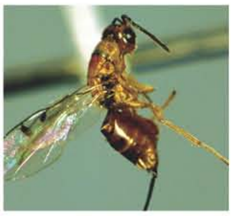
Impact of Himalayan tahr (*Hemitragus jemlahicus*) on snow tussocks in the Southern Alps, New Zealand



Landcare Research
Manaaki Whenua

Impact of Himalayan tahr (*Hemitragus jemlahicus*) on snow tussocks in the Southern Alps, New Zealand

Jennyffer Cruz, Caroline Thomson

Landcare Research

John Parkes

Kurahaupo Consulting

Prepared for:

Department of Conservation

70 Moorhouse Ave
Addington
Christchurch 8011

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Landcare Research, Gerald Street, PO Box 69040, Lincoln 7640, New Zealand,
Ph +64 3 321 9999, Fax +64 3 321 9998, www.landcareresearch.co.nz

Reviewed by:	*Approved for release by:*
Andrew Gormley (Quantitative Wildlife Ecologist) Sarah Richardson (Researcher) Landcare Research	Andrea Byrom Portfolio Leader – Managing Invasive Weeds, Pests & Diseases
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Summary

Project and Client

- The Department of Conservation has been monitoring the impacts of Himalayan tahr (*Hemitragus jemlahicus*) on alpine vegetation in eight study catchments in the Southern Alps since 1990. In 2014, the Department commissioned Landcare Research to update the analysis of this series of surveys.

Objectives

- The Department's overall aim was to determine whether the densities of tahr set in the national *Himalayan Thar Control Plan* allow alpine vegetation to be in an ecologically acceptable state. The objectives of this report are to determine whether the extent of tahr activity about vegetation monitoring plots:

  1) was related to changes in the condition of snow tussocks (particularly *Chionochloa pallens*, *C. flavescens*, *C. rigida*), and in overall vegetation cover since the sites were first measured, and

  2) could be related to overall catchment densities of tahr,

  to determine which densities allow vegetation recovery and how these densities compare to the proposed intervention densities set in the national plan.

Methods

- Individual snow tussocks were measured on 117 variable-area plots, each with at least 20 individuals across all species, in up to four surveys in eight catchments since 1990. The percentage of each plot covered with vegetation was also measured. The proportion of 'pellet plots' with faecal pellets from ungulates (assumed to be mostly from tahr) was used as an index of ungulate activity about each vegetation plot. Estimates of tahr densities were also obtained by counting the numbers of tahr in each study catchment. Methods used changed between catchments and through time.
- Changes in condition were assessed for mature tussocks using linear-mixed effects models from the lme4 package in R version 3.0.2. Height (cm) was modelled as the response variable with plot ID and catchment ID as random intercepts, and crown death (%), altitude (m), year of monitoring, live diameter (cm), aspect ($\circ$) and ungulate activity as fixed coefficients. Ungulate activity was also included as a random, catchment-level coefficient to evaluate differences in responses of tussocks to ungulate activity between catchments.
- Changes in vegetation cover were assessed using generalised Poisson models including aspect ($\circ$), altitude (m), year of monitoring and ungulate activity as predictors.
- Lastly, catchment-level estimates of ungulate activity were related to estimates of tahr density derived from counts of tahr using a generalised Poisson model with ungulate activity as a response variable and the log of tahr density as a predictor.

Results

- Across catchments, tussock height had a strong negative relationship with ungulate activity about each vegetation plot. Tussock height also had a quadratic relationship with tussock diameter, a negative relationship with plot altitude, a weak positive relationship with crown death, and a weak negative relationship with year of monitoring. The results suggest that, on average across catchments, tussock condition (i.e. height) has decreased slightly during the monitoring period and continues to be negatively affected by ungulate activity. The relationship between height and ungulate activity differed between catchments.
- Across catchments, vegetation cover was higher on south-facing slopes, decreased with ungulate activity and increased throughout the monitoring period, suggesting overall recovery of plants across catchments over the last two decades, but also an ongoing negative effect of tahr where densities are high.
- There was large uncertainty in the predicted relationship between catchment-level estimates of tahr densities from counts of animals and activity around the vegetation plots measured by the pellet index. This made it impossible to then relate changes in vegetation condition to catchment-level estimates of tahr density without violating pseudo-replication rules.
- The aim set out by the tahr management plan could therefore not be directly met from this analysis. However, we note that our measure of tussock condition had, on average, slightly declined over the monitoring period while tahr densities in most study catchments had, on average, exceeded the intervention densities set in the plan. That is, we have no strong evidence to suggest the original upper range of target densities set in the national plan would, if met, not allow snow tussocks to maintain their current condition. Whether that is 'acceptable' is unclear and would need to be tested by comparing snow tussock conditions in areas where tahr were reduced to zero densities.

Recommendations

- Changes in condition, such as cover, of other common species on these plots (e.g. *Aciphylla* spp.) might be analysed to supplement this report, but if DOC wishes to monitor tahr impacts on rare or vulnerable species (such as *Ranunculus*) it would be best to design a system specifically aimed at them, e.g. monitor survival along transects or at sites where they occur.
- The current aerial methods to estimate tahr densities by counting tahr across the whole study catchments may have practical uses for managers wanting to confirm over-abundance, but these estimates are not reliable enough to meet the specific prescriptions for intervention in the tahr plan, let alone the purposes of this study. We recommend using estimates of ungulate activity derived from the pellet plots around the vegetation plots in future analyses, but also recommend that the census count method as described by Challies (1992) be used in the year the vegetation and pellet plots are remeasured to allow better linking of the ungulate activity to catchment-level measures of tahr density, and thus to the tahr-plan intervention densities.

1 Introduction

The Department of Conservation (DOC) has been monitoring the impacts of Himalayan tahr (*Hemitragus jemlahicus*) on snow tussock (*Chionochloa* spp.) communities in eight study catchments in the Southern Alps since 1990. In 2014, DOC commissioned Landcare Research to update the analysis of the study data following remeasurements in all study catchments between 2011 and 2013.

2 Background

The biological and management history of Himalayan tahr in New Zealand is briefly summarised here to place this project in context.

