 'minimum number known to be present' estimate as some animals may have been missed. The whole observable area of each study site, i.e. including habitats and places not apparently used by thar but excluding forested areas at lower altitudes, was used to calculate animal densities. Map areas were used as this directly relates to intervention densities set in the thar control plan.

Animal use about each vegetation plot was estimated using the frequency of faecal pellets of ungulates, hares, and possums on each 1 m × 1 m quadrat for the earlier surveys, and from 1999 onwards, on 40 plots (each 1 m^2) at 5-m intervals along eight transects radiating out from each tussock plot. This gives an index of recent use (depending on how long pellets survive) about each plot.

4.3 Permanent-plot field methods

The variable-area, permanently marked plot method developed by Rose & Platt (1990, 1992) and Rose & Allen (1990) was adapted to measure trends in vegetation condition (DOC 2001). Adaptations took note of the recommendations of a review of the monitoring programme

(Sparrow & Kelly 2000). However, the recommendation that exclosures be constructed was not implemented as it is impossible to maintain fences that exclude thar in steep alpine environments that regularly receive heavy snowfall. Rectangular plots were located in areas dominated by snow tussock and known from census observations to be used by thar, i.e. they were not located at random and can only be used to infer impacts in tussock areas used by thar. The plots varied in size so as to contain at least 20 snow tussocks of the dominant palatable species: *Chionochloa pallens, C. flavescens,* or C. *rigida.* The top left plot-corner was marked with a steel stake, and the other three corners with aluminium pegs.

Vegetation present in the plot was described and visually assessed following the Reconnaissance or Recce plot procedure (Allen 1992) with cover of species estimated in four height tiers (<0.1, 0.1–0.3, 0.3–1.0, and >1.0 m). Six cover classes were used (<1%, 1–5, 6–25, 26–50, 51–75, and 76–100). Total ground-tier vegetation and litter cover, and the proportions of exposed topsoil, subsoil, erosion pavement, broken rock, and bedrock, were estimated similarly.

At each measurement the plot was divided with tape measures and string into quadrats 1 m × 1 m. Palatable tussocks (*Chionochloa pallens, C. rigida* and *C. flavescens*) were measured by quadrat as follows:

- basal diameter of green tillers (the 1990 North Branch survey and all surveys from 1999 onwards measured both the live and dead diameters of tussocks but here we analyse only the basal areas calculated from the diameters of green tillers).
- maximum leaf length of tussocks made by pulling a handful of tillers to their maximum height.
- level of browse present in four classes (1, no browse; 2, low = <33% of leaves with browse; 3, medium = 34–66% browsed; and 4, high = >66% browsed).
- percentage crown death.

Individual plants were indistinguishable on plot 3 in the North Branch and a line intercept method was used to measure tussock basal diameters. The plot was divided into 1-m strips with tapes set out every metre and running from the top to the bottom of the plot. Basal diameters of tussocks intercepting the tapes were measured.

Tussocks were assigned to one of four age-state classes based on their size and degree of morbidity (see Rose & Platt 1990). Seedlings were classified as individuals that are up to 1 cm basal diameter, juveniles are 1.1–5 cm basal diameter, mature tussocks are >5 cm basal diameter and less than 50% crown death, and senescent tussocks are mature plants showing more than 50% crown death. For each plot, tussock measurements are summarised for each species by year and age-state class to provide estimates of basal area (m^2/ha), tussock density (number/ha), mean tussock height (cm), and crown death (%).

On each 1 m × 1 m quadrat we estimated the percentage ground cover and the percentage cover of common species (as well as the palatable snow tussocks) known to be eaten by thar or other herbivores, i.e. *Ranunculus lyallii*, *Aciphylla crenulata*, *A. montana*, *A. aurea*, *A. divisa*, *Carmichaelia grandifolia*[1], *Gaultheria depressa*, *G. crassa*, *Podocarpus nivalis*, *Discaria toumatou*, *Dracophyllum uniflorum* and *D. kirkii*. In later surveys, these species were counted and their heights and diameters measured, but we have not analysed these data for this report. In this report we have summarised the species cover data as the percentage of

[1] A recent revision has renamed this species *Carmichaelia arborea*.

quadrats with the species present. However, as percentage cover estimates were not done for the 1999 Zora, Townsend, and FitzGerald surveys (when the Scott-height frequency measurement was used instead but subsequently discontinued) presence/absence data were obtained from the quadrat diameter data. The percent cover of the relatively unpalatable snow tussock species *C. crassiuscula* and *C. oreophila* was recorded on each 1 m × 1 m plot when these were present.

Apart from the experimental design issues noted below, there were some difficulties with the application of the method used in this project (see Newell et al. 2002). The vegetation data have been collected over a period of 12 years with different people involved in each survey. This has meant that there have been some variations between surveys in what has been collected. Methods also evolved over time to focus on the most important data before the data collection form was standardised. We have also encountered some difficulties with data inconsistencies. In some surveys the species name of individual tussocks changed between measurement years because identification of snow tussocks to species level is not always clear. In North Branch, all tussocks were eventually allocated to *C. rigida*. Since we eventually pooled species for analysis, this was not a problem.

4.4 Experimental design

4.4.1 Original study design

The original design proposed for this study was to relate changes in vegetation condition over the survey period to thar densities where the thar were to be kept below, at, or above certain intervention densities (Parkes et al. 1999). These intervention densities ranged from <1 to 2.5 thar/km^2 depending on the area (Table 1). The three treatments were to be replicated as follows:

Below intervention density: Average estimated thar densities should never exceed 50% of intervention density.

At intervention density: Average estimated thar densities should be held at plus or minus 0.5 thar/km^2 of intervention density.

Above intervention density: Average estimated thar densities should be held at 3 times the intervention densities plus or minus 1.0 thar/km^2.

Table 1. Thar densities proposed in the original study design, those achieved on average (in ascending order), the general trend in densities in each of eight study catchments between the first and latest vegetation surveys, and the density grouping used in the analysis.
(I.D. = Intervention density)

Catchments	Intervention density (thar/km^2)	Target density for the original study design (thar/km^2)	Average density over vegetation survey period (thar/km^2)	Trend in thar density	Thar analysis group
Hooker – Tasman	< 1	0.5 (below I.D.)	0.8	Stable	Low
FitzGerald – Godley	< 1	0.5 (below I.D.)	1.0	Down	Low
Townsend – Landsborough	1.5	0.75 (below I.D.)	2.1	Stable	Medium
Whymper – Whataroa	2	2 (at I.D.)	2.6	Stable	Medium
Carneys Creek –	2.5	2.5	4.0	Up then	Medium

Catchments	Intervention density (thar/km^2)	Target density for the original study design (thar/km^2)	Average density over vegetation survey period (thar/km^2)	Trend in thar density	Thar analysis group
Rangitata		(at I.D.)		down	
North Branch – Godley	2	6 (above I.D.)	6.6	Up then down	High
Zora – Landsborough	1.5	1.5 (at I.D.)	8.9	Up	High
Arbor Rift – Landsborough	1.5	4.5 (above I.D.)	12.3	Down	High

In a previous analysis (Parkes & Thomson 1999) the relationship between thar density and vegetation impact was assessed in two ways. The main hypothesis tested was that vegetation condition should remain stable or improve where average thar densities did not exceed the intervention densities set in the thar plan. However, as thar densities fluctuated above and below these target densities at most sites, we also tested whether trends in thar density irrespective of the absolute numbers were reflected in trends in vegetation condition. The former analysis relates more specifically to the spirit of the thar plan, but the latter might be more useful if management regimes lead to unstable thar densities.
Keeping thar numbers at about the proposed densities has proved to be difficult, and so few of the study catchments had densities consistent with the original study design (Table 1). An alternative method of analysis was therefore needed. This was done by comparing the densities of thar seen in each catchment during the years the vegetation was surveyed with various indices of snow tussock condition in a repeated measures model.

4.4.2 Tussock condition vs. density

A linear mixed-effects analysis using the module in S-Plus (Version 6.1; Pinheiro & Bates 2000) was used to assess whether tussock condition (basal area, height, density, browse scores) changed as thar (and hare) densities changed. Tussock heights and densities were analysed both as a pooled dataset and further divided by the age class of the tussock (seedling, juvenile, mature and senescent). Due to inconsistencies with data collection, measurements for plot 3 of the North Branch, plot 14 of the FitzGerald and plot 11 of the Whymper were taken out of some of the analyses. We ran the pooled analyses twice, with and without seedlings, to examine whether year-to-year variation in seedling presence, caused by periodic flowering, influenced the results. Thar densities were taken as the number of animals/km^2 estimated in each year surveyed, and hare use of the plots was taken from the catchment average index of faecal pellets observed about each vegetation plot. For all study catchments we pooled the dominant snow tussock species (*C. pallens* or *C. rigida* in the case of the North Branch) and the less-common snow tussock species (*C. flavescens*).

Plots within study catchments were treated as random terms, and year (taken as year since 1990), thar density and hare pellet density were treated as fixed terms within the analyses. Tussock basal areas and density data were log transformed to ensure assumptions of normality and constant variance in the residuals were met, but transformation of the height data was not required. Correlations between measurements on the same plot were modelled as a first-order autoregressive process, thus allowing for the repeated measures design.

An alternative analysis treated thar density as a factor with tussock condition indices as the response variable. This was done to partially address the objective to assess the appropriateness of intervention densities. We compared tussock basal areas in study sites with low thar densities (Hooker and FitzGerald), medium thar densities (Townsend, Whymper and Carneys) against a baseline of those with high thar densities (Zora, Arbor Rift and North Branch; Table 1). Inferences from this analysis have to be treated with caution because the selection of sites for comparison was made *a posteriori*.

Four models of increasing complexity were fitted to the data:

Model 1: Random intercepts between catchments and common slopes within catchments.

Model 2: Random intercepts within catchments and common slopes within catchments.

Model 3: Random intercepts between catchments and random slopes within catchments

Model 4. Random intercepts and random slopes within catchments.

Akaike's Information Criterion (AIC) and likelihood ratio tests were used to select the most parsimonious model for each analysis.

The results are presented in two ways. First they are tabulated with significance levels of the percent changes in a tussock parameter (e.g. basal area) over time (year) or as thar density changed, that is they are back-transformed from the log scales. For example, in the top line of results in Table 2 for the trend in basal area of all tussocks, a slope on the log scale of 0.0278 was obtained from the analysis of the data. This is back transformed to give a finite change of $e^{.0278} = 1.0282$ or a 2.80% annual increase in the density of tussocks averaged across all sites – a result that could have occurred by chance 13% of the time. Similarly, for each 1 × thar/km^2 increase in thar density across all sites, the basal area of tussocks decreased by 3.0%, but this would only occur by chance 0.01% of the time. Second the results are presented graphically where the tussock parameter for each plot at each study site is shown and a trend over time or at each thar density is drawn using Loess curves (a locally weighted regression taken from S-Plus) (Venables & Ripley 1999) (see Figs 4 & 5).

