Abundance of Himalayan Tahr in the South Rakaia/Upper Rangitata and Gammack/Two Thumb Management Units

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Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

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Summary

Context:

Aerial surveys undertaken during 2016 – 2019 have provided the first estimates of Himalayan tahr (*Hemitragus jemlahicus)* population size on Public Conservation Land across their range in the Southern Alps of New Zealand (Ramsey and Forsyth 2019). Estimates from these surveys showed that average tahr densities exceeded the intervention densities specified in the Himalayan Thar Control Plan (HTCP) (Department of Conservation 1993) in all but one of seven management units (MUs). Following these surveys, tahr control was undertaken during 2019 and 2020. Further aerial surveys were conducted in two management units during February – May 2021, South Rakaia/Upper Rangitata (MU1) and Gammack/Two Thumb (MU3).

Aims:

- Estimate the abundances and densities of tahr in MUs 1 and 3 from aerial surveys undertaken in 2021, and determine if increased sampling intensities have increased the precision of these estimates.
- Assess whether the tahr control undertaken in 2019 and 2020 has reduced the tahr populations in MUs 1 and 3 below the intervention densities specified in the Himalayan Thar Control Plan.

Methods:

Helicopter counts of tahr were conducted on three occasions during February – May 2021 at 43 plots (2 x 2 km) located on Public Conservation Land (PCL) in MUs 1 (n = 17 plots) and 3 (n = 26 plots). The repeat counts were used to estimate tahr abundance, corrected for imperfect detection, using an *N*-mixture model for open populations (Dail and Madsen 2011). Design-based, finite sampling methods were then used to estimate the density and total abundance of tahr on PCL within these two MUs. The estimated tahr densities were compared with the intervention densities specified in the HTCP.

Results:

- Summaries of the aerial counts show that the average number of tahr observed on plots during the 2021 surveys was slightly higher than the average number observed for these MUs during the 2016 – 2019 surveys.
- Estimated average tahr density on PCL in the South Rakaia/Upper Rangitata (MU1) was 8.6 tahr/km^2 (95% CI: 6.1 – 11.9), similar to that in 2016 – 2019 (8.1 tahr/km^2). Estimated average tahr density on PCL in Gammack/Two Thumb (MU3) was 10.6 tahr/km^2 (95% CI: 7.0 – 16.0), also similar to that in 2016 – 2019 (10.0 tahr/km^2).
- The total abundance of tahr on PCL in the South Rakaia/Upper Rangitata and Gammack/Two Thumb management units in 2021 were 6600 (95% CI: 4740 – 9150) and 9350 (95% CI: 6200 – 14150), respectively.
- Totals of 2668 and 2244 tahr were culled during helicopter shooting operations conducted in the South Rakaia/Upper Rangitata and Gammack/Two Thumb management units, respectively, during 2019 and 2020.
- The precision of tahr abundance estimates for these MUs increased from the 2016 – 2019 surveys, with coefficients of variation (CV) of 17% for MU1 and 21% for MU3, which were close to the desired target level (20%).

Conclusions:

- The estimates of average densities in the South Rakaia/Upper Rangitata and Gammack/Two Thumb management units exceed the intervention densities defined for those management units in the HTCP (2.5 and 2.0 tahr/km^2, respectively).
- The hypothesis that average densities for these MUs could be below the intervention densities has no support. If the average densities for these MUs were as low as the intervention densities, the chance of obtaining the observed monitoring data was less than 1 in 10000.
- The limited change in the tahr populations in these MUs since the 2016 – 2019 surveys is consistent with compensation for culling offtake from natural rates of population increase (up to 32% per annum) and/or immigration from outside the PCL.
- The increased precision of tahr abundance estimates was due to the increased numbers of plots sampled in the two MUs in 2021.

Recommendations:

- Future aerial surveys of tahr should consider increasing the number of sampled plots across PCL to achieve increased precision in abundance estimates at the MU level. Cost savings could be achieved by decreasing the number of temporal replicates for each plot from three to two.
- Given the amount of tahr control occurring across PCL, future monitoring and model development should be adapted so that trends in tahr abundance over time could be estimated for each MU.
- Further work should also investigate models of the relationship between tahr abundance and habitat characteristics. Such model-based approaches could provide more precise estimates for each MU or other specific areas.

