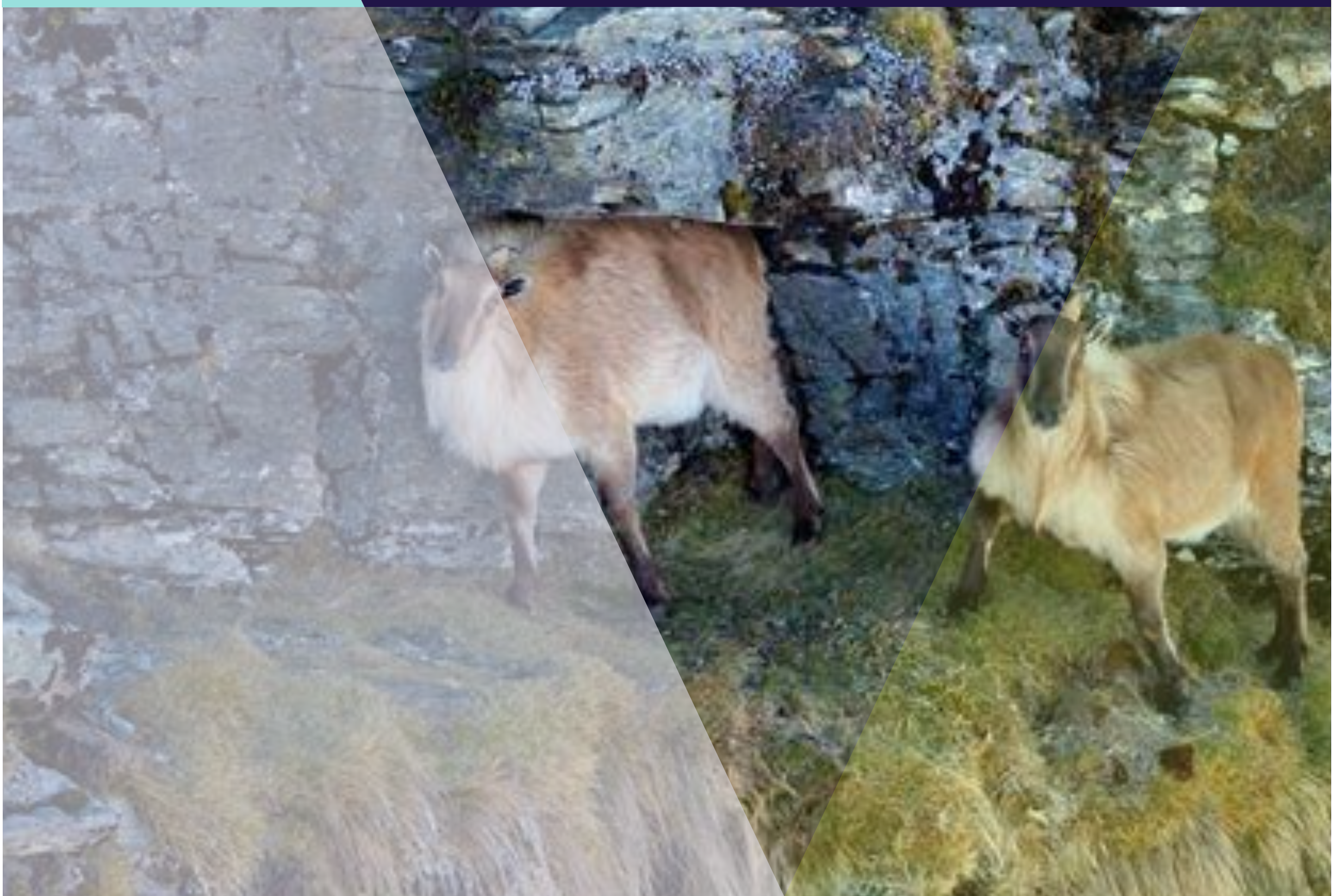
Abundance of Himalayan Tahr on Public Conservation Land in New Zealand