4.4.3 Thar browse

We examined the impact of thar browse on tussocks. Points were allocated to the following browse categories: no browse = 0 points, 1–33% browse = 1 point, 34–66% browse = 2 points, and 67–100% browse = 3 points. The data for each plot were the number of plants in each browse category. The total browse scores in each plot were summed.

A different type of analysis was necessary for the browse score as the data are discrete and extremely right skewed. Two competing models were fitted to data from each age class:

Model 1 – random intercepts with fixed slope

Model 2 – random intercepts and slope.

In all cases model 1 gave a better fit to the data, assessed by Akaike's Information Criterion and likelihood ratio tests.

A bootstrap mean browse score for each plot in each year was then calculated using 1000 samples. The mean bootstrap scores were then analysed using linear mixed effects models with catchments as a random factor and thar density as a fixed factor. Models were fitted to all age classes of tussocks as before. No modelling of autocorrelation was necessary as the data are not part of a time series.

4.4.4 Species richness

Linear mixed effects models were fitted to the species richness data to investigate temporal changes in numbers of species per plot. These models were used to model log species richness (number of native vascular plant species) with catchment and plot within catchments as random effects and year (coded as years since 1990), area of plot (expressed on a log scale) and thar density as fixed effects. The best-fit model was the same as model 4 in the above analyses for tussock condition with random slopes and intercepts within catchments.

Differences in species composition between the study sites were quantified using the ordination technique, detrended correspondence analysis (DCA), in the package PC_ORD (McCune & Mefford 1999). Ordination is used to find dominant compositional gradients in complex multidimensional data, and the technique allowed us to arrange the vegetation plots in each study catchment along axes (or dimensions) based on their species composition alone rather than other ordination techniques where composition is constrained to be related to a set of specific environmental gradients. We used the species abundance data collected using the Recce method from the most recent survey at each site. We note that the design (variable area plots located only in tussock communities) does not lend itself to a complete assessment of the potential impacts of thar on species richness.

5. Results

5.1 Data management

The vegetation data collected by the Department of Conservation up to and including the surveys completed over the summer of 2002/03 are now in an electronic database (see Appendix 2). All data have been archived in NVS (electronic and hard copies) at Landcare Research, Lincoln. A CD-ROM is also held by the Department of Conservation in Hokitika.

5.2 Changes in thar numbers

Thar densities have been generally above the intervention densities in all study catchments except for those in Mt Cook National Park (the Hooker and FitzGerald). However, the trend in densities has generally been either stable or downward since the first vegetation plots were established in each study site (Fig. 2). Chamois have been present in only a few study catchments since 1984 (Fig. 2).

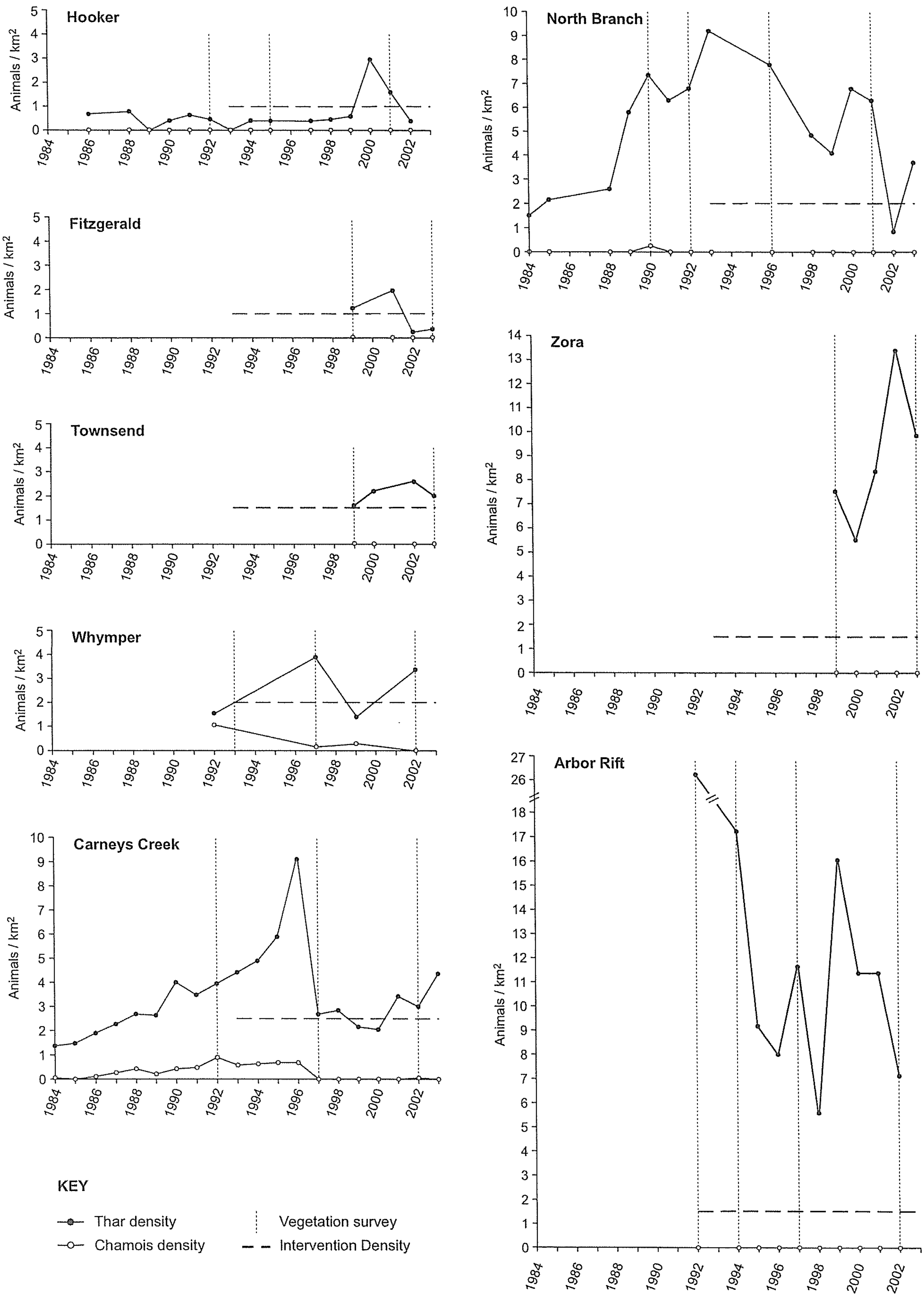

Figure 2. Changes in densities (minimum number known to be present) of thar and chamois in eight study catchments, 1984 to 2003.

5.3 Difference in vegetation composition between sites

The composition of each plot is represented by its stand scores, or position, on the two major compositional gradients (axis 1 and axis 2) of the DCA ordination and this is visually represented in a scatter plot (Fig. 3). Plots with similar composition are grouped close to one another in ordination space, and will have similar stand scores on the two major compositional gradients, whereas plots with highly different composition will be well-separated in ordination space and have very different stand scores.

The DCA analysis groups most North Branch plots (each represented by a green cross) near one another in ordination space indicating that they are compositionally similar to one another. However, most North Branch plots are separated from plots in the other seven surveys on the right half of axis 1 indicating that North Branch plots are compositionally different from plots in other surveys. The Hooker plots (red dots) are grouped with most of the FitzGerald and Zora plots on the lower-left of the scatter plot indicating that they are compositionally similar. Plots from Carneys Creek, Arbor Rift and Townsend have a similar position on axis 2 but there is no clear separation between plots in the latter two surveys on axis 1. Plots from Whymper (blue squares) are scattered across the full breadth of axis 2, indicating that plots in this catchment have variable composition. This perhaps reflects the fact that they are positioned on two sides of the catchment.

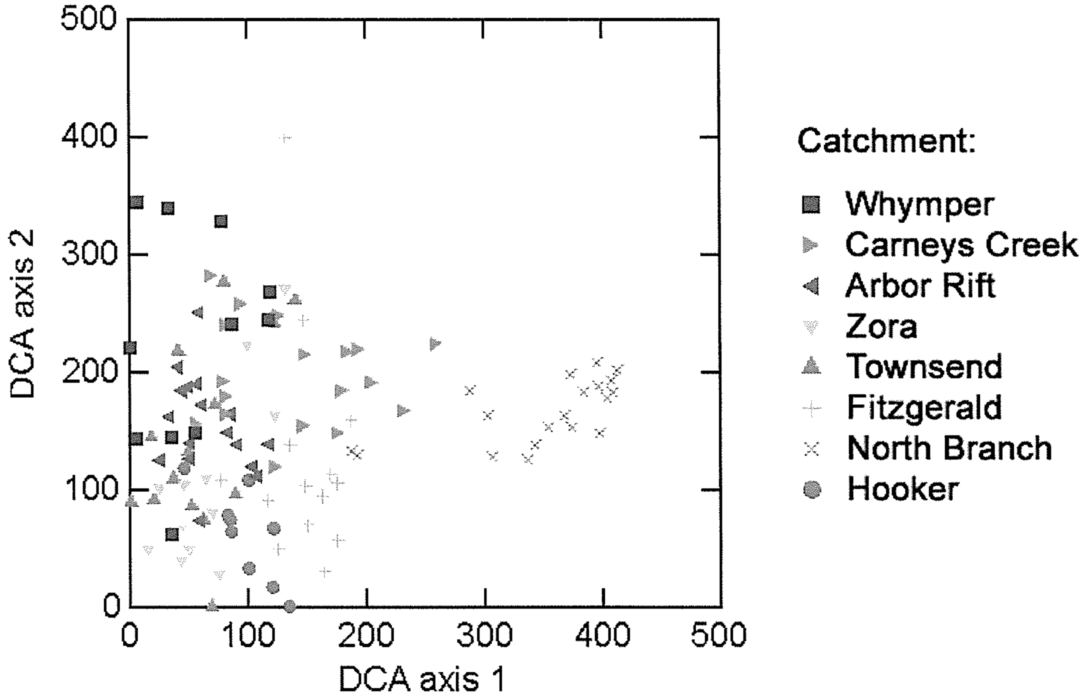

Figure 3. Detrended correspondence analysis ordination of the most recent Recce measurements of all plots in eight study sites. Plots are classified by catchment (represented by a different symbol) and are positioned on the scatter plot by their composition, represented by the scores on the two major gradients of species composition (axis 1 and axis 2) of the DCA ordination.

5.4 Changes in tussock condition

5.4.1 Trends since 1990

When snow tussocks of all ages are pooled, there has been no significant change in basal area, height, or density (Table 2). However, there were some significant changes in the condition indices of different age classes (Table 2). In particular, the basal area and density of mature tussocks increased, while those of juveniles and senescent classes decreased. The rapid decrease of senescent tussocks may represent fragmentation of large, old tussocks with a high proportion of dead crowns into smaller (but healthier) individuals now counted in mature classes (C. Newell, unpubl. data). Annual changes in tussock heights were small and only significant for juvenile and senescent classes (Table 2).