Tahr were introduced to New Zealand in 1904 as game meat and quickly reached high densities (over 30 tahr/km^2 were recorded), spreading over about 6000 km^2 of the Southern Alps (Forsyth & Tustin 2005; Parkes 2006). High densities of tahr led to negative impacts on native vegetation in alpine areas (Anderson & Henderson 1961; Burrows 1974). As tahr populations increased in density, a shift from tall snow tussock species to shorter *Festuca* tussock species was observed (Caughley 1970). In response to these negative impacts, the government decided to control tahr populations following the removal of all legal protection from the species in 1930. This initial attempt at control had limited success until aerial hunting by helicopter was introduced in the late 1960s. Over 90% of the population was culled between 1971 and 1982 following the development of markets for game meat and the use of helicopters to harvest tahr. The residual population of tahr dropped to a few thousand animals as a result. At these lower densities, the economics of harvesting tahr for game became marginal. This, in conjunction with lobbying by recreational hunters who desired to retain tahr as a hunting resource, led to a moratorium on commercial hunting in 1983, which allowed some recovery of the population towards about 10 000 animals over a contracted range of about 5000 km^2. The range included the southern catchments of the Rakaia River in the north to the head catchments of Lake Hawea in the south (Parkes & Tustin 1985).

In 1984, the government called for public comments on how to manage tahr and in response developed a draft management strategy. This draft policy was developed under the ‘balanced use’ mandates of the Forest Service, and revised after the formation of DOC in 1987, with its primary mandate to protect native biodiversity. The preferred outcome of this draft policy was the eradication of tahr. However, a review commissioned by DOC in 1988 concluded that eradication was not feasible at the time, partly because of the government’s limited access across land tenures to control all individuals (Parkes 1988).

The Minister of Conservation published a policy on tahr management in 1991 (Marshall 1991), which set out the government’s rationale for managing tahr. Accepting that eradication was not feasible, the government recognised the role of recreational hunters and set limits on the range of tahr (no more than the 6000 km^2 as at 1991) and on the total population size (no more than 10 000 animals). The 10 000 limit was estimated to represent about 20% of the carrying capacity of tahr in the system. At this level, the tahr population was predicted not to be limited by food availability so that it would not result in the decline of native vegetation (Forsyth & Caley 2006). This assumption required testing.

Following publication of the policy on tahr management, a formal national tahr management plan (DOC 1993) was developed to determine how to achieve the limit of 10 000 individuals across different management units within the tahr range. The plan identified roughly how many tahr needed to be removed each year (c. 2000; Parkes 2006), and proposed various densities across management units ranging from <1 (in the national parks) to 2.5 animals per km^2 (Table 1). The plan specified that tahr should be maintained below intervention densities by hunting from recreational, commercial-guided and game hunters, but that if these densities were exceeded, DOC would intervene with additional control.

The tahr management plan also posed the question of whether the specified intervention densities were adequate to allow alpine vegetation to be in an 'ecologically acceptable' state. Determining what an ecologically acceptable state of the vegetation meant, and relating this to tahr densities and their impacts, was to be achieved by later research. Results from this research were expected to result in adjustments to the intervention densities.

Table 1. Study catchments used in this survey in relation to the management units of the tahr plan

Study catchment	*Area km^2*	*Management unit in plan*	*Intervention density from the tahr plan (tahr/km^2)*	*Year tahr colonised*	*Dominant snow tussock*
Hooker-Tasman	17.5	Mt Cook–Westland NP	<1	1904	*C. pallens*
Carneys Creek (Rangitata)	19	S. Rakaia–Upper Rangitata	2.5	Late 1940s	*C. pallens*
North Branch (Godley)	20	Gammack–Two Thumb	2	Late 1940s	*C. rigida*
Abor Rift (Landsborough)	4.5	Landsborough	1.5	Late 1940s	*C. pallens*
Whymper (Whataroa)	24	S. Whitcombe/ Wanganui/Whataroa	2	1960s	*C. pallens*
Fitzgerald (Godley)	8	Mt Cook–Westland NP	<1	Late 1940s	*C. pallens*
Townsend	5	Landsborough	1.5	Late 1940s	*C. pallens*
Zora	6	Landsborough	1.5	Late 1940s	*C. pallens*

Relevant research since the tahr management plan was published includes studies on:

- The diet of tahr (Parkes & Forsyth 2008)
- The impacts of other herbivores within the range of tahr (Wong & Hickling 1999)
- The population dynamics of tahr (Forsyth & Hickling 1998; Forsyth 1999; Forsyth 2000; Forsyth & Caley 2006)
- Improved control techniques (Simmons & Thomas 2001)

- Improved ways of estimating tahr densities (Forsyth & Hickling 1997; Wilde & Trotter 1999; Choquenot et al. 2000)
- Field assessments of vegetation responses to tahr (Rose & Allen 1990; Parkes & Thomson 1995, 1999; Harding 1996; Sparrow & Kelly 2000; Parkes et al. 2004).

This report presents an update of Parkes et al. (2004), using an updated analytical approach and additional data from vegetation and pellet monitoring conducted during 2011–2013 and from tahr counts from 2008 to 2012.

3 Objectives

- The Department of Conservation's overall aim was to determine whether the densities of tahr set in the national *Himalayan Thar Control Plan* (DOC 1993) allow alpine vegetation to be in an ecologically acceptable state. The objectives of this report are to determine whether the extent of activity by tahr about vegetation monitoring plots:

  1) was related to changes in the condition of snow tussocks (particularly *Chionochloa pallens*, *C. flavescens*, *C. rigida*), and in overall vegetation cover since the sites were first measured, and

  2) could be related to overall catchment densities of tahr,

  to determine which densities allow vegetation recovery and how these densities compare to the proposed intervention densities set in the national plan.

4 Methods

4.1 Study areas

Eight (sub)catchments were monitored within the area of the Southern Alps occupied by tahr. The catchments were generally situated in areas permanently occupied by adult females and their young of the year and juvenile offspring from the previous year. Adult male tahr often live in different areas and only move into these female range areas in the breeding season (e.g. see Forsyth & Tustin 2005).