1 Introduction

Himalayan tahr (*Hemitragus jemlahicus*) were first introduced into New Zealand in 1904 and now occupy around 9600 km^2 of the Southern Alps (Cruz *et al.* 2017). After commercial harvesting reduced tahr populations by around 90% during the 1960's and 1970's, the population increased 6-fold following a moratorium on commercial harvesting in 1982 (Parkes 2009). Tahr are a declared wild animal under the "Wild Animal Control Act 1977", which provides provisions for the control of introduced wild animals to protect against their damaging effects on native vegetation, soils, water and other wildlife (Department of Conservation 1993). Tahr graze primarily on alpine tussock grassland and caused widespread impacts on montane grasslands during the 1960's when their densities were high (Parkes 2009). However, impacts are still occurring at current population densities (Cruz *et al.* 2017).

The Himalayan Thar Control Plan (HTCP) (Department of Conservation 1993) defines intervention densities in terms of number of tahr per km^2 in each of seven management units (MU), ranging from <1.0 to 2.5 tahr per km^2), and in two exclusion zones (EZ) (0.0 tahr per km^2) (Table 1). Recent monitoring of Himalayan tahr during 2016 – 2019 conducted as part of the national Biodiversity Monitoring and Reporting System (BMRS) (Allen *et al.* 2013) has provided the first estimates of tahr densities and abundances across their range on Public Conservation Land (PCL) (Ramsey and Forsyth 2019). Monitoring consisted of counts of tahr from a helicopter at 117 plots (2 x 2 km) centred on the BRMS 8 x 8 km Tier 1 monitoring network, which were conducted on three separate occasions at each plot over an approximate two-month period. Analysis of the monitoring data estimated a total population of 34400 tahr on PCL within the seven management units and two exclusion zones. This estimate had a relative error (coefficient of variation; CV) of 13%. Estimates of average tahr densities exceeded the thresholds defined in the HTCP for all management units and exclusion zones except MU7. Although the total abundance estimate for tahr had acceptable precision, the precision of the estimates for each of the seven management units was variable, ranging from 22% to 52%.

Further helicopter surveys of tahr were undertaken in February – May 2021 in two management units, South Rakaia/Upper Rangitata (MU1) and Gammack/Two Thumb (MU3), using an increased sample of plots to provide tahr abundance and density estimates for these two MUs with acceptable precision (defined as a CV of $\leq$ 20%). Here we report on the analyses of these monitoring data using the same approach described in Ramsey and Forsyth (2019).

2 Methods

2.1 Plot selection

Within MUs 1 and 3, helicopter surveys were conducted on the same plots that were monitored during 2016 – 2019, with the exception of plots AS132 and AU128 in MU1, which were not surveyed during 2021 (i.e. 11 and 17 plots, respectively) (Ramsey and Forsyth 2019). To increase the precision of abundance estimates for both MUs, 15 additional plots were sampled to give a total of 17 and 26 plots for MU1 and MU3, respectively (43 plots in total) (Figure 1). The number of additional plots was estimated from a power analysis that was calculated to give a 70% chance of achieving abundance estimates with relative precisions (CV) of $\leq$ 20% (see Appendix 1 for details of these calculations). The additional plots were sampled from a 4 x 4 km grid superimposed on the existing 8 x 8 km Tier 1 grid, excluding grid points that coincided. Sample plots were drawn using Halton Iterative Partitioning (HIP) algorithm (Robertson *et al.* 2018) to give a spatially-balanced sample using the `hip.point` function from the `R` package `SDraw` (McDonald and McDonald 2020).