Results from the 2023 aerial survey

D.S.L. Ramsey

October 2023



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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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Abundance of Himalayan Tahr on Public Conservation Land in New Zealand

Results from the 2023 aerial survey

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Summary

Context:

Aerial surveys undertaken during 2016–2019 provided the first estimates of Himalayan Tahr (*Hemitragus jemlahicus)* population size on Public Conservation Land (PCL) across their range in the Southern Alps of New Zealand (Ramsey et al. 2022). Estimates from these surveys showed that average tahr densities exceeded the intervention densities specified in the Himalayan Tahr Control Plan (HTCP) (Department of Conservation 1993) in all but one of seven management units (MUs). Following on from surveys conducted in two MUs during 2021, further aerial surveys were conducted between February and May 2023 on a subset of 42 plots originally surveyed during 2016–2019, selected across each of the seven MUs. This report analyses the monitoring data collected during the 2023 survey to obtain an updated estimate of total tahr abundance within the seven MUs.

Aims:

To estimate the total abundance and density of tahr on PCL within the seven tahr MUs by conducting an analysis of aerial survey data collected on 42 plots during 2023.

Methods:

Helicopter counts of tahr were conducted on two occasions during February – May 2023 at 42 plots (2 x 2 km) located on PCL across seven MUs within the tahr feral range. No surveys were conducted in the two exclusion zones and hence, these areas were excluded from the current analyses. 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 seven MUs. The estimated tahr densities were compared with equivalent estimates obtained during the 2016–2019 survey.

Results:

- The estimate of overall tahr abundance within the seven MUs from the 2023 survey was 29,800 (95% CI: 22,100–40,150). This equates to a 13% decline compared with the equivalent estimate from the 2016–2019 survey (34,400; 95% CI: 26,500–44,800). However, the estimated decline was statistically uncertain.
- Despite the uncertain decline in overall abundance, relatively strong evidence of declines in estimated tahr abundance occurred in MU4, MU5 and MU6 with average reductions of 38%, 60% and 44%, respectively. However, there were also corresponding increases in estimated tahr abundance for MU1 (28%) and MU2 (27%), but these were statistically uncertain.
- The number of tahr culled during aerial and ground operations led or directed by the Department of Conservation in each management unit between July 2019 and June 2023 revealed that the highest culling rates occurred in MU4 and MU6 (around 20 tahr culled/10 km^2/year). Around 8–10 tahr/10 km^2/year were culled in most other MUs, with very few tahr culled in MU7.

Conclusions:

Despite relatively strong evidence of significant decreases in estimated tahr abundance since the 2016–2019 surveys in MU4, MU5 and MU6, the evidence for a significant decrease in overall abundance across the seven MUs was equivocal. Tahr abundance within the seven MUs was almost three times the maximum of 10,000 specified for the tahr range in the HTCP, with the lower 95% confidence interval more than double, providing definitive evidence that overall abundance still far exceeds the maximum of 10,000.

High culling rates, in excess of 20 tahr/10 km^2/year may be required to significantly reduce tahr abundance within MUs, as was observed in two MUs where significant population declines occurred. However, it is recommended that detailed demographic modelling be used to determine the actual culling rates required to reduce tahr abundance in each MU down to the intervention densities specified in the HTCP. Ongoing monitoring within each MU would also be required to determine the actual population reductions achieved. If

more precise estimates of population reduction are required for specific MUs then additional monitoring effort may be required in those management units to increase statistical power.

Recommendations:

- Develop a detailed demographic model of tahr populations and use it to estimate the required levels of culling needed to reduce tahr abundance within each MU to the required densities specified in the HTCP.
- Continue monitoring periodically (e.g., annually, or biennially) to estimate the abundance of tahr across the seven MUs to determine the trends in tahr abundance and their response to management. Future monitoring should aim to monitor the same 42 plots used for the current survey (surveyed twice) to enhance the time-series of monitoring data collected on these plots.
- If a more precise estimate of population reduction is required for specific MUs, then the number of additional plots required to be monitored to increase statistical power to detect the desired reduction should be determined.