4.2 Plot design

Permanently marked plots (*n* = 117) were established in the eight study catchments in areas dominated by snow tussock species (*Chionochloa* spp.). The plots were established in five catchments in 1990 and in three in 1999 and have been remeasured up to four times since establishment (Table 2).The plots were generally located on side slopes between 1150 and 1600 m above sea level – see the photographs in Parkes et al. (2004).

Table 2. Number of plots and measurement years in eight study catchments

Study catchment	*No. plots*	*Year plots established*	*Years plots remeasured*	*Tahr counted in catchment*
Hooker–Tasman	9	1992	1995, 2001, 2013	1984–2002, 2008–2012
Carneys Creek (Rangitata)	20 → 18[1]	1992	1997, 2002, 2013	1965–2003, 2008–2012
North Branch (Godley)	15 + 6[2]	1990, 1992	1996, 2001, 2011	1972–2003, 2009–2013
Abor Rift (Landsborough)	9 + 8[2]	1992, 1994	1997, 2002, 2012	1992–2002, 2008–2011
Whymper (Whataroa)	12 → 11[1]	1993	1997, 2002, 2011	1992–2003, 2011–2012
Fitzgerald (Godley)	15	1999	2003, 2013	1999–2003, 2008–2013
Townsend	15	1999	2003, 2013	1999–2003, 2008–2011
Zora	15	1999	2003, 2012	1999–2003, 2008–2012

[1] Two plots were abandoned for one reason or another. [2] Plots were added during the study.

Each plot was of variable area sufficient to include a minimum of 20 snow tussocks usually of either *Chionochloa pallens*, *C. flavescens* or *C. rigida* and their hybrids, but with a small proportion (< 15%) of *C. crassiuscula* (when it was mistaken for one of the other species), and *C. macra* (Rose & Platt 1990). Each plot was gridded at each measurement into 1-m^2 contiguous quadrats in which all live snow tussocks were mapped, measured, assigned to a species and to an age class following Rose & Platt (1990). Individual tussocks were classed as seedlings (≤1-cm live diameter), juveniles (1- to ≤5-cm live diameter), senescent (>5-cm diameter and >50% crown death), and the rest as mature. Measurements for each individual plant included basal live diameter (cm), maximum height of the extended live leaves (cm) and the amount of crown death estimated to the nearest 10%.

The choice of tall snow tussocks as the main indicator species is supported by the following evidence.

a) *Chionochloa* spp. form the largest (30% by dried weight) part of the diet of tahr but only 2.3% of the diet of chamois (*Rupicapra rupicapra*) and 0% of possums (*Trichosurus vulpecula*) (Parkes & Forsyth 2008) – two of the sympatric introduced herbivores present that might otherwise confuse measures of changes in vegetation condition. The tall snow tussocks (*C. pallens*, *C. flavescens* and *C. rigida*) are preferred by tahr over shorter growing *Chionochloa* species (e.g. *C. crassiuscula*). Hares (*Lepus europaeus*) are also usually present at low densities in the range of tahr, but we have no data on their diet from the study areas. Hares in alpine catchments in Nelson did eat *C. pallens*, which formed 26% of their diet (Flux 1967), so it is possible they contribute to the changes in snow tussock condition within the range of tahr.

b) *Chionochloa* spp. are the dominant species in some habitats used by tahr that are also accessible to field staff (i.e. vegetated slopes < 50º).

c) Tahr in one study area spent 39% of their time within snow tussock communities (Tustin & Parkes 1988).

d) The population dynamics of snow tussocks have been studied (e.g. Rose & Platt 1990, and earlier papers quoted therein).

e) A trial study developed a method to assess the impacts of tahr on tussocks (Rose & Allen 1990).

f) Earlier work in Carney's Creek (Rangitata catchment, Canterbury) when tahr were at very high densities showed the catastrophic impact on snow tussocks, but also that their condition improved dramatically after tahr were reduced (see plates 1 and 2, page 8 of the tahr plan). In other words we expected the condition (however that is measured) of snow tussocks to have improved after the large reduction in tahr densities in the 1970s, but whether the current densities of tahr had allowed this improvement to continue or not was the moot point.

Estimates to the nearest 5% of the area in each vegetation plot that was covered by vegetation, litter, bare soil, broken rock and bedrock were also collected.

4.3 Density of tahr and other herbivores

The number of tahr were counted using methods that changed over the years. Most counts were made in late February to early March, i.e. before the start of the breeding season and so before adult males disperse into the females' range. The earliest counts were attempts at a census using the methods described by Challies (1992). Later counts reduced the number of times each sub-area in the study catchments was assessed for each count (see Parkes et al. 2004) and a ground-based double-count method (Forsyth & Hickling 1997) was used at some study sites between 1998 and 2000 in an attempt to provide an estimate of the population size with a measure of variance. After 2007, ground-based counts were replaced by irregular aerial counts using a single pass by a helicopter or counts made during aerial hunting. In all cases, the areas surveyed were estimated and a density of tahr was calculated for each catchment (animals per km^2). However, the changing methodologies meant these estimates of density are unlikely to be comparable.

As pointed out by Sparrow and Kelly (2000), the vegetation plots in each catchment are pseudo-replicates if the ‘treatment’ variable is catchment estimates of tahr density, so an index of ungulate activity (mainly tahr, judging by the absence of other ungulates in most catchment surveys) about each plot was also measured to provide estimates of impact at a spatial scale matching the vegetation plots. This index was the proportion of ‘pellet plots’ containing ungulate faecal pellets. Up to 1999, these pellet plots were the 1 × 1 m quadrats on the vegetation plots, but thereafter the pellet plots were 40 or 64 circular plots (each 1 m^2) set at 5-m intervals on eight transects radiating out from each vegetation plot. We pooled indices from quadrats and circular plots in the analysis.

A few chamois were seen in the Carney’s, Whymper and North Branch study catchments in some years, and most catchments had high densities of red deer (*Cervus elaphus*) before the 1960s. Since chamois do not eat snow tussocks we did not include them in the estimates of animal density, but any chamois faecal pellets that may have been on the ‘pellet plots’ could not be reliably distinguished from those of tahr and are therefore included in the ungulate activity index.