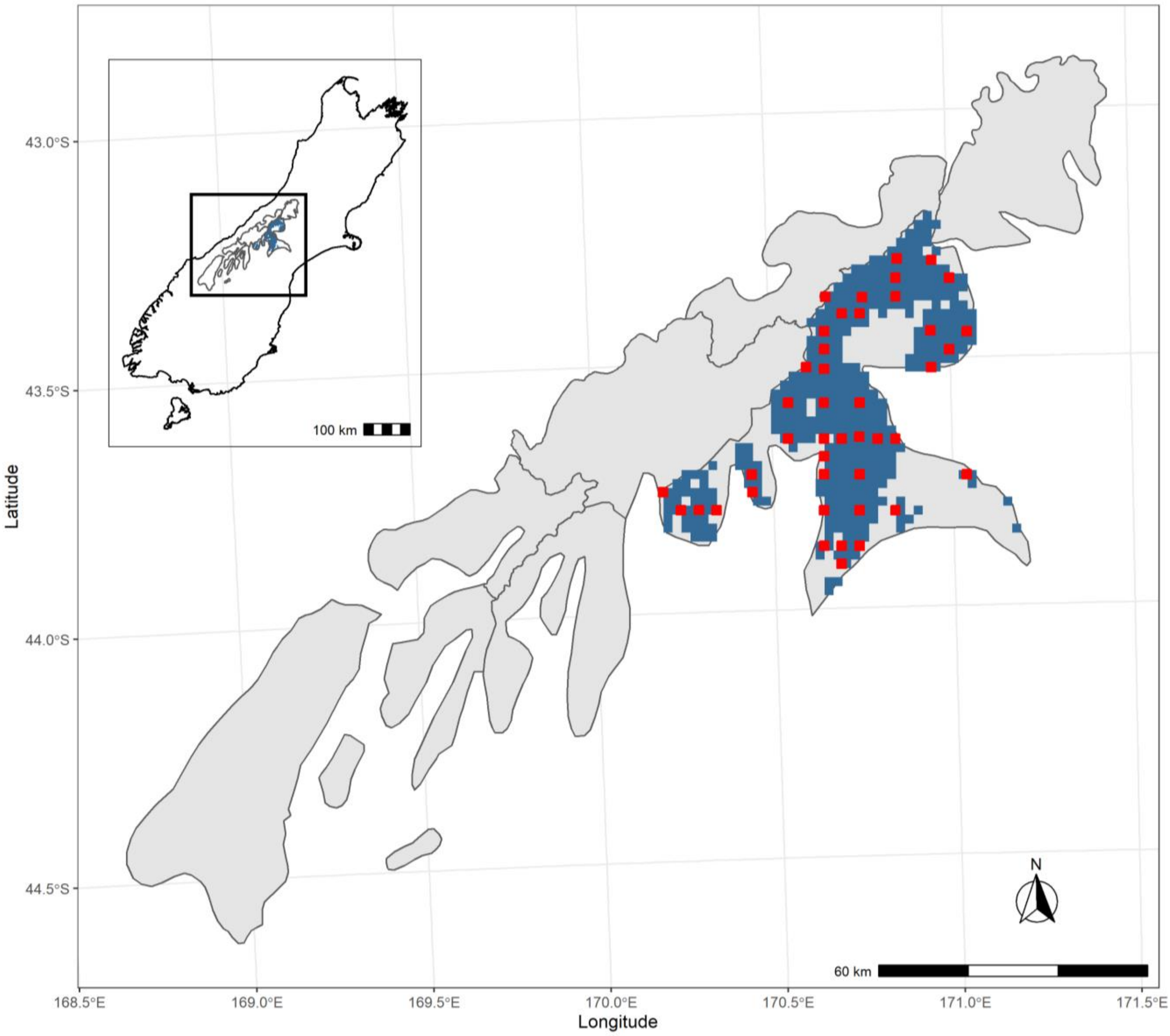

Figure 1. Location of the 43 plots (2 x 2 km) subject to aerial surveys of tahr during 2021 (red squares). Grey shaded areas are the seven tahr management units (MU) and two exclusion zones (EZ) while the blue shaded region is the area of Public Conservation Land in MU1 and MU3 rasterised into 2 x 2 km sampling units.