The decline in juvenile basal areas and densities (3.8% and 8.4% per year, respectively) probably represents the fact that more are making the transition into mature tussocks without replacement from the seedling class. Seedling densities will depend both on the periodic flowering events, for which we have minimal data from our sites, and on their changing survival as competition from their parents increases with increasing basal areas.

Table 2. Annual trend in snow tussock condition indices across all study sites since 1990. *P* values test the hypothesis of no change in the tussock condition indices with time.

Age/State	Basal area			Height			Density		
	Model	Annual % change	*P*	Model	Annual % change	*P*	Model	Annual % change	*P*
All tussocks (with seedlings)	4	+2.8	0.13	4	+0.003	0.99	4	−1.04	0.1
All tussocks (less seedlings)	4	+2.8	0.13	4	−0.08	0.7	4	−1.05	0.03
Seedling	4	0	0.99	2	−0.23	0.4	1	−24.0	<0.0001
Juvenile	1	−3.8	0.007	2	−0.40	0.05	2	−8.4	0.01
Mature	4	+7.6	<0.0001	4	−0.23	0.4	1	+3.2	0.04
Senescent	3	−25.8	0.03	1	−1.21	0.002	4	−34.8	0.03

At each study site there was considerable variation in trends in tussock condition indices between the vegetation plots (Fig. 4a–c). For all tussocks pooled, basal areas trended upwards in three study sites with low or medium thar densities (Hooker, Whymper and Carneys Creek; Table 1). The three sites with highest thar densities (Arbor Rift, North Branch, Zora) and one site with medium thar densities (Townsend) remained about the same (Fig. 4a). One site with low thar densities (FitzGerald) trended downwards. This showed that there was no apparent pattern based on recent thar densities. Similarly, no pattern in trends was apparent for tussock heights (Fig. 4b) or densities (Fig. 4c).

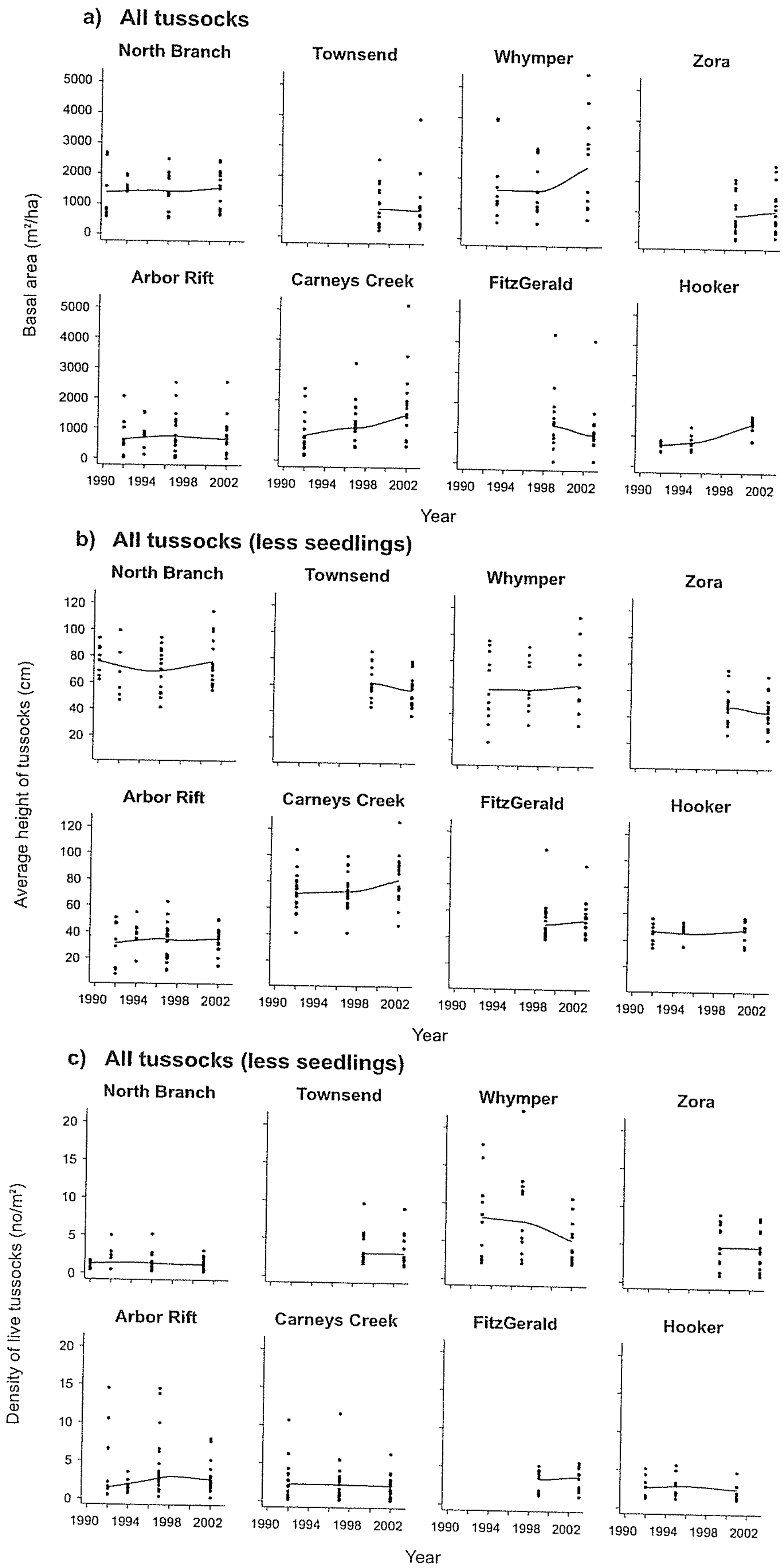

Figure 4a–c. Changes in (a) basal area, (b) height and (c) density over time for all age classes in all eight catchments studied. The line is a non-parametric smoother (drawn using Loess curves) and is meant to reveal trends in the data (it is not derived from the models discussed above). Note the large spread around the lines and three catchments that have only two years worth of observations.

Another way of analysing these trends is to look at the proportion of plots where the vegetation condition indices improved or declined over the survey period. The basal area of the dominant snow tussocks increased on 62% of individual plots between the first and last survey (Table 3).

Table 3. Number of plots at each of eight study catchments where basal areas of the dominant snow tussock species (*C. pallens* (incl. *C. flavescens*) in all but North Branch (*C. rigida*)) remained within 10% of that in the first survey, or increased or decreased by more than 10% over the survey periods.

Study catchment	No. plots with similar basal areas	No. plots where basal area increased	No. plots where basal area decreased	Average thar density/km^2
Hooker	0	9	0	0.8
FitzGerald	5	2	7	1.0
Townsend	2	9	4	2.1
Whymper	0	9	2	2.6
Carneys	1	17	0	4.0
North Branch	8	6	2	6.6
Zora	2	11	2	8.9
Arbor Rift	1	8	8	12.3
Total	19	71	25	

5.4.2 Effect of thar densities

There was a detectable effect of thar on tussocks. On average across the eight study catchments, for every increase of 1 thar/km^2 the basal area, height and density of all tussocks pooled declined significantly by 3.0%, 0.61% and 2.0%, respectively (Table 4, Fig. 5a–c). Removing the year-to-year variation of seedlings did not change the results markedly.

At each study site the regressions of thar density on tussock condition indices need to be treated with caution as only the Arbor Rift site had a reasonable spread of thar densities (from 7 to 26 thar/km^2) between the surveys (Fig. 5a–c).

Table 4. Changes in tussock condition as thar densities increase by one animal per square kilometre. *P* values test the hypothesis of no change in tussock condition indices as thar densities change

Age/State	Basal area			Height			Density		
	Model	% change	P	Model	% change	P	Model	% change	P
All tussocks (with seedlings)	4	−3.0	0.01	4	−0.61	0.006	4	−2.0	0.01
All tussocks (less seedlings)	4	−3.0	0.01	4	−0.64	0.001	4	−1.5	0.01
Seedling	4	+1.0	0.02	2	−0.15	0.59	1	−13.9	0.03
Juvenile	1	−3.5	0.03	2	−0.60	0.01	2	−7.0	0.07
Mature	4	−3.5	0.02	4	−0.62	0.02	1	−7.0	<0.0001
Senescent	3	+6.7	0.3	1	−0.50	0.24	4	+7.2	0.5