Little is known about the abundance of hares or possums in the study catchments other than that they are present. Hares were regularly seen during fieldwork, and the presence or absence of hare (and possum) pellets was noted on the pellet plots, although it was not used in this report.

4.4 Statistical analyses

4.4.1 Mature tussock condition

Tussock species were difficult to distinguish in the field and some hybrids were also present, so *Chionochloa* species were pooled for analysis. The abundance and condition of juvenile/seedlings are likely to be influenced by a variety of factors besides tahr, including the timing of masting events, abundance of seed predators such as mice (*Mus musculus*) and insects, and the availability of nearby adult tussocks (e.g. Kelly et al. 2000). We therefore did not evaluate population recruitment and turnover but focused the analysis on changes in condition for mature tussocks only, which we predicted would show the most direct relationship with ungulate (presumed to be tahr) activity. We excluded senescent individuals, which had higher proportions of dead leaves (>50% crown death), because their measures of live diameter were biased when the dead leaves occurred in the middle of the plant. Using linear mixed-effects models from the *lme4* package in R version 3.0.2 (R Core Team 2013), height (cm) of mature tussocks was modelled as the response variable with random intercepts at two hierarchical levels: (1) plot ID within catchments and (2) catchment ID, to account for variable sampling effort between catchments and unaccounted differences between plots. We selected tussock height as the response variable, rather than some combined index of tussock condition, because tahr at high densities have an obvious effect on tussock height without (in the short term) killing the tussock – see the photographs of tussocks in Carney’s Creek in 1965 and 1991 on page 8 in the tahr plan. Fixed effects (that average the effect across catchments) included ungulate activity around the vegetation plots (as the proportion of pellet plots occupied with faecal pellets), crown death (%), live diameter (cm), aspect (◦), altitude (m) and year of monitoring. Diameter was included as a quadratic effect following the relationship presented by Rose and Platt (1990). Aspect was also included as a quadratic effect to allow for north-facing slopes (with degree values either close to zero or 360) to show a similar relationship with tussock height. A positive coefficient associated with the quadratic aspect term would suggest that height increased in north-facing slopes, while a negative coefficient would suggest that south-facing slopes had taller tussocks. Ungulate activity was also incorporated as a random coefficient to allow for possible differences in the relationship between tussock height and activity between catchments. Significant covariates in the global model of tussock condition were those with 95% confidence intervals (CIs) not overlapping zero. The predicted partial relationships between significant covariates and height in the global model of tussock condition were plotted by keeping all other significant covariates at their mean values.

An additional mixed-effect model that also included a random coefficient for year was also assessed (to account for possible differences between sites in changes in tussock height through time), but the small variance suggested it caused over-fitting (the data did not support differences in the relationship between height and year between sites) and so it was dropped from further analysis.

4.4.2 Cover of main species

Changes in overall cover (measured between 0 and 100%) of all plant species were assessed using generalised linear models with Poisson error to account for the skewed distribution of the response variable. The Poisson model related the log of overall cover to ungulate activity (as the proportion of pellet plots occupied with faecal pellets), aspect (◦), which was included as a quadratic effect, year of monitoring, to assess changes throughout the monitoring period, and altitude (m). Significant covariates had 95% CIs not overlapping with zero. The predicted partial relationships between significant covariates and overall cover were plotted by keeping all other significant covariates in the overall model of vegetation cover at their mean values.

Additional mixed-effect models including random intercepts for catchment and plots within catchments were also assessed but the small random variances indicated that they were over-fitted and were thus not used further.

4.4.3 Relationship between indices of tahr activity and density

The two analyses of vegetation condition (tussock height and overall cover) assessed the effects of tahr by including an index of ungulate activity about each vegetation plot (assumed to be mainly tahr) as a predictor, rather than by using catchment-level estimates of tahr density, because the former provides a more accurate description of the potential impact of tahr on each vegetation plot. However, the tahr management plan specified intervention densities of tahr across different management units within the tahr range that were expected to allow vegetation recovery (Table 1). The management plan also recommended testing the validity of this assumption. In order to relate changes in vegetation condition to tahr densities during the monitoring period and to evaluate this relationship against the intervention densities in the tahr management plan, we needed firstly to relate catchment-level measures of tahr density to the activity index from pellet plots.

Catchment-level counts of tahr numbers were repeated sporadically across the eight monitored catchments. Sometimes they were done on the same years when vegetation and ungulate pellets were monitored. This allowed us to assess the relationship between ungulate activity around the vegetation plots (defined as the proportion of pellet plots occupied with faecal pellets within a catchment) and counts/estimates of tahr density (defined as total counts divided by sampling area). We modelled the relationship using a generalised linear model with ungulate activity as a response variable and the log of tahr density as a predictor. The model was quasi-Poisson, to account for over-dispersion and for the skewed distribution of the response variable, and also included the total number of pellet plots sampled per catchment each sampling period as an offset variable. Model parameters were estimated using the *glm* function and response values were predicted using *predict.glm* in R version 3.0.2 (R Core Team 2013). The predicted relationship between ungulate activity and tahr density was plotted by keeping the offset variable (sampled pellet plots) in the model at its mean value.

5 Results

5.1 Mature tussock condition

The inclusion of all random effects (plot ID within catchment, catchment ID and ungulate activity) in the tussock condition model was supported by their variance estimates, which were 104 for plot ID within catchments, 197 for catchment ID, and 380 for ungulate activity. The large variances suggested large differences between plots, catchments, and differences in the relationship between ungulate activity and height between catchments.

Tussock height was significantly associated with all fixed covariates in the model except the quadratic relationship with aspect, i.e. the 95% CIs did not overlap zero (Table 3). Across catchments, tussock height had a strong negative relationship with ungulate activity suggesting an ongoing negative effect of tahr on tussocks (Table 3). Height of adult tussocks also had a quadratic relationship with tussock diameter, with greater heights associated with intermediate diameters (Figure 1). Height was negatively associated with plot altitude and also showed a weak positive relationship with crown death. A weak negative relationship with year of monitoring suggested that on average (across catchments) tussock height has decreased slightly during the monitoring period. Plots of the partial relationships between height and year of monitoring for each catchment showed little variation between sites (close parallel lines) and so were not included here.