2.2 Aerial survey protocol

The aerial survey protocol is described in detail elsewhere (Forsyth *et al.* 2018 and references therein). Briefly, a 2 x 2 km plot was established at each site, with the centre of each plot being the vertex of a grid point (either 8 x 8 km or 4 x 4 km). Each 4 km^2 plot was subject to three separate counts undertaken from a helicopter (usually a Hughes 500D or Hughes 500E) at least 10 days apart. This interval between successive counts at a plot was chosen to minimise the disturbance effects of the helicopter on tahr in the subsequent two counts at that plot. Counts were undertaken during February – May 2021.

On each of the three sampling occasions the 4 km^2 plot was systematically flown by the helicopter flying at about 40–60 knots and at 20–70 m from the ground (depending on topography and wind). The pilot and one primary observer, seated next to the pilot, searched for tahr and when any were sighted, the primary observer counted the individuals and assigned them to species (and sex-age classes where possible, but that information was not used in the analyses reported here). A third person, seated in the rear behind the primary observer, recorded the location (with a GPS) and other details for each tahr group.

2.3 Abundance estimation

The total number of tahr counted within each plot, at each of the three sampling occasions, was used to estimate abundance on each sampled plot corrected for imperfect detection using an *N*-mixture model for open populations (Dail and Madsen 2011). This is the same model used for abundance estimation for the aerial monitoring data collected between 2016 – 2019 (Ramsey and Forsyth 2019). Similarly, the total abundance and density of tahr in MU1 and 3 were estimated using the same finite sampling inference procedures as detailed in Ramsey and Forsyth (2019). The hypothesis that average tahr densities in each MU could be below the intervention densities specified in the HTCP was examined using a one-sample test, assuming this statistic was normally distributed.

2.4 Tahr culling data

The numbers of tahr killed during culls led or directed by the Department of Conservation in management units 1 and 3 during the 2019 and 2020 calendar years were tabulated.

3 Results

3.1 Summary of aerial survey counts

The number of tahr counted on each of the 43 sampled plots during each sampling occasion averaged 25, which was higher than the counts for these two management units during the 2016 – 2019 surveys, which averaged 21. The average number of tahr counted on the 28 plots sampled in both the 2016 – 2019 and 2021 surveys increased 2.3% from 21.6 to 22.1 per sampling occasion, respectively.

3.2 Tahr density and abundance

The fit of *N*-mixture model to the counts of tahr on the 43 plots was adequate, as judged by comparing the posterior mean of the total counts of tahr on each plot, predicted by the *N*-mixture model, versus the observed total counts of tahr (Figure 2). The model slightly underestimated the counts on plots with high tahr abundance and slightly overestimated counts on some plots with low or zero tahr abundance (Figure 2).

The mean density of tahr on each plot varied widely, from 0.73 to 45 tahr/km^2 (Figure 3). Precision of the plot density estimates was generally acceptable, with an average CV of 13%. A comparison of tahr density estimates at each sampling occasion with the naïve density estimates (i.e. raw counts divided by plot area) is provided in Figure A1, Appendix 2.

The corresponding average density and total abundance of tahr within management units 1 and 3 (Tables 1 & 2) were similar to that estimated from the 2016 – 2019 surveys (Ramsey and Forsyth 2019). Estimated average tahr densities exceeded the intervention densities specified in the HTPC for both these management units. The hypothesis that average densities could be below the intervention densities has essentially no support. If average densities were as low as the intervention densities, the probability of obtaining the observed monitoring data was less than 1 in 10000 (i.e., P < 0.0001). The precision of the estimates for South Rakaia/Upper Rangitata (MU1) and Gammack/Two Thumb (MU3) were 17% and 21%, respectively, which were improvements on the precision obtained for these MUs in the 2016 – 2019 surveys (26% and 27%, respectively) (Ramsey and Forsyth 2019) and better than (MU1) or close to (MU3) the target level of 20%.