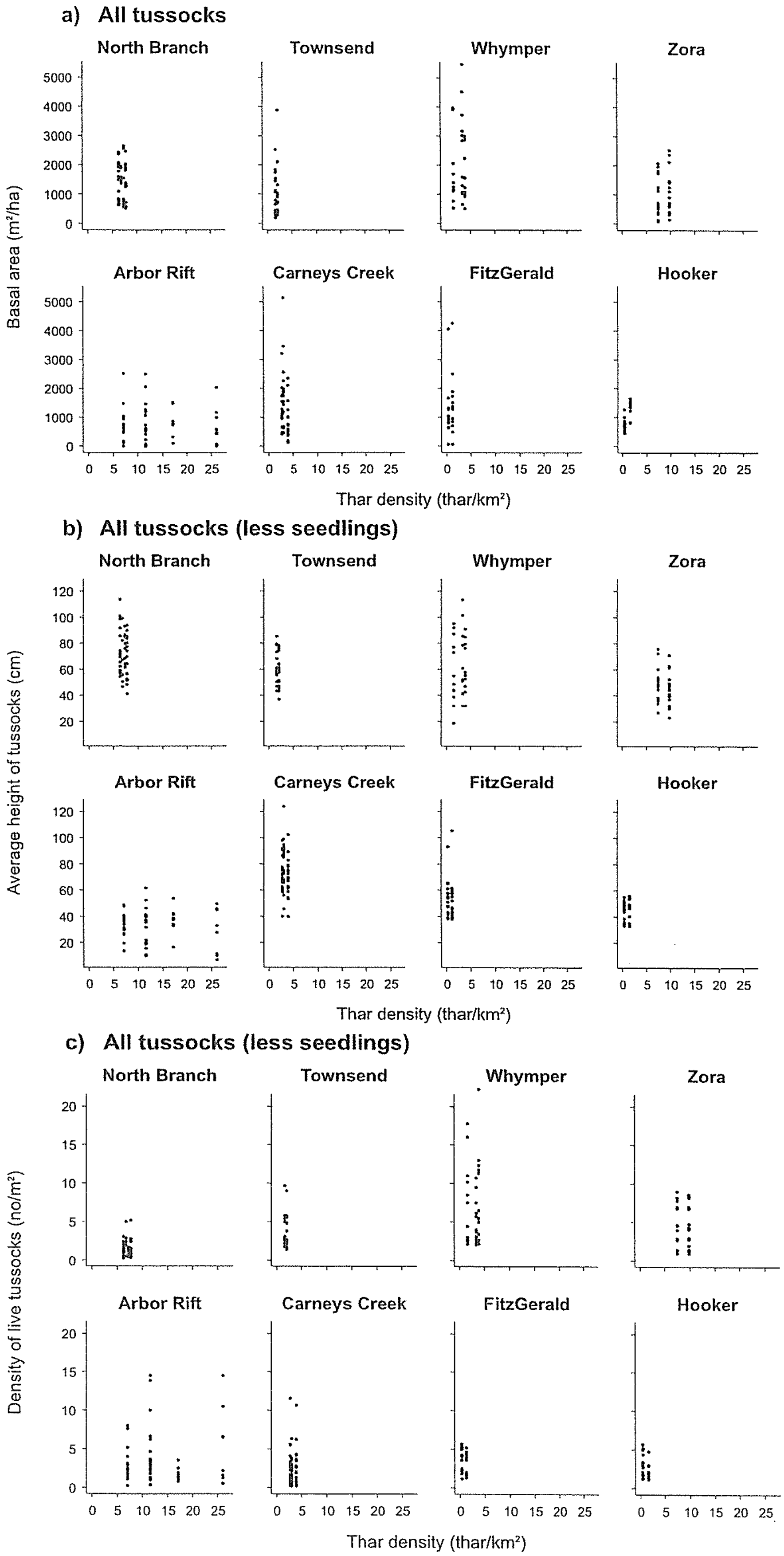

Figure 5a–c. Changes in (a) basal area, (b) height and (c) density of all tussocks as thar densities increase. Only the Arbor Rift catchment has a reasonable spread of thar densities (see text for caveats).

The analyses of individual age/state classes showed a significant decline in juvenile and mature tussock basal area and tussock height, and seedling and mature tussock density with increasing thar density (Table 4). There was no relationship between thar density and senescent tussock condition. Tussock senescence is likely to be determined by several natural factors such as fragmentation in size over time and increased mortality after masting (C. Newell, unpubl. data). The positive relationship between seedling basal area and thar density most likely relates to flowering periodicity and associated recruitment patterns.

Classifying each study site according to its average thar density as high, medium and low (see Table 1) showed (using model 4) that although the basal areas were highest where thar densities were lowest, there was no significant difference between the three classes (F = 0.891, d.f. = 2,5, P = 0.47).

There was a significant relationship between thar densities in each catchment and the frequency of ungulate faecal pellets about the vegetation plots (F = 59.1, d.f. = 1, 294, P = <0.0001) but the relationship only accounted for 16.7% of the variation in occurrence of ungulate faecal pellets. The negative relationship between trend in snow tussock condition indices on each plot and hare faecal pellet frequency about plots was marginally significant for juvenile tussock basal area and all tussocks (less seedlings) and mature tussock densities (P = 0.05, 0.02, 0.06, respectively), but the effect was very small.

5.4.3 Thar densities and the amount of browse on tussocks

For tussocks of all age/state classes there was a significant increase in the amount of browse as thar densities increased. This was largely due to a significant effect of browse on tussocks in the juvenile and senescent age/state classes (Table 5).

Table 5. Changes in browse score for different age classes of tussocks for a unit increase in thar density.

Age class	% change in browse	P
All tussocks	3.102	0.0078
Seedling	0.225	0.83
Juvenile	2.729	0.016
Mature	1.207	0.25
Senescent	3.001	0.0095

5.5 Trends in frequency of other species

The frequency of occurrence of some plant species common at all study sites and either eaten by thar or important as structural components of the tussock grasslands has increased over the survey period (Appendix 3, Table 6). The pattern varies between species within a catchment and also between catchments. Comparisons for the Whymper catchment are between 1997 and 2002 as no cover class data were recorded for the 1993 survey.

Table 6. Percent change in frequency of selected herb and shrub species eaten by thar compared with changes in tussock biomass and average thar densities in eight study catchments. The percentage of thar diet (averaged for the Mt Cook, Rangitata/Rakaia and West Coast areas (Parkes & Thomson 1995)) that these species made up was: *Ranunculus lyallii* 2.0%, all *Aciphylla* spp. 3.6%, and all *Carmichaelia* spp. 7%. (NA = not present)

Study catchment	% change in tussock basal area	Average thar density/km^2	% change in frequency between 1st and last surveys (for Whymper % change is between 2nd and last surveys)			
			Ranunculus lyallii	*Aciphylla montana*	*Aciphylla aurea*	*Carmichaelia grandiflora*
Hooker	+96	0.8	+38	NA	NA	0
FitzGerald	−20	1.0	−25	−40	+40	NA
Townsend	+14	2.1	+22	NA	NA	NA
Whymper	+54	2.6	+500	+501	NA	+17
Carneys	+98	4.0	+50	+4	0	−13
N. Branch	+6	6.6	NA	+31	+144	NA
Zora	+18	8.9	+19	NA	NA	NA
Abor Rift	+1	12.3	−50	NA	NA	+∞

5.6 Effect of thar on species richness

Native species richness did not change significantly over the duration of the study (slope = -0.0062, SE = 0.0067, t_{159} = 0.93, P=0.36). Log area of plot (the plots were of variable size) had a highly significant effect on the number of species present (slope = 0.1809, SE = 0.0499, t_{111} = 3.63, P = 0.0004) while there was no significant relationship between thar density and species richness (slope = -0.0085, SE = 0.0056, t_{159} = 1.52, P = 0.13). The slope of the regression for log area is similar to other species area slopes (see Begon et al. 1990).

The presence of introduced plant species was low to non-existent in six of the eight catchments and did not change during the study. The number of introduced plants per plot ranged between one and six in the remaining two catchments (Carneys, North Branch) but did not change during the study. The presence of introduced plants in both catchments most likely relates to their proximity to modified montane grasslands.

6. Discussion

Two main conclusions can be drawn from the results. First, the condition of the snow tussocks has remained much the same, although that of mature tussocks has improved over the last decade. Second, we can still detect a general effect of current thar densities on all age/state classes except senescent tussocks. In the context of past and current management of thar these conclusions suggest that the improving trend in tussock condition, resulting from large reductions in thar densities because of commercial harvesting between 1970 and 1983 (Parkes et al. 1996), has not been halted by thar densities achieved under the current thar plan (at least in the areas surveyed). In addition, a more stringent control strategy with fewer thar would have increased the rate of improvement and reduced the detectable effect of thar on snow tussock condition.

There are potential effects of thar on tussock population dynamics that our study cannot determine. Research elsewhere suggests that long-term grazing influences the recruitment processes and thus the age structure of snow tussocks (Rose & Platt 1992; Lee at al. 2000; C. Newell unpubl. data). Grazing not only limits snow tussock flowering, seed production, and seedling recruitment, but also, indirectly through trampling, reduces the quality and extent of intertussock sites where snow tussock seedlings establish (Rose & Platt 1992, C. Newell unpubl. data). Grazed snow tussock populations tend to have more older, senescent individuals and fewer juveniles and seedlings than ungrazed populations (Rose & Platt 1992). In this study the significant negative effect of thar density on juvenile and mature tussock basal area, height, and density shows that thar continue to have a deleterious effect on the dynamics of snow tussock stands. However, increases in the basal area and numbers of mature tussocks over time demonstrate a continuing recovery in the eight catchments from higher thar densities in the past. Recovery reflects an increase in the size of mature tussocks as well as the growth and transition of juvenile-sized individuals to the mature age/state class. The absence of a pattern for seedlings probably relates to the short period of the study, variability of time between high flowering years (see McKone et al. 1998) and the length of time for seedling establishment following a high flowering year (C. Newell unpubl. data). High flowering years cause a pulse of recruitment into the seedling class and also reduce the energy that a plant can put into vegetative growth (Rose & Platt 1992).

We would expect that increases in the basal area of the dominant snow tussocks would eventually have an effect on the composition and species richness of the plots. However, a number of factors may contribute to the lack of a relationship between thar density and species richness. The foremost of these is the uneven time period over which richness was quantified across the eight catchments. The period (1999–2003) between species richness estimates for three of the eight catchments is likely to be too short to find real changes, especially if past high thar densities had removed or limited some species and so reduced available seed sources. In addition, species richness could only be quantified for a subset of plots in another two catchments. Species richness values may also be affected by short-term influences, such as seasonal variation in climate, which make it important to compare data from at least three time periods to quantify any real changes in richness. In addition, there may have been year-to-year variation in the taxonomic ability of field staff collecting the data. Nevertheless, a simpler analysis of the frequency of occurrence of other herbs and shrubs eaten by introduced herbivores shows that some taxa have also increased in abundance under the regime of reduced thar numbers of the last decade.

7. Recommendations

- The vegetation plots should be maintained and remeasured about every 5 years if thar (and other herbivore) densities remain at current historically low levels. However, it is important to ensure that the standard methodologies are adhered to.

  Changes in vegetation condition and structure have (at least since the major reductions in ungulate numbers in the 1970s and 1980s) been subtle and so frequent assessment is not justified. However, we note the current potential for deer to reinvade these alpine grasslands as the wild venison industry declines, and that some of the thar plots might be used to assess their impact.

- The surveys of thar and other ungulate numbers in the eight study catchments should be continued as these are the only reliable measures of trends in thar densities available.

8. Acknowledgements

We thank the many Department of Conservation staff and volunteers, and Landcare Research staff involved with the numerous vegetation and animal surveys associated with this study over the years, in particular, Neil Bolton and Tom Belton (DOC), and Morgan Coleman and Richard Heyward (Landcare Research). We thank Richard Duncan, Phil Cowan, Terry Farrell, Phil Knightbridge, Christine Bezar, Dave Kelly and two anonymous referees for comments on drafts of this report, Greg Arnold for statistical advice, and Wendy Weller for final word processing. Unpublished data cited by C. Newell refers to a *Chionochloa* study in the Harper-Avoca, Canterbury, where stand dynamics parameters have been remeasured annually between 1989 and 2004.

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10. Appendices

Appendix 1. Summary of information collected for permanent vegetation plots in this thar impact study

Appendix 2. Thar impact site data files archived in the National Vegetation Survey databank at Landcare Research, Lincoln.

Appendix 3. Changes in frequency of selected herb and shrub species on 1 × 1 m quadrats and mean basal area per plot of *Chionochloa* spp. in eight study sites.

Appendix 4. Oblique photographs of selected plots taken in each survey.