Table 3. Estimated mean and 95% confidence intervals (CIs) of fixed effects in a model relating tussock height to diameter, crown death, year of monitoring, aspect and altitude of plot, and ungulate activity. The model was a mixed-effects model that also included catchment and plot as random intercepts and ungulate activity as a random coefficient. Significant fixed effects (highlighted with *) had 95% CIs not overlapping zero

Fixed effects	*Mean*	*Lower CI*	*Upper CI*
Diameter (cm)	0.747*	0.709	0.785
Diameter^2	−0.003*	−0.004	−0.003
Crown death (%)	0.030*	0.010	0.050
Year	−0.167*	−0.217	−0.117
Aspect (◦)	0.057	−0.042	0.156
Aspect^2	0.000	−0.000	0.000
Altitude (m)	−0.056*	−0.069	−0.043
Ungulate activity	−16.684*	−32.455	−0.933

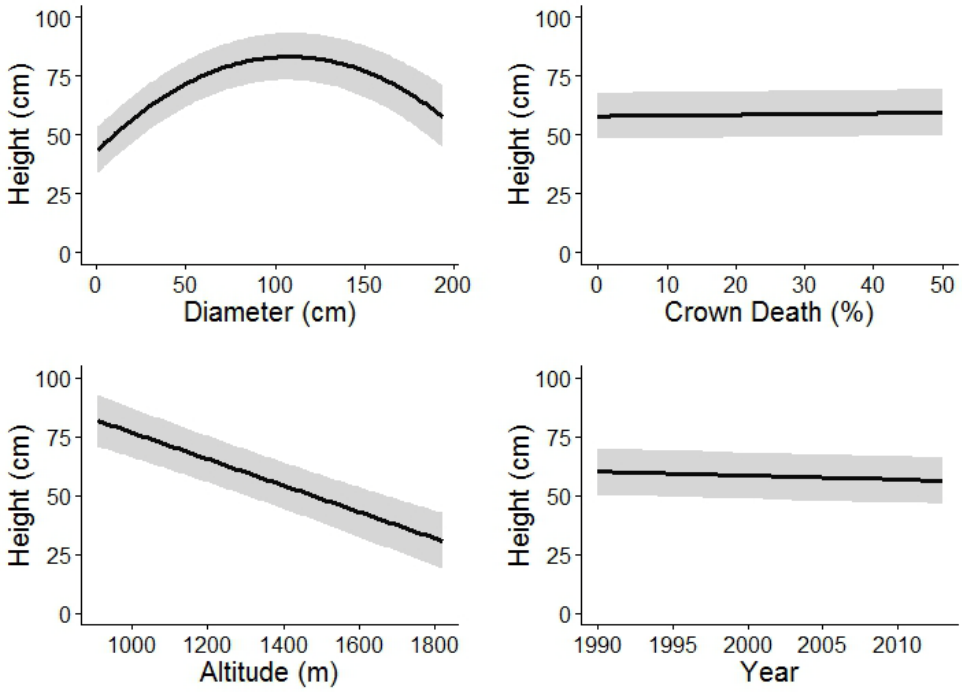

Figure 1. Predicted mean relationships between tussock height and significant fixed effects for diameter, crown death, altitude and year, while keeping all other fixed effects at their mean values. Relationships were derived from a mixed-effects linear model with catchment and plot as random intercepts and ungulate activity as a random coefficient. The model incorporated fixed effects for ungulate activity, altitude and aspect of the plot, year of sampling and, live diameter and percentage of crown death for the adult tussocks. Shaded areas are the 95% confidence intervals.

The predicted relationship between tussock height and ungulate activity varied between catchments (Figure 2). The intercepts on the *y*-axis in Figure 2 represent the predicted height of tussocks in areas without (detectable) ungulate activity within each catchment. The different starting values reflect notable differences between catchments. In areas where ungulate activity was absent (or undetected) within the Carney's Creek, Fitzgerald, North Branch and Whymper catchments, tussocks were predicted to show relatively good condition (on the basis of their height). At Arbor Rift, tussock condition (height) was predicted to be low even for areas where ungulate activity was undetected. Areas without ungulate activity at Townsend, Hooker and Zora were predicted to have average height, relative to the other catchments. In areas where ungulate activity was detected, tussock height decreased with increasing ungulate activity at all catchments except the Carney's Creek, Whymper and Hooker sites. This relationship was most pronounced for the Fitzgerald, Zora and North Branch catchments (Figure 2).

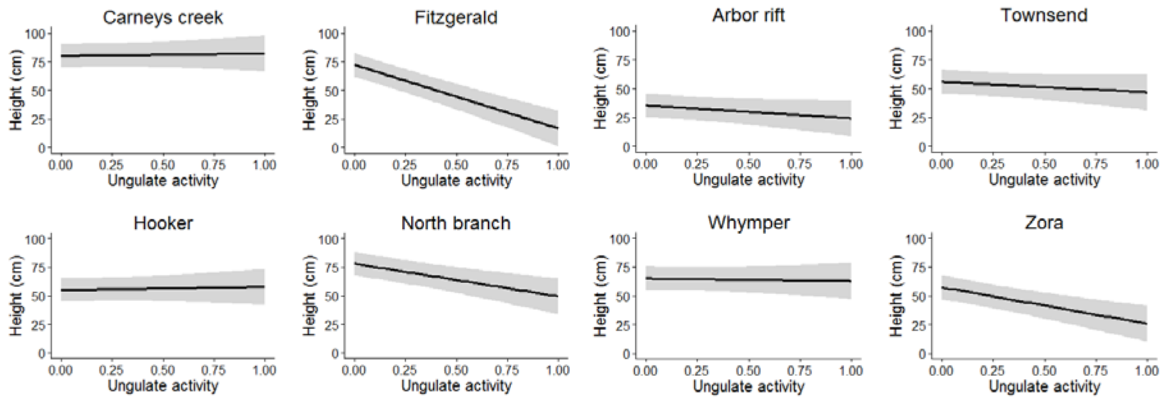

Figure 2. Predicted mean relationships between tussock height and ungulate activity (as proportion of pellet plots with faecal pellets) for each catchment derived from a mixed-effects linear model with catchment and plot as random intercepts and ungulate activity as a random coefficient. The model also incorporated fixed effects (that averaged effects across catchments) for ungulate activity, altitude and aspect of the plot, year of sampling and, live diameter and percentage of crown death for the adult tussocks. Shaded areas are the 95% confidence intervals.