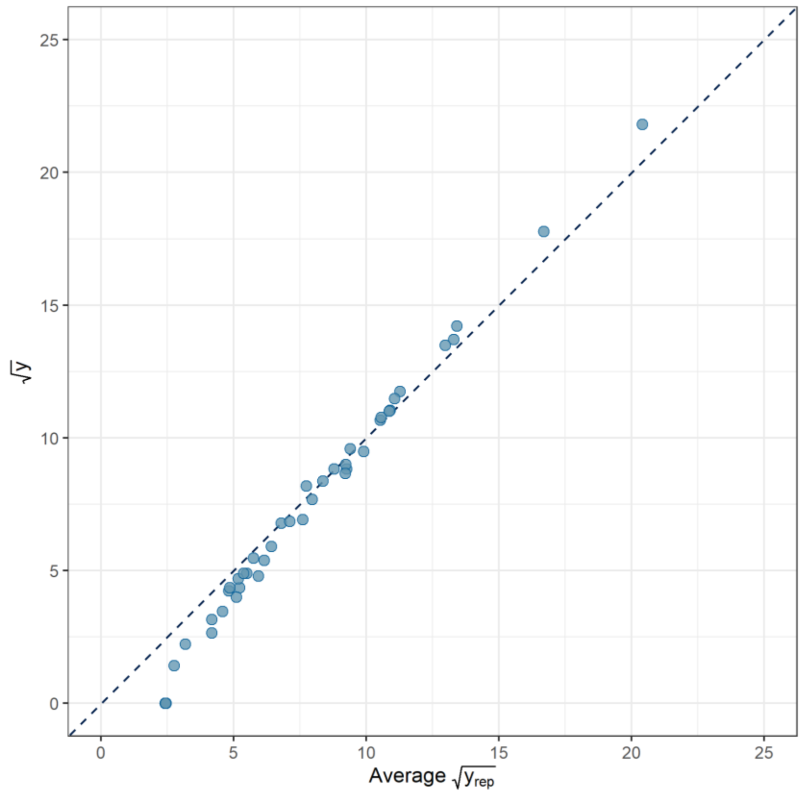

Figure 2. Posterior mean of the total counts of tahr on each plot predicted by the *N*-mixture model (average y_{rep}) versus the observed total counts of tahr (y). Predicted and observed counts have been square root transformed for clarity.

Table 1. Average densities of tahr (tahr/km^2) within the South Rakaia/Upper Rangitata and Gammack/Two Thumb management units (MU) estimated from plots subject to aerial surveys during 2021. SD – standard deviation; LCL – lower 95% confidence limit; UCL – upper 95% confidence limit; *n* – number of plots; D_{19} – equivalent density estimate from the 2016 – 2019 surveys. ID – Intervention density.

MU	Density	SD	LCL	UCL	*n*	D_{19}	ID
South Rakaia/Upper Rangitata (MU1)	8.6	1.46	6.1	11.9	17	8.1	2.5
Gammack/Two Thumb (MU3)	10.6	2.26	7.0	16.0	26	10.0	2.0

Table 2. Design-based estimates of total abundance (*N*) of tahr within the the South Rakaia/Upper Rangitata and Gammack/Two Thumb management units (MU) estimated from plots subject to aerial surveys during 2021. SD - standard deviation; CV (%) – percent coefficient of variation; LCL - lower 95% confidence limit; UCL - upper 95% confidence limit; *u* - number of sampled plots; *U* - estimated number of plots available to be sampled.

MU	*N*	SD	CV (%)	LCL	UCL	*u*	*U*
South Rakaia/Upper Rangitata (MU1)	6600	1119	17	4740	9150	17	192
Gammack/Two Thumb (MU3)	9350	2000	21	6200	14150	26	221
Total	15950	2292	14	12050	21100	43	413