Appendix 1. Summary of information collected for permanent vegetation plots in this thar impact study

Catchments	**Hooker Tasman**	**FitzGerald Godley**	**Townsend Landsborough**	**Whymper Whataroa**	**Carneys Creek Rangitata**	**North Branch Godley**	**Zora Landsborough**	**Arbor Rift Landsborough**
Area (km^2)	17.5	8	5	24	19	20	6	4.5
Intervention density (thar/km^2)	< 1.0	< 1.0	1.5	2	2.5	2	1.5	1.5
Target density for study (relative to intervention density – I.D.)	0.5 (below I.D.)	0.5 (below I.D.)	0.75 (below I.D.)	2 (at I.D.)	2.5 (at I.D.)	6.0 (above I.D.)	1.5 (at I.D.)	4.5 (above I.D.)
Average thar density (thar/km^2) since first vegetation plots established	0.8	1.0	2.1	2.6	4	6.6	8.9	12.3
Average chamois density (chamois/km^2) since first vegetation plots established	0	0	0	0.4	0.3	0	0	0
Year thar established (Caughley 1970)	1904	1948	1947	1960s	1948	1948	1947	1947
Dominant tussock (*Chionochloa*) species	*C. pallens*	*C. pallens*	*C. pallens*	*C. pallens*	*C. pallens*	*C. rigida*	*C. pallens*	*C. pallens*
Number of vegetation plots remeasured	9	15	15	12	18	16	15	17
Ecological region	D'Archiac	Tasman	Aspiring	Whataroa	D'Archiac	Tasman	Aspiring	Aspiring
Ecological district	Mt Cook	Godley	Landsborough	Glaciers	Armoury	Godley	Landsborough	Landsborough
Ecological code	58.03	60.01	51.03	50.06	58.02	60.01	51.03	51.03
Map no. (NZMS 260 series)	H36	I35	H36	I35	I35	I36	H36 / H37	H37
DOC Conservancy	Canterbury	Canterbury	West Coast	West Coast	Canterbury	Canterbury	West Coast	West Coast

Catchments	**Hooker Tasman**	**FitzGerald Godley**	**Townsend Landsborough**	**Whymper Whataroa**	**Carneys Creek Rangitata**	**North Branch Godley**	**Zora Landsborough**	**Arbor Rift Landsborough**
Vegetation plot survey years:						1990		1992
	1992			1993	1992	1992		1994
	1995	1999	1999	1997	1997	1996	1999	1997
	2001	2003	2003	2002	2002	2001	2003	2002
Data in NVS up to year:	2001	2003	2003	2002	2002	2001	2003	2002
Data on CD to DOC West Coast up to year:	2001	2003	2003	2002	2002	2001	2003	2002
Survey year	1992			1993	1992	1990		1992
Number of vegetation plots	9			12	20	15		9
Recce data. Files are in excel (XL) and text (txt)	yes (txt)			yes (XL+txt)	yes (txt)	yes (13 plots–txt)		yes (XL+txt)
Tussocks measured	yes			yes	yes	yes		yes
Tussocks tagged	no			no	no	no		no
***Aciphylla* or shrubs measured**	*Aci*, shrubs			*Aci*, shrubs	*Aci*, shrubs	*Aci*, shrubs		*Aci*, shrubs
Ground cover per quadrat	yes			yes (8 plots)	yes	yes		yes
All species cover per quadrat	yes (no tiers)			no	yes (no tiers)	yes (tiers)		yes (no tiers)
Animal pellets by quad or lines	quad			quad	quad	quad		quad
Data entered	yes			yes	yes	yes		yes
In NVS	yes			yes	yes	yes		yes

Catchments	**Hooker Tasman**	**FitzGerald Godley**	**Townsend Landsborough**	**Whymper Whataroa**	**Carneys Creek Rangitata**	**North Branch Godley**	**Zora Landsborough**	**Arbor Rift Landsborough**
Survey year	1995			1997	1997	1992		1994
Number of vegetation plots	9			12	18	6		8
Recce data	no			yes (XL+txt)	yes (txt)	yes (txt)		yes (XL+txt)
Tussocks measured	yes			yes	yes	yes		yes
Tussocks tagged	no			most	yes	no		no
***Aciphylla* or shrubs measured**	*Aci*, shrubs			*Aci*, shrubs	*Aci*, shrubs	*Aci*, shrubs		*Aci*, shrubs
Ground cover per quadrat	yes			yes	yes	yes		no
All species cover per quadrat	yes (tiers)			yes (no tiers)	yes (tiers)	yes (no tiers)		no
Animal pellets by quad or lines	quad			quad	quad	quad		quad
Data entered	yes			yes	yes	yes		yes
In NVS	yes			yes	yes	yes		yes
Survey year	2001	1999	1999			1996	1999	1997
Number of vegetation plots	9	15	15			16 (10 – '90)	15	17
Recce data	yes (txt)	yes (txt)	yes (txt)			yes (txt)	yes (txt)	yes (XL+txt)
Tussocks measured	yes	yes	yes			yes	yes	yes
Tussocks tagged	yes	yes	yes			sample	yes	sample
***Aciphylla* or shrubs measured**	*Aci*, shr- ht	*Aci + R.lya*	*Aci + R.lya*			*Aci*, shrubs	*Aci + R.lya*	*Aci*, shrubs
Ground cover per quadrat	yes	no	no			yes	no	yes
All species cover per quadrat	-	Scott-height	Scott-height			yes (tiers)	Scott-height	yes (tiers)
***Chi, Aci, Ran* covers - no tiers**	yes	no	no			-	no	-
Animal pellets by quad or lines	lines	lines	lines			quad	lines	quad
Data entered	yes	yes	yes			yes	yes	yes
In NVS	yes	yes	yes			yes	yes	yes

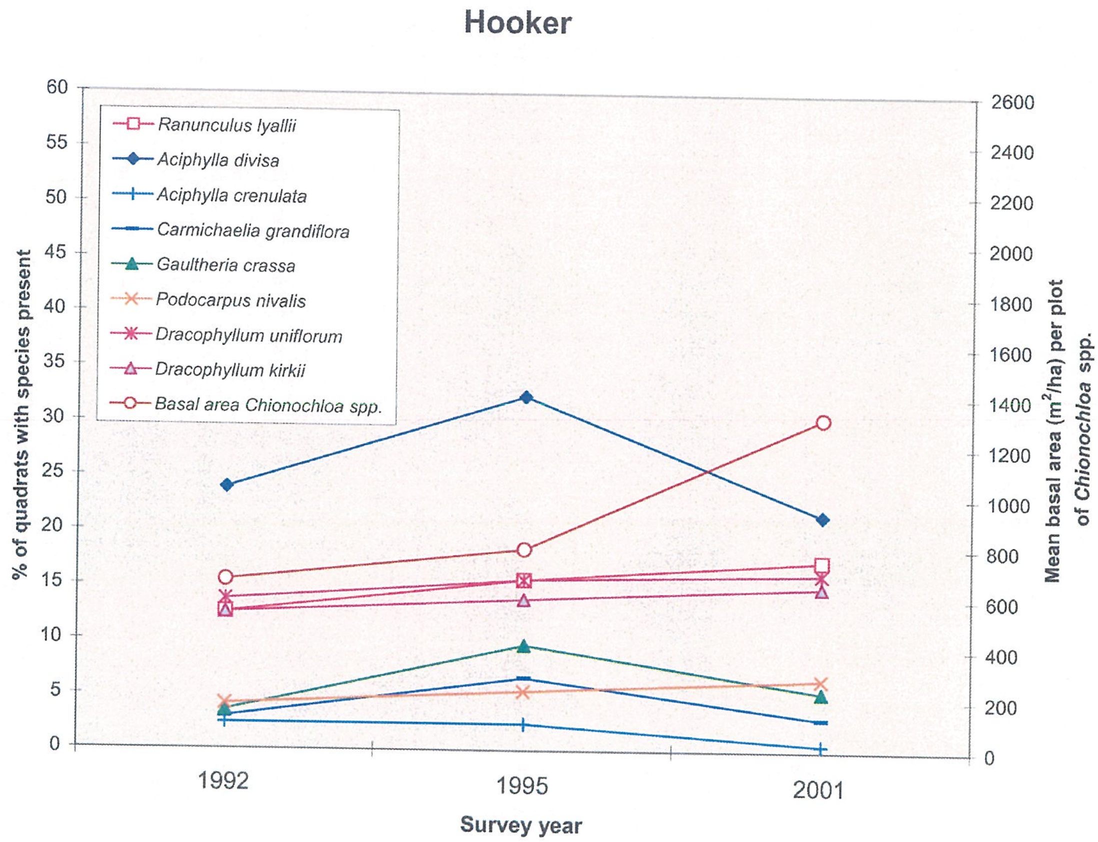
Catchments	**Hooker Tasman**	**FitzGerald Godley**	**Townsend Landsborough**	**Whymper Whataroa**	**Carneys Creek Rangitata**	**North Branch Godley**	**Zora Landsborough**	**Arbor Rift Landsborough**
Survey year		2003	2003	2002	2002	2001	2003	2002
Number of vegetation plots		15	15	11	18	19 (13 – '90)	15	17
Recce data		yes (txt)	yes (txt)	yes (txt)	yes (txt)	yes (txt)	yes (txt)	yes (txt)
Tussocks measured		yes	yes	yes	yes	yes	yes	yes
Tussocks tagged		yes	yes	yes	yes	yes	yes	yes
***Aciphylla* or shrubs measured**		*Aci*, shr - ht	*Aci*, shr - ht	*Aci*, shr - ht	*Aci*, *Ran*, shr - ht	*Aci*, shr – ht	*Aci*, shr - ht	*Aci*, *Ran*, shr - ht
Ground cover per quadrat		yes	yes	yes	yes	yes	yes	yes
***Chi*, *Aci*, *Ran* covers - no tiers**		yes	yes	yes	yes	yes	yes	yes
Animal pellets by quad or lines		lines	lines	lines	lines	lines	lines	lines
Data entered		yes	yes	yes	yes	yes	yes	yes
In NVS		yes	yes	yes	yes	yes	yes	yes