5.2 Vegetation cover

The log of vegetation cover within a plot was significantly associated with plot aspect, year of monitoring and ungulate activity (their 95% CIs did not overlap zero) but was not significantly related to plot altitude (Table 4). The negative coefficient for the quadratic term for aspect suggested greater cover in south-facing slopes (Table 4 and Figure 3). Cover decreased with greater ungulate activity suggesting an ongoing negative effect of tahr (Figure 3). Lastly, cover increased throughout the monitoring period, suggesting overall recovery of plants across all catchments (Figure 3).

Table 4. Estimated mean and 95% confidence intervals (CIs) of covariates in a generalised Poisson model relating overall vegetation cover in a plot to year of monitoring, aspect and altitude of plot, and ungulate activity (proportion of pellet plots with faecal pellets). Significant covariates (marked with *) have 95% CIs not overlapping zero

Fixed effects	*Mean*	*Lower CI*	*Upper CI*
Year	0.005371*	0.003766	0.006976
Aspect (◦)	0.002546*	0.001988	0.003106
Aspect^2	−0.000008*	−0.000010	−0.000007
Altitude (m)	0.000010	−0.000054	0.000073
Ungulate activity	−0.103500*	−0.159614	−0.047713

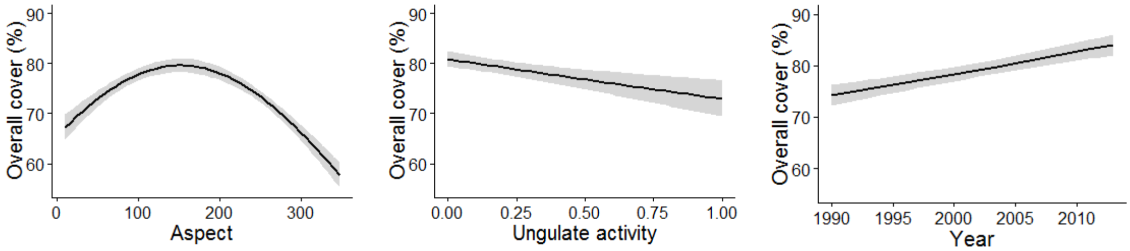

Figure 3. Predicted mean relationships between overall vegetation cover and significant effects for aspect, ungulate activity and year of monitoring, while keeping other covariates at their mean values. Relationships were derived from a generalised linear model with Poisson error to account for the skewed distribution of cover. The model included covariates for altitude and aspect of the plot, year of sampling and ungulate activity (defined as proportion of pellet plots with faecal pellets). Shaded areas are the 95% confidence intervals.

5.3 Relationship between indices of tahr activity and density

Estimates of tahr density exceeded the intervention densities set in the tahr management plan for all catchments on some occasions, with densities being constantly above intervention densities (by orders of magnitude) at the Carneys Creek, North Branch, Arbor Rift and Zora catchments (Table 1 and Figure 4).