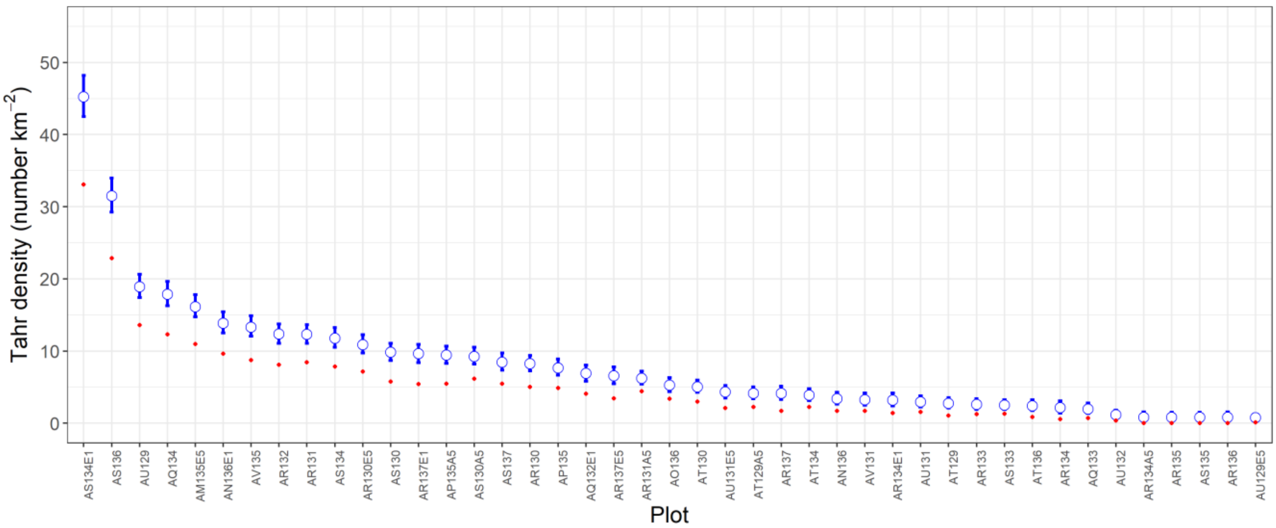

Figure 3. Estimated mean tahr density (open circles) and associated 95% credible intervals (solid lines) on each of the 43 plots sampled by aerial surveys during 2021. The plots are shown in descending order of mean tahr density. Red circles indicate the naïve density estimate obtained by dividing the (average) observed count by the plot area.

3.3 Tahr culling data

A total of 4912 tahr were culled during 2019 and 2020 in MU1 and MU3 during control operations led or directed by the Department of Conservation (Table 3). Within South Rakaia/Upper Rangitata (MU1) and Gammack/Two Thumb (MU3), totals of 2668 and 2244 tahr were culled during 2019 – 2020. These verified removals represented 43% (95% CI: 25% – 74%) and 26% (95% CI: 14% – 44%) of the estimated abundance in those MU, respectively, from the 2016 – 2019 surveys.

Table 3. Numbers of tahr culled in management units (MU) 1 and 3 during the 2019 and 2020 calendar years.

MU or EZ	2019	2020	Total
MU1	2113	555	2668
MU3	1603	641	2244
Total	3716	1196	4912

4 Discussion

Estimates of tahr abundance on Public Conservation Land in the South Rakaia/Upper Rangitata (MU1) and Gammack/Two Thumb (MU3) management units, using the same survey and modelling methods used in Ramsey and Forsyth (2019), were similar to the estimates obtained from the 2016 – 2019 surveys, with abundances of 6600 and 9350 tahr in MU1 and 3, respectively. These abundances equate to densities of 8.6 (cf. 8.1) and 10.6 (cf. 10.0) tahr/km^2, respectively, still well above the intervention densities in the Himalayan Thar Control Plan. The lower 95% confidence limits for the average density were well above the intervention densities for both management units (6.1 tahr/km^2 in South Rakaia/Upper Rangitata and 7.0 tahr/km^2 in Gammack/Two Thumb) and moreover, it would be extremely unlikely to observe a density as low as the intervention densities for either MU. The precision of the 2021 abundance and density estimates were better than or close to the desired target of 20% (South Rakaia/Upper Rangitata – 17%; Gammack/Two Thumb – 21%).