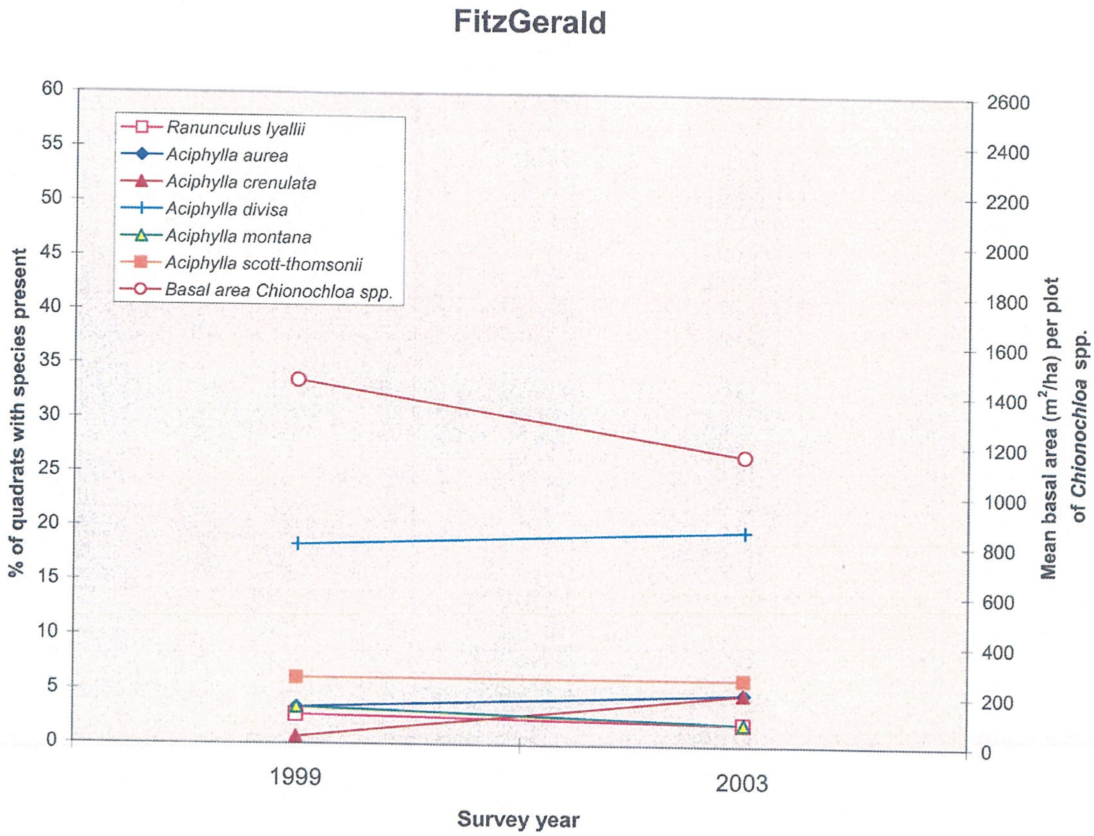
Appendix 2. Thar impact site data files archived in the National Vegetation Survey databank at Landcare Research, Lincoln.

Catchment	Year	Files	Notes (Excel files - XLS; text files - REC, TXT)
Arbor Rift Landsborough	1992	ARBOR92.REC AREC92CV.XLS ARB92CVAN.XLS ARB92DM.XLS	Recce file in text form Recce data in Excel form Quadrat ground & species cover data (not tiered), animal pellet P/A Diameters (diams) & heights (hts) etc for tussocks, *Aciphylla* & shrubs
	1994	ARBOR94.REC AREC94CV.XLS ARB94DM.XLS	Recce file in text form Recce data in Excel form Diams & hts for tussocks, *Aci.* & shrubs, animal pellet P/A per quad *(Species & ground cover not measured per quadrat)*
	1997	ARBOR97.REC AREC97CV.XLS ARB97CVAN.XLS ARB97DM.XLS APLOT.XLS	Recce file in text form Recce data in Excel form Quadrat ground & species cover (tiered), animal pellet P/A per quad Diameters & hts for tussocks, *Aci* & shrubs, incl. tussock age-states Plot characteristics for 1992, '94, '97
	2002	ARB02DM.XLS ARB02CV.XLS ARB02AN.XLS ARB02RC.REC	Diameters & heights for tussocks etc. Species (not tiered) & ground cover per quadrat Animal pellet data for 8 lines (40 plots) per tussock plot Plot recce data - text file
Carneys Creek Rangitata	1992	CARN92CV.XLS CARN92DM.XLS CARNCHI92.XLS ANDENSITY.XLS CARN92RC.REC	Species (not tiered) & ground cover per quadrat Diams & hts for tussocks, *Aci* & shrubs, animal pellet P/A per quad Shows age states of tussocks with diameter data (only *Chionochloa*) Animal densities from animal counts in Carney's Creek up to 1997 Plot recces - text file
	1997	CARN97CV.XLS CARN97DM.XLS CARNCHI97.XLS CARN9297.XLS ANDENSITY.XLS CARN97RC.REC	Species (tiered) and ground cover per quadrat Diams & hts for tussocks, *Aci*, & shrubs, animal pellet P/A per quad Shows age states of tussocks with diameter data (*Chionochloa* only) Data from 1992 & 1997 used in the statistical analyses Animal densities from animal counts in Carney's Creek up to 1997 Plot recces - text file
	2002	CARN02DM.XLS CARN02CV.XLS CARN02AN.XLS CARN02RC.REC	Diameters & heights for tussocks etc. Species (not tiered) & ground cover per quadrat Animal pellet data for 8 lines (40 plots) per tussock plot Plot recce data - text file
Hooker Tasman	1992	HOOK92CV.XLS HOOK92DM.XLS HOOK92RC.REC	Species (not tiered) and ground cover per quadrat Diams & hts for tussocks, *Aci*, & shrubs, animal pellet P/A per quad Plot recces - text file
	1995	HOOK95CV.XLS HOOK95DM.XLS HCLASS25.XLS	Species (not tiered) & ground cover per quadrat Diams & hts for tussocks, *Aci*, & shrubs; animal pellet P/A Age classes of tussocks for 1992 & 1995 *(Recces not done)*
	2001	HOOK01CV.XLS HOOK01DM.XLS HOOK01AN.XLS HOOK01RC.REC	Species (not tiered) & ground cover per quadrat Diams & hts for tussocks, *Aci*, & shrubs (hts only); tag nos Presence / absence of animal pellets on 40 plots per tussock plot Recce data from each of 9 plots – text file
North Branch Godley	1990	NRTH90CV.XLS NRTH90DM.XLS NRTH90RC.REC	Species (tiered) & ground cover per quadrat Diams & hts for tussocks, *Aci*, & shrubs; animal pellet P/A per quad Plot recces - text file
North Branch Godley	1992	NRTH92CV.XLS NRTH92DM.XLS NRTH92RC.REC	Species (not tiered) & ground cover per quadrat Diams & hts for tussocks, *Aci*, & shrubs; animal pellet P/A per quad Plot recces - text file

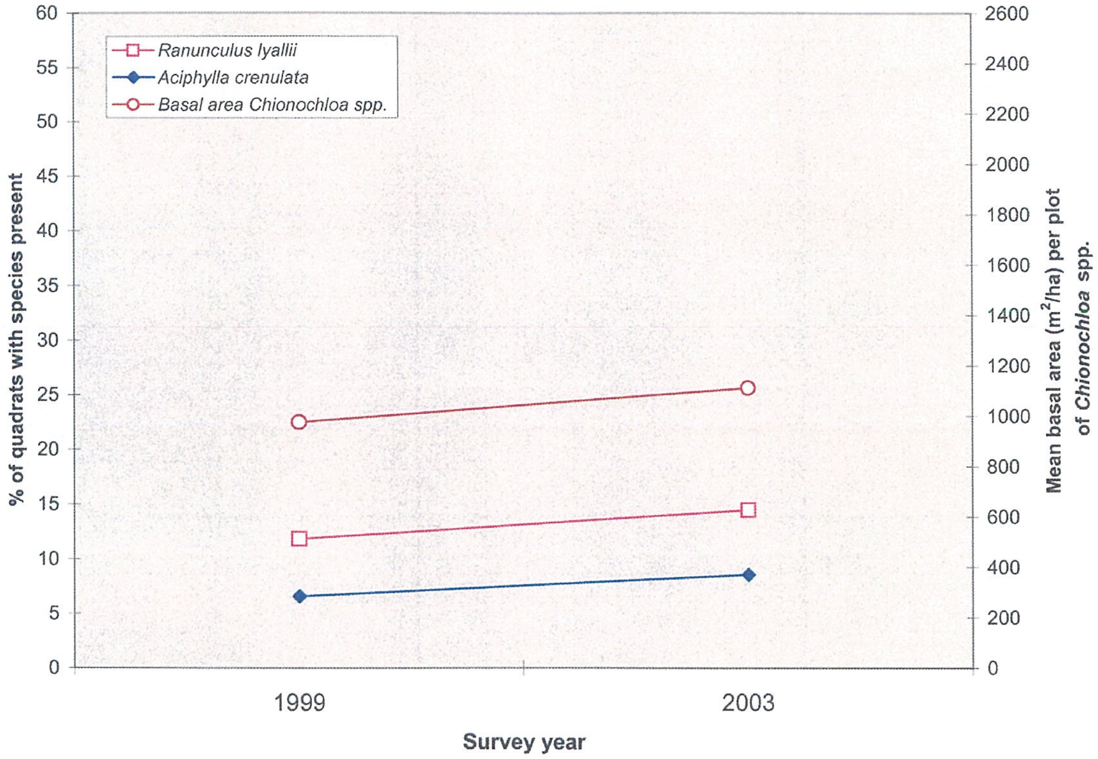
Catchment	Year	Files	Notes (Excel files - XLS; text files - REC, TXT)
	1996	NRTH960CV.XLS NRTH962CV.XLS NRTH960DM.XLS NRTH962DM.XLS NRTH96RC.REC	Species (tiered) & ground cover per quad for plots estab. in 1990 Species (tiered) & ground cover per quad for plots estab. in 1992 Diams & hts for tussocks, *Aci*, & shrubs for plots estab. in 1990; + pellets Diams & hts for tussocks, *Aci*, & shrubs for plots estab. in 1992; + pellets Plot recces - text file
	2001	NRTH01CV.XLS NRTH01DM.XLS NRTH01AN.XLS NRTH01RC.REC	Species (not tiered) & ground cover per quadrat Diams & hts for tussocks & *Aciphylla*. Shrub hts only Animal pellet data for 8 lines (40 plots) per tussock plot Recce data - text file
Whymper Whataroa	1993	WHVLB93.XLS WHYM93DM.XLS WHRE93CV.XLS WHREC93.REC WHREC93.INI	Ground cover per quadrat Diams & hts for tussocks, *Aci.*, & shrubs; animal pellet P/A per quad Recce data in Excel form Recce data - text file Recce - initial file (may not need this now) *(species cover per quadrat not done)*
	1997	WHYM97CV.XLS WHYM97DM.XLS WPLOT937.XLS WHRE97CV.XLS WHREC97.REC WHREC97.INI	Species (not tiered) & ground cover per quadrat Diams & hts for tussocks, *Aci.*, & shrubs; animal pellet P/A per quad Plot characteristics 1993 and 1997 Recce data in Excel form Recce data - text file Recce - initial file *(may not need this now)*
	2002	WHYM02DM.XLS WHYM02CV.XLS WHYM02AN.XLS WHYM02RC.REC	Diams & hts for tussocks etc. Species (not tiered) & ground cover per quadrat Animal pellet data for 8 lines (40 plots) per tussock plot Plot recce data - text file
Zora, Townsend & FitzGerald combined files	1999	ZTFtuss99dm.XLS ZTFrec99.TXT ZTFpel99.XLS	Diams & hts for tussocks, *Aciphylla*, and *Ranunculus lyallii* Recce data - text file Pellet count data from plots on lines around each tussock plot
Zora Landsborough	1999	ZORA99DM.XLS ZORA99REC.TXT	Diams & hts for tussocks, *Aciphylla* and *Ranunculus lyallii* Recce data - text file
	2003	ZORA03DM.XLS ZORA03CV.XLS ZORA03AN.XLS ZORA03RC.REC	Diams & hts for tussocks etc. Species (not tiered) & ground cover per quadrat Animal pellet data for 8 lines (40 plots) per tussock plot Plot recce data - text file
Townsend Landsborough	1999	TOWN99DM.XLS TOWN99REC.TXT	Diams & hts for tussocks, *Aciphylla*, and *Ranunculus lyallii* Recce data - text file
	2003	TOWN03DM.XLS TOWN03CV.XLS TOWN03AN.XLS TOWN03RC.REC	Diams & hts for tussocks etc. Species (not tiered) & ground cover per quadrat Animal pellet data for 8 lines (40 plots) per tussock plot Plot recce data - text file
FitzGerald Godley	1999	FITZ99DM.XLS FITZ99REC.TXT	Diams & hts for tussocks, *Aciphylla* and *Ranunculus lyallii* Recce data - text file
	2003	FITZ03DM.XLS FITZ03CV.XLS FITZ03AN.XLS FITZ03RC.REC	Diams & hts for tussocks etc. Species (not tiered) & ground cover per quadrat Animal pellet data for 8 lines (40 plots) per tussock plot Plot recce data - text file