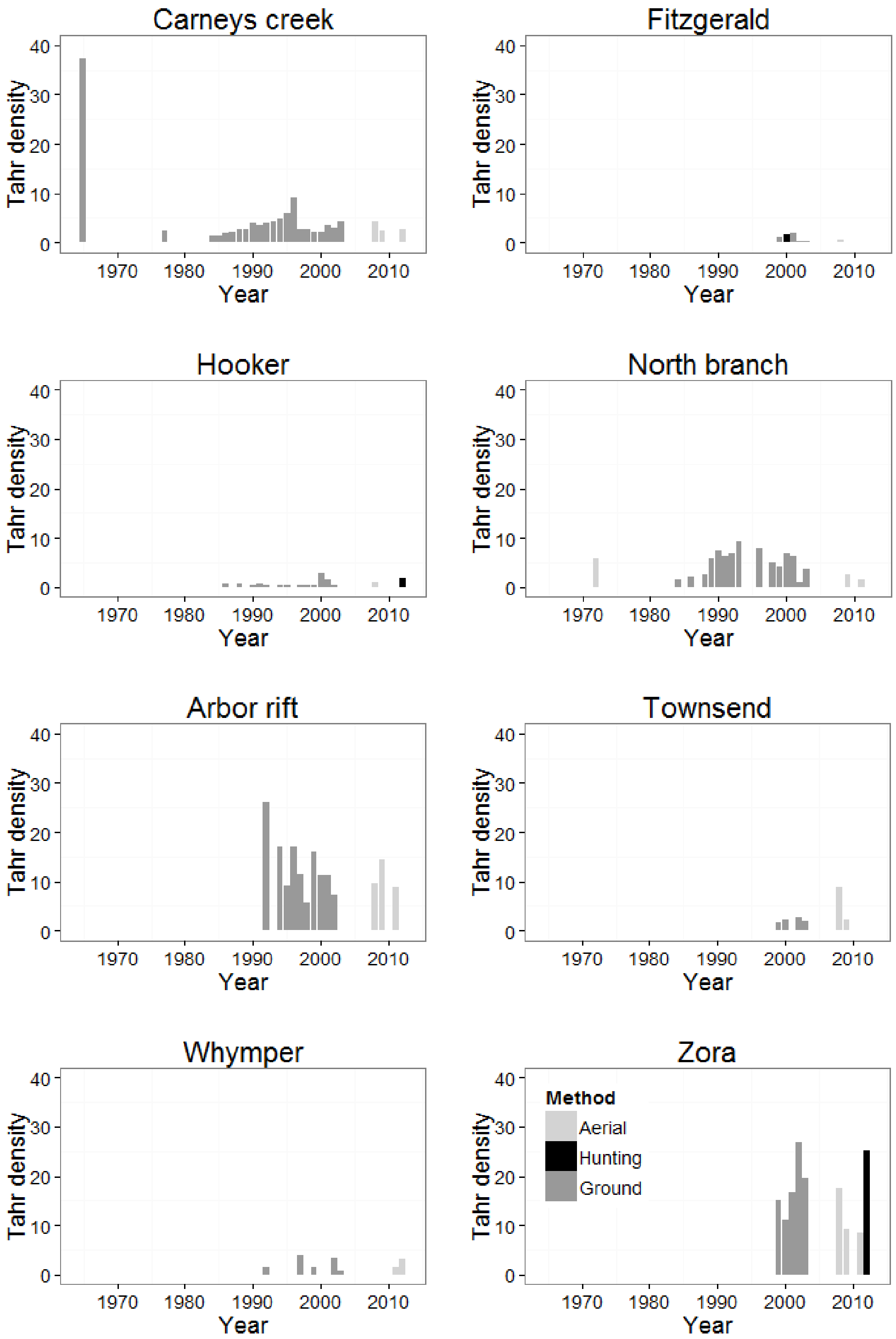

Figure 4. Estimates of tahr density (animals/km^2) through time from ground counts, aerial counts or counts during aerial hunting, for eight monitored catchments in the east and west coasts of the South Island, New Zealand.

The model of ungulate activity and tahr density showed large over-dispersion (Table 3), and wide 95% CIs (Figure 6), suggesting that it was a poor model for relating the two variables.

Table 3. Estimated mean and 95% confidence intervals (CIs) of covariates in a generalised linear model relating ungulate activity (defined as the proportion of pellet plots with faecal pellets) to indices of tahr density in the South Island, New Zealand. The model also included the number of pellet plots sampled as an offset, and quasi-Poisson error, to account for over-dispersion and skewed counts of occupied pellet plots. Significant covariates (marked with *) had 95% CIs not overlapping zero

Covariates	*Mean*	*Lower CI*	*Upper CI*
Log(tahr density)	0.37*	0.17	0.59
Over-dispersion	30.33		

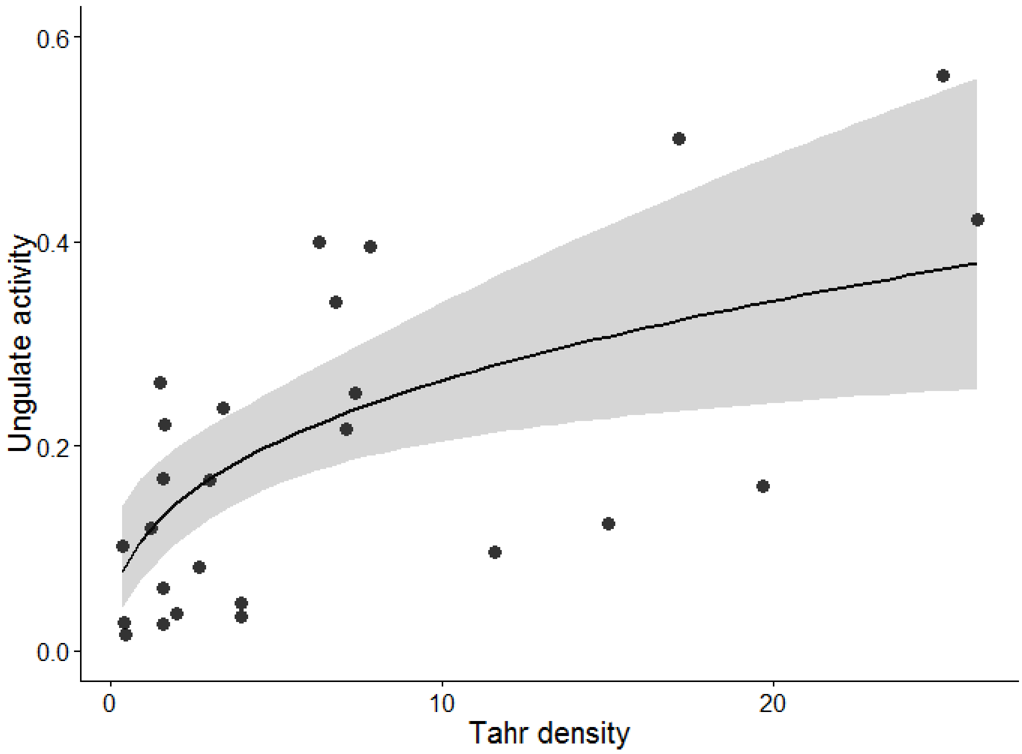

Figure 6. Predicted relationship between catchment-level ungulate activity (proportion of pellet plots with faecal pellets within a catchment) and catchment-level tahr density from tahr counts in the South Island, New Zealand. The relationship was derived from a generalised linear model with the number of pellet plots sampled as an offset, and quasi-Poisson error, to account for over-dispersion and skewed counts of occupied quadrats. The points represent real values. Shaded areas are the 95% confidence intervals.

6 Discussion

Prior to the large reduction of the tahr population in the 1970s, tahr had an obvious effect on snow tussocks when at very high densities (DOC 1993). The evidence that the reduced tahr population size allowed significant improvement in the condition of snow tussock is largely anecdotal although it is supported by some limited photographic evidence (DOC 1993). That is, the condition of the vegetation in the early 1990s when this study began was already much improved and the question is really whether the variable (but historically low) tahr densities since then have allowed a continuing improvement, a decline, or the same condition. What the condition of the vegetation would be in the absence of tahr is not known. Exclosures are impossible to maintain in these habitats, but areas with consistently low tahr activity allowed us to assess tussock condition under the assumed absence of tahr.

An earlier analysis of data from the vegetation plots used in this study, covering the period between 1990 and 2003, showed no overall change in tussock condition, albeit with some improvement in basal areas (but not height) among adult tussocks at the expense of juvenile tussocks. However, across the range of tahr densities observed in the study catchments, the earlier analysis found that tussock height declined as tahr density increased (Parkes et al. 2004).