Around 43% and 26% of the average estimated abundances of tahr present in the South Rakaia/Upper Rangitata and Gammack/Two Thumb management units during 2016 – 2019, respectively, were culled during 2019 – 2020. However, despite these removals (and additional unspecified removals by recreational hunters) the abundances had changed little and were still well above the intervention densities. As noted above, the tahr abundance estimates for PCL in the South Rakaia/Upper Rangitata and Gammack/Two Thumb management units during 2016 – 2019 had lower precision than those from 2021, primarily because fewer plots were sampled. Hence, there is higher uncertainty about the abundances and densities of tahr in those management units in 2016 – 2019 and this also applies to the estimate of the actual percentage of tahr removed. The uncertainty in tahr population estimates, represented by the standard error, needs to be accounted for when estimating the proportion of the population removed by culling.

One reason for the continued high abundances of tahr in the South Rakaia/Upper Rangitata and Gammack/Two Thumb management units in 2021, following two years of culling, is recruitment. The median birth date for Himalayan tahr in New Zealand is 30 November (Caughley 1971). Hence, there have been two breeding seasons since the 2019 cull and one breeding season since the 2020 cull. Annual ground-based counts in North Branch (in the Gammack/Two Thumb management unit) during 1984 – 1996 revealed that the female population there, which was not subject to harvesting, increased 32% annually (Forsyth 1999). This is likely a maximum rate of increase because the population was increasing from very low densities caused by helicopter-based harvesting prior to 1984.

Immigration of tahr into the PCL from nearby non-PCL (which has not been sampled by aerial survey and hence no estimates of abundance are available) is also possible. Female tahr are sedentary (Tustin and Parkes 1988), and hence immigration of this sex is unlikely to have been important. In contrast, male tahr can be highly mobile, moving away from female-juvenile herds outside of the autumn-winter rut (Forsyth 1999; Forsyth 2000).

In conclusion, aerial surveys of tahr in South Rakaia/Upper Rangitata and Gammack/Two Thumb management units in 2021 have revealed little change in tahr abundances and densities since the 2016 – 2019 aerial surveys. Hence, aerial culling and recreational hunting conducted in 2019 and 2020 have not had a substantial impact on tahr abundances and densities in these management units, with tahr densities still substantially greater than the intervention densities specified in the Himalayan Thar Control Plan (Department of Conservation 1993).

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Appendix 1

The sampling effort (i.e. number of 4 km^2 plots - u) that would need to be sampled to give an abundance estimate with a desired relative precision (ε), with a certain probability (1-α) are related by the following equation (Skalski 1994),

$$u = \frac{U\left(S_{N_i}^2 + \overline{\mathrm{var}\left(\widehat{N_i}|N_i\right)}\right)}{U\left(\frac{\varepsilon\overline{N}}{t_{\left(1-\frac{\alpha}{2}\right),u-1}}\right)^2 + S_{N_i}^2} \qquad 1$$

Where u is the number of required plots, U is the total number of plots that could potentially be sampled, $S_{N_i}^2$ is the variance in tahr abundance among the U plots and $\overline{\mathrm{var}\left(\widehat{N_i}|N_i\right)}$ is the average sampling error among the sampled plots (Skalski 1994). Equation 1 must be solved iteratively by finding the quantile for the t distribution ($t_{\left(1-\frac{\alpha}{2}\right),u-1}$) for successive values of u that satisfies the equation. Here we undertook sample size calculations using equation 1 for management units 1 and 3. We aimed for a sample size for each unit that gave a relative precision of the abundance estimate (CV) of at least 20% with a probability (1-α) of 70%. That is, a sample size that should have a 70% chance of achieving an abundance estimate that has, at least, a 20% relative precision. The resulting sample size estimates (total number of plots) required for each MU are provided in Table A1.

Table A1. Sample size calculations for management units 1 and 3 using equation 1. **U** – total available plots, **u** – number of plots sampled, **u*** – required number of plots to reach 20% relative precision, with a probability of 70%.