Appendix 3. Changes in frequency of selected herb and shrub species on 1 × 1 m quadrats and mean basal area per plot of *Chionochloa* spp. in eight study sites.

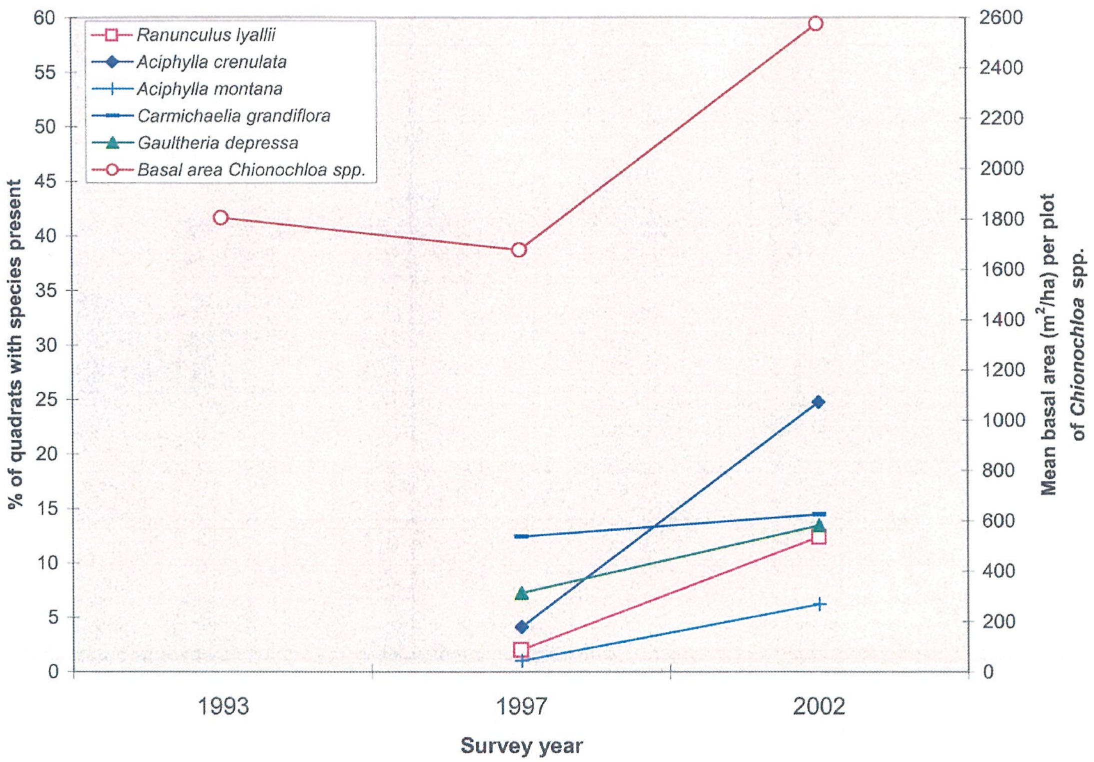

Hooker
Ranunculus lyallii
Aciphylla divisa
Aciphylla crenulata
Carmichaelia grandiflora
Gaultheria crassa
Podocarpus nivalis
Dracophyllum uniflorum
Dracophyllum kirkii
Basal area Chionochloa spp.
% of quadrats with species present
Mean basal area (m2/ha) per plot of Chionochloa spp.
1992
1995
2001
Survey year

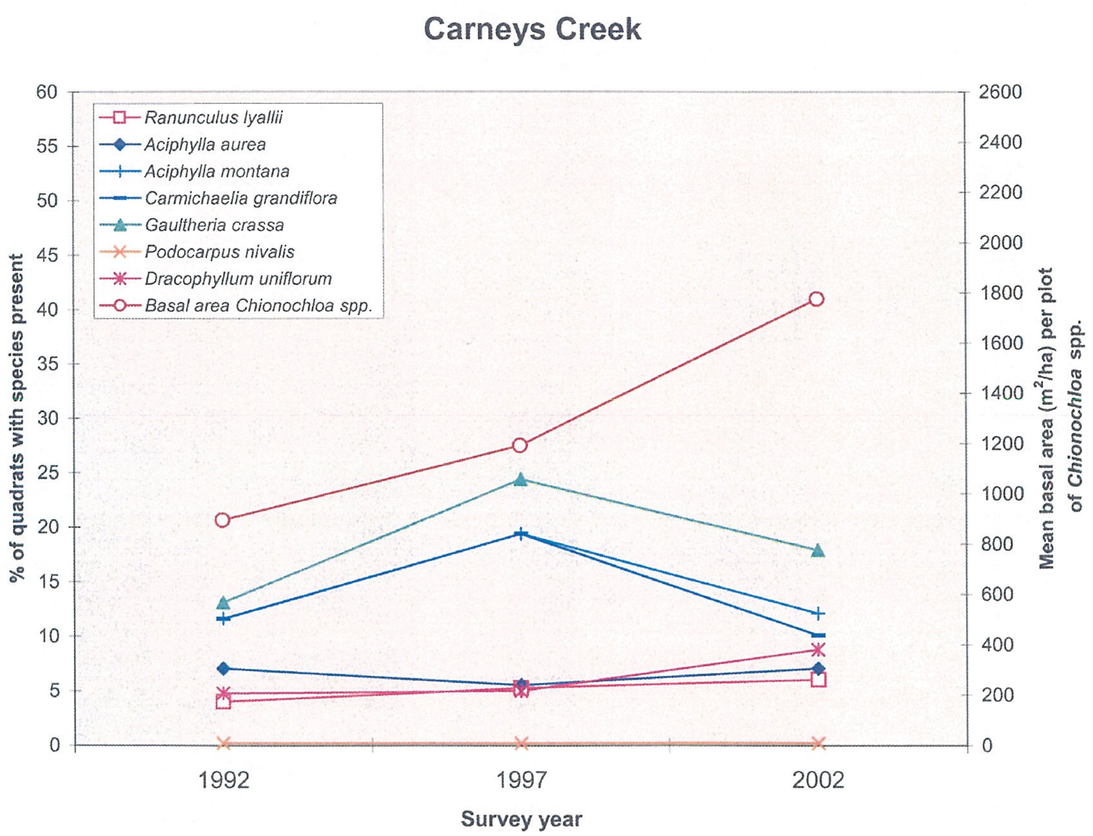

FitzGerald
Ranunculus lyallii
Aciphylla aurea
Aciphylla crenulata
Aciphylla divisa
Aciphylla montana
Aciphylla scott-thomsonii
Basal area Chionochloa spp.
% of quadrats with species present
Mean basal area (m2/ha) per plot of Chionochloa spp.
1999
2003
Survey year