Adding an extra decade (and using a different analytical technique) has not much altered this conclusion. The relationship between tussock height and year of monitoring suggested no overall recovery of mature tussocks during the two decades of monitoring; rather it suggested a slight decline. The slope of the relationship between tussock height and ungulate activity suggested an ongoing negative impact of increasing ungulate activity on tussock condition, which was particularly pronounced at the Fitzgerald, Zora and North Branch catchments. Intervention densities proposed in the tahr management plan were exceeded at all catchments. The average levels of tahr density during the monitoring period appear to have been too high to allow improvement in tussock condition at any of the catchments.

The Arbor Rift and Zora catchments had the shortest tussocks even in areas with no detectable ungulate activity. We propose two possible explanations for this result. First, tussocks may have been impacted by herbivores other than tahr during the monitoring period. However, no chamois were detected at these catchments. Hare pellets were detected, but they were present at similar levels at Carneys Creek, Fitzgerald and North Branch catchments, which had relatively tall tussocks in areas with no ungulate activity. Little is known about hare densities in alpine habitats, their diet and the degree of impact on native vegetation. Research on these issues would be helpful to understand the full picture of the status of native alpine ecosystems. An analysis of hare activity in relation to vegetation change could be done from the data collected for this study. However, a more plausible explanation for this result is that tussocks have not recovered from the historical impact by tahr, if densities were consistently high at these catchments prior to monitoring commencing in the early 1990s. We do not have records of tahr counts prior to the monitoring period that would help assess this. However, the Zora and Arbor Rift catchments had the highest levels of tahr density over the monitoring period (>20 animals/km^2) and these levels may reflect historical densities.

Overall vegetation cover increased during the monitoring period suggesting possible recovery of vegetation under the currently reduced tahr pressure (compared with historical levels). However, the significant negative relationship between overall cover and ungulate activity also suggests that tahr continue to have negative effects in areas where their activity is high.

We have not analysed which plant species contributed towards the observed recovery in vegetation cover. However, since tussock condition overall did not improve during the monitoring period, the species that increased in cover are likely to have been others. These species could be natives that are also eaten by tahr or, alternatively, they could be species unpalatable to tahr so that the recovery in vegetation cover reflects a transition of the ecosystem towards species that are unpalatable to tahr (which does not seem like an ecologically acceptable state as outlined in the tahr management plan). Vegetation cover increased more in south-facing slopes, which are known to be the areas that are least preferred by tahr (Tustin & Parkes 1988). This may indicate that palatable species may be responsible for the increase in vegetation cover. Additional analyses of the condition of other key plant species (preferred and not preferred by tahr) in relationship with ungulate activity is required to help decipher which species have recovered in the last two decades. However, the vegetation plot design used in this study focused on snow tussock habitats, and although other species are monitored on the plots, the design is not really ideal for measuring any trends in these species, and particularly not for rare species. The design also tells us nothing about tahr impacts on plants restricted to other communities used by tahr (alpine bluffs, scree slopes or lower scrub habitats).

We attempted to relate estimates of tahr density (from animal counts over the whole catchment using a variety of methods) and ungulate activity (as the proportion of pellet plots with faecal pellets). However, the large over-dispersion and wide confidence intervals in the model relating ungulate activity to tahr density suggested poor model fit, making it impossible to then relate measures of vegetation condition to catchment-level estimates of tahr density, apart from very general trends. This means that we could not meet the overall objective set out by DOC of determining which tahr densities would allow tussock grasslands to recover and persist in an ecologically acceptable state. Part of the issue in relating tahr counts to pellets is the difference in decomposition rates of pellets due to differences in weather (particularly rainfall levels) between catchments. Variability may also stem from different detection rates of faecal pellets depending on the complexity of the habitat (open grassland vs interspersed with shrubs). However, the most likely source of uncertainty in the model is likely the result of the inconsistent methodology used to estimate tahr density and the limitations related to the survey techniques chosen (e.g. aerial counts often underestimate densities to a greater extent compared with ground surveys).

The tahr management plan sets densities as a trigger for control interventions. If DOC wishes to relate vegetation condition to estimates of tahr densities and avoid the problem of pseudo-replication by linking ungulate activity about the plots (from pellet plots) to tahr densities in the catchments, it needs to improve the accuracy and reliability of the tahr count methods and needs to standardise protocols. The choices are to return to the protocols set out in Challies (1992) and reiterated in Parkes et al. (1999), which provide close to a census, or to use double-count methods, either ground-based or aerial, which sample the catchments and provide estimates of density and the precision of the estimates (Forsyth & Hickling 1997; Choquenot et al. 2000). These are relatively expensive compared with the single counts (ground and aerial) or fly-bys during hunting used in later years. Single counts may provide managers with some quick information on the need to add control effort, if the numbers of tahr clearly exceed the intervention densities, but provide no information when the tallies are low – and arguably unreliable.

7 Recommendations

1. The vegetation plots were located and the monitoring designed to assess changes in the condition of snow tussocks. Changes in condition, such as cover, of other common species on these plots (e.g. *Aciphylla* spp.) might be analysed, but if DOC wishes to monitor tahr impacts on rare or vulnerable species (such as *Ranunculus*) it would be best to design a system specifically aimed at them, e.g. monitor survival along transects or at sites where they occur.

2. The intervention densities of tahr were exceeded at all catchments on at least some occasions, and were highest at the Arbor Rift and Zora catchments. The densities present during the monitoring period appear to have hampered recovery of snow tussocks, particularly at those catchments with high densities. We therefore recommend improved efforts to maintain tahr levels below the densities proposed in the tahr management plan.

3. The attempts to count tahr across the larger catchments may have practical uses for managers wanting to confirm over-abundance, but the estimates are not reliable enough to meet the specific prescriptions for intervention in the tahr plan. We recommend using estimates of activity from the pellet plots around the vegetation plots in future analyses, but also recommend that tahr are counted using the census count method as described by Challies (1992) in the year the vegetation and pellet plots are remeasured, to allow better linking of the activity to catchment-level measures of tahr density, and thus to the tahr-plan intervention densities.

4. Tahr are but one introduced herbivore in the study area and although they are likely to be the main influence on snow tussocks (judging by the comparative diets of the herbivores), a study of the combined impacts of at least the ubiquitous species (hares and possums) would be required to assess the wider status of the native species (e.g. see Forsyth et al. 2000).

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