MU	U	u	u*
1	190	13	17
3	216	17	26

Appendix 2

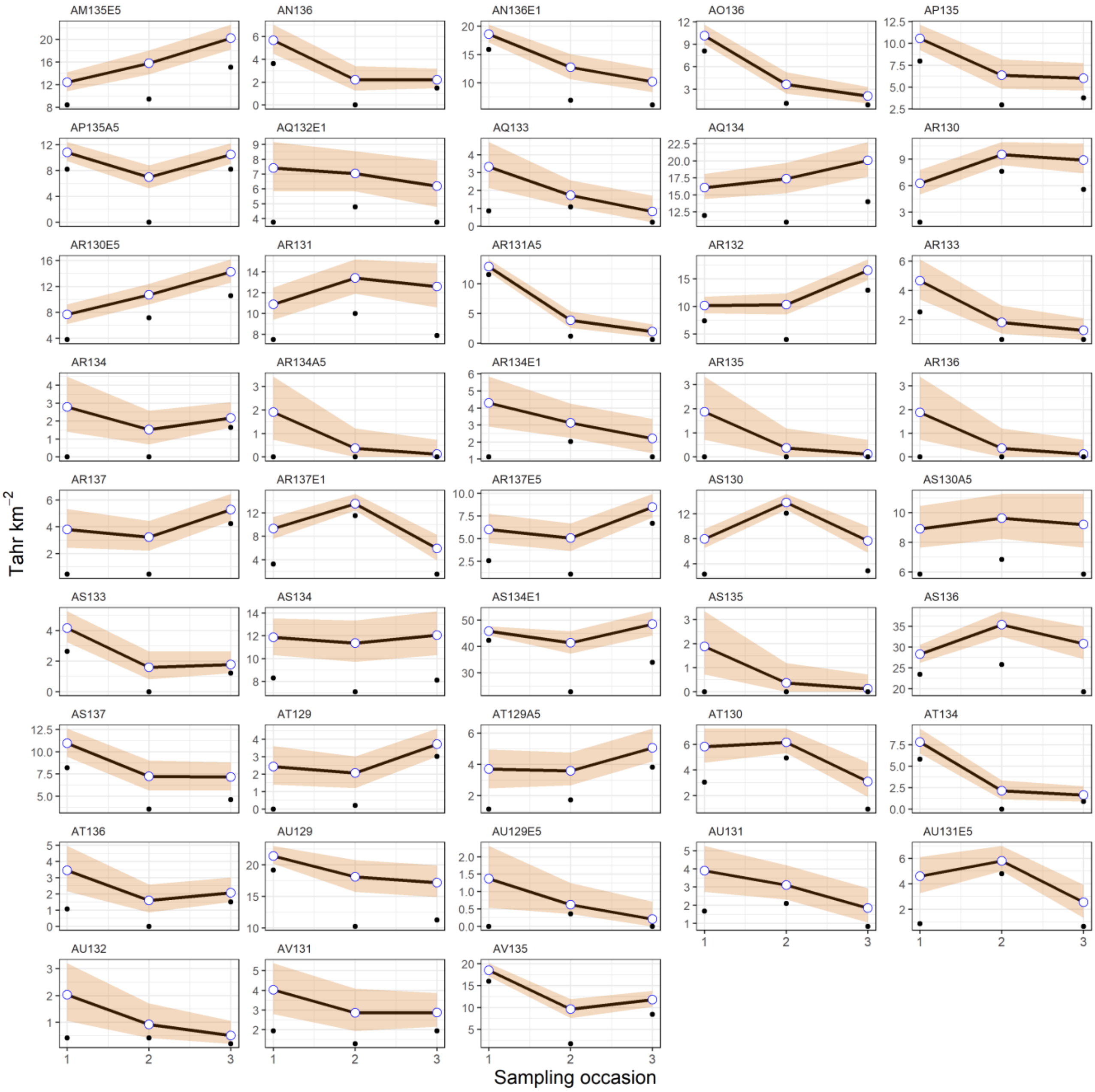

Figure A1. Estimated tahr density (km^2) on each of the three sampling occasions for each of the 43 plots sampled during 2021 (open circles and lines). Black solid circles are the naïve estimates of tahr density calculated from the raw counts. For each plot, the range for the *y*-axis is scaled to the range of the data. The alpha-numeric (e.g., AN136) is the unique plot identifier.

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