Townsend

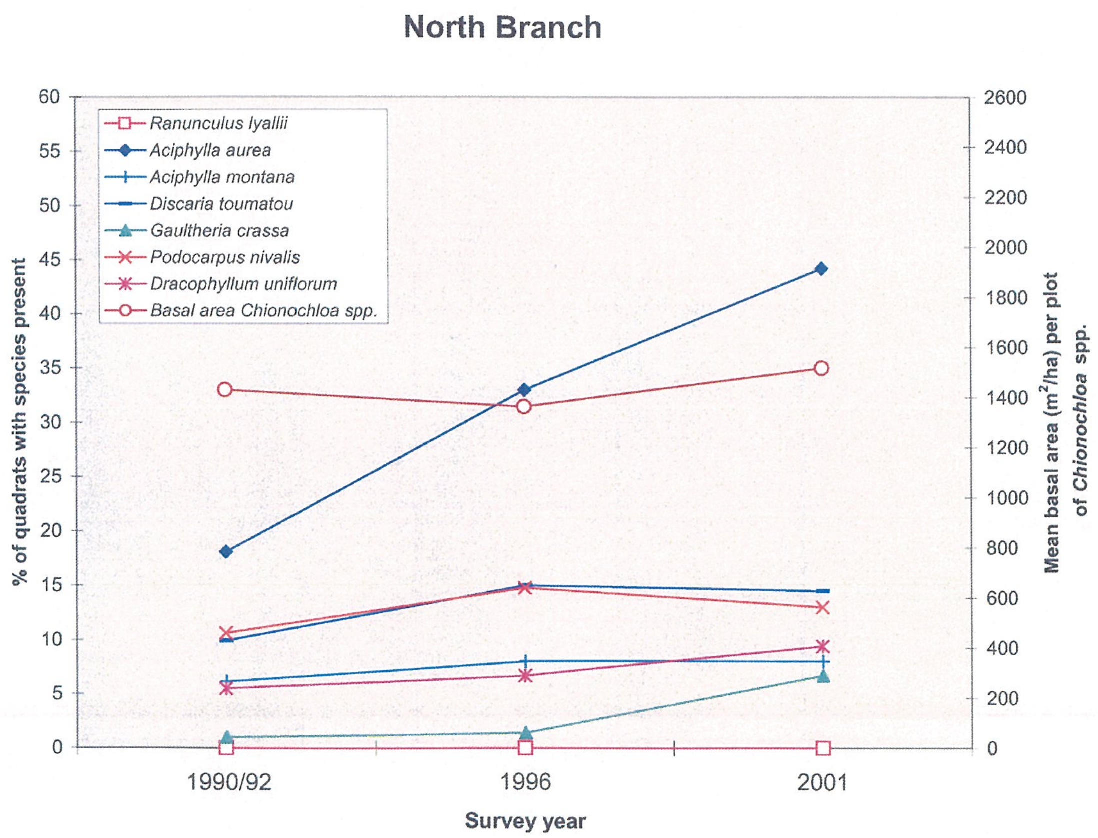


Whymper



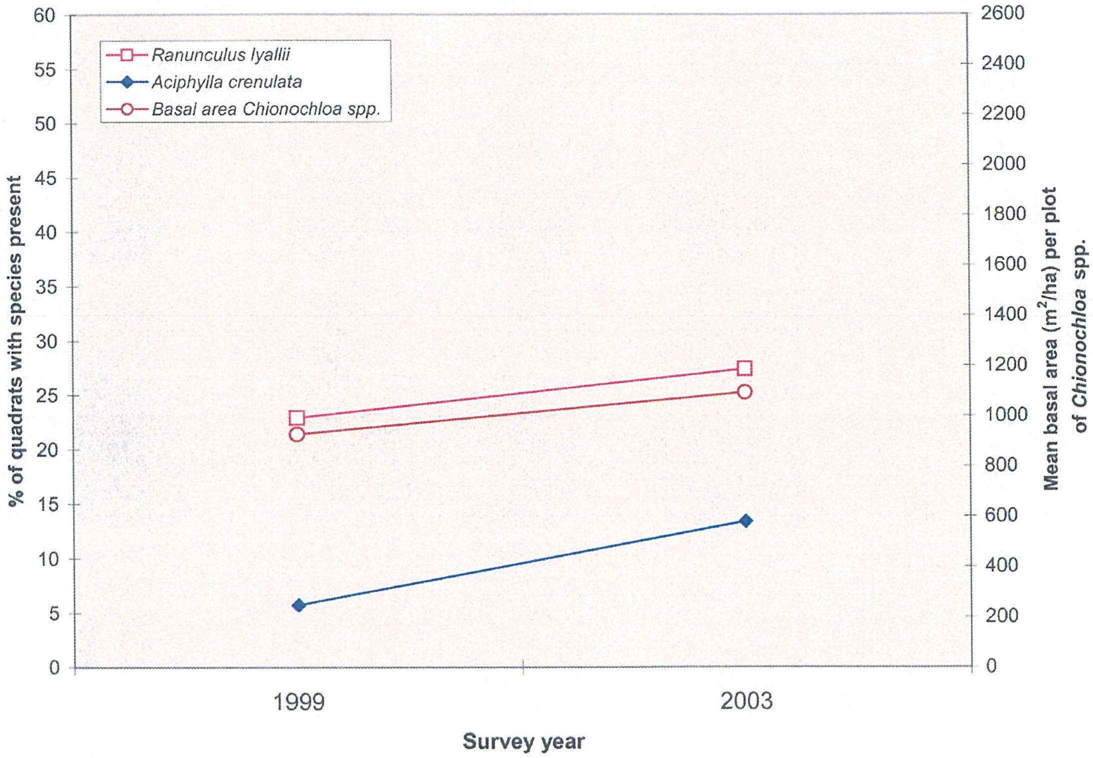


Carneys Creek
Ranunculus lyallii
Aciphylla aurea
Aciphylla montana
Carmichaelia grandiflora
Gaultheria crassa
Podocarpus nivalis
Dracophyllum uniflorum
Basal area Chionochloa spp.
% of quadrats with species present
Mean basal area (m²/ha) per plot of Chionochloa spp.
0
5
10
15
20
25
30
35
40
45
50
55
60
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
1992
1997
2002
Survey year

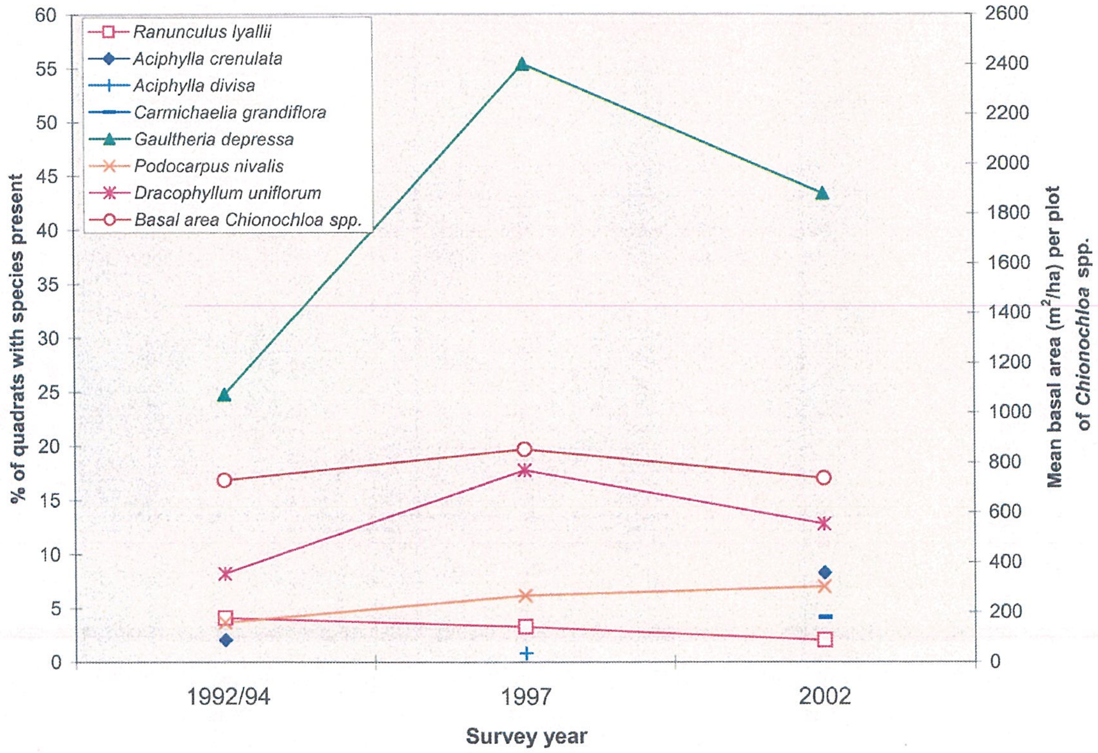


North Branch
Ranunculus lyallii
Aciphylla aurea
Aciphylla montana
Discaria toumatou
Gaultheria crassa
Podocarpus nivalis
Dracophyllum uniflorum
Basal area Chionochloa spp.
% of quadrats with species present
Mean basal area (m²/ha) per plot of Chionochloa spp.
0
5
10
15
20
25
30
35
40
45
50
55
60
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
1990/92
1996
2001
Survey year

Zora



Arbor Rift



Appendix 4. Oblique photographs of selected plots taken in each survey.

Hooker: Oblique photographs of plot 9, Hooker, Tasman taken in 1992 (top left), 1995 (top right), and 2001 (bottom). This plot is at 1255 m a.s.l. and is dominated by *Chionochloa pallens, Celmisia verbascifolia* and *Celmisia walkeri*. Tussocks were flowering in 1995. Basal area of tussocks improved on this plot from 797 to 1283 to 1488 m^2/ha but density of tussocks >1 cm diameter was variable, changing from 27 222 to 32 778 to 21 111 tussocks/ha. Senescent tussocks were counted in 1992 only. No seedlings were counted in any of the surveys.

Fitzgerald: Oblique photographs of plot 4, Fitzgerald, Godley taken in 1999 (left) and 2003 (right). This plot is at 1530 m a.s.l. and is dominated by *Chionochloa pallens* and *Rytidosperma setifolium*. Basal area of tussocks decreased from 1732 to 1673 m^2/ha but density (>1 cm diameter) increased from 37 000 to 41 000 tussocks/ha over the survey period. Seedlings were present in both years. Senescent tussocks were counted in 1999 only.

Townsend: Oblique photographs of plot 11, Townsend, Landsborough taken in 1999 (top) and 2003 (bottom). This plot is at 1200 m a.s.l. and is dominated by *Chionochloa pallens* and *C. oreophila*. Basal area of tussocks increased from 658 to 1003 m^2/ha but density (>1 cm diameter) decreased from 17 333 to 16 667 tussocks/ha over the survey period. No seedlings were noted but senescent tussocks were present in both years.

Whymper: Oblique photographs of plot 10, Whymper, Whataroa taken in 1993 (top), 1997 (middle), and 2002 (bottom). This plot is at 1350 m a.s.l. and is dominated by *Chionochloa pallens, Poa colensoi* and *Schoenus pauciflorus*. Condition of tussocks varied with basal area changing from 3957 to 2992 to 4513 m^2/ha and density (>1 cm diameter) from 44 375 to 50 000 to 40 000 over the survey years. Seedlings were present only in 1993 and 1997. Senescent tussocks were present in all years.

Carneys Creek: Oblique photographs of plot 17, Carney's Creek, Rangitata taken in 1992 (top), 1997 (middle), and 2002 (bottom). This plot is at 1600 m a.s.l. and is dominated by *Chionochloa pallens* and *Celmisia lyallii*. Condition of tussocks on this plot improved with basal area increasing from 531 to 1192 to 1196 m^2/ha and density (>1 cm diameter) increasing slightly from 13 000 to 13 000 to 14 000. Seedlings were present only in 1997 with no senescent tussocks present in any survey year.

North Branch: Oblique photographs of plot 21, North Branch, Godley taken in 1992 (top left), 1996 (top right), and 2001 (bottom). This plot is at 1600 m a.s.l. and is dominated by *Chionochloa rigida*, *Dracophyllum pronum* and *Podocarpus nivalis*. Condition of tussocks remained much the same with basal area increasing slightly from 1377 to 1382 to 1493 m^2/ha and density of >1 cm diameter tussocks varying from 24 000 to 24 500 to 20 500. Senescent tussocks were noted in all survey years. Seedlings were present in 1992 and 1996 only.

Zora: Oblique photographs of plot 10, Zora, Landsborough taken in 1999 (left) and 2003 (right). This plot is at 1500 m a.s.l. and is dominated by *Chionochloa pallens* and *C. crassiuscula*. Condition of tussocks on this plot improved slightly over the survey period. Basal area of tussocks increased from 130 to 315 m^2/ha and density (>1 cm diameter) from 40 000 to 41 000 tussocks/ha. Seedlings and senescent tussocks were noted in 1999 only.

Arbor Rift: Oblique photographs of plot 18, Arbor Rift, Landsborough taken in 1994 (top), 1997 (middle), and 2002 (bottom). This plot is at 1150 m a.s.l. and is dominated by *Chionochloa pallens* and *Celmisia walkeri*. Condition on this plot varied over the survey period with tussock basal area changing from 810 to 563 to 771 m^2/ha and density (>1 cm diameter) increasing from 16 500 to 25 500 and then to 23 000 tussocks/ha. Seedlings were present only in 1997. Senescent tussocks were noted in all years.