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 1960s and 1970s, the population increased six-fold following a moratorium on commercial harvesting in 1982 (Parkes 2009). Tahr are a defined 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 (e.g. *Chionochloa* spp.), and caused widespread impacts on montane grasslands during the 1960s when their densities were high (Parkes 2009). However, despite subsequent large reductions in tahr abundance, impacts were still apparent through the 1990's and 2000's suggesting tahr needed to be controlled to lower densities to further reduce impacts on native vegetation (Cruz et al*.* 2017).

The Himalayan Thar Control Plan (HTCP) defines intervention densities in terms of number of the tahr per km^2 in each of seven management units (MUs) (range: <1 to 2.5 tahr per km^2) and two exclusion zones (EZs) (0 per km^2), with the total population limited to 10,000 individuals (Department of Conservation 1993). However, insufficient monitoring data existed to estimate tahr abundances on these MUs and EZs. To address that knowledge gap, aerial surveys of tahr and other ungulates were conducted at 117 plots (2 x 2 km) monitored as part of the national Biodiversity Monitoring and Reporting System (BMRS) (Allen et al. 2013) from 2016–2019. These data were then used to estimate the density and total abundance of Himalayan tahr on Public Conservation Land (PCL) in each of the seven MUs and two EZs (Ramsey and Forsyth 2019; Ramsey et al*.* 2022). The total abundance of tahr on PCL was estimated to be 34,500 (95% confidence interval: 27,750–42,900) with a coefficient of variation (CV) of 11% (Ramsey et al. 2022). Hence, the total population clearly exceeded the 10,000 specified for the entire tahr range (Ramsey and Forsyth 2019).

Between February and May 2021, aerial surveys were repeated on a subset of the original plots within MU1 and MU3, which were supplemented by an additional 15 randomly selected plots, for a total of 43 plots (Ramsey and Forsyth 2021). These surveys were undertaken to obtain abundance estimates for tahr specifically for those MUs with increased precision compared with the estimates from the previous 2016–2019 survey, which was designed primarily to estimate the overall tahr population. The results from these surveys revealed that tahr abundance within these two MUs were similar to that estimated from the previous survey. The estimates also had increased levels of precision, with CVs of 17% and 21% achieved for MU1 and MU3, respectively, close to the desired target level of 20% (Ramsey and Forsyth 2021).

During 2023, aerial surveys were repeated on 42 plots across each of the seven MUs (but not the two EZs). These plots were randomly selected from the original 117 plots, with the number sampled considered to be the minimum number of plots sufficient to obtain an estimate of total abundance with the desired level of precision (i.e., CV of $\leq$ 20%). Here we report on the analyses of these monitoring data, using the same methods to that used in Ramsey et al. (2022). We also report on the number of tahr culled between July 2019 and June 2023 during control programs undertaken or led by the Department of Conservation.

2 Methods

A total of 42 plots were selected from the original pool of 117 plots surveyed during 2016–2019 (Ramsey and Forsyth 2019). Ramsey and Forsyth (2019) also suggested the minimum numbers of plots that should be monitored in each MU to make up the total sample of 42 plots (Table 1). No plots were selected from the EZs (EZ1 and EZ2), as the focus of the current survey was confined to the tahr population on PCL within the seven MUs (Figure 1).

Table 1. Minimum sample size of plots (*n*) for each management unit (MU) recommended for aerial surveys of tahr.

MU	MU1	MU2	MU3	MU4	MU5	MU6	MU7	Total
n	6	5	8	9	4	5	5	42

Plot selection was undertaken using stratified random sampling from the pool of 117 plots, with the strata consisting of the MUs. A spatially-balanced sample was selected from each strata, assuming equal selection probabilities for each plot, using the generalized random-tessellation stratified (GRTS) algorithm (Dumelle et al. 2023). Use of this algorithm achieves spatial balance with respect to the sampling frame (i.e. the total pool of 117 plots). The selected plots are shown in Figure 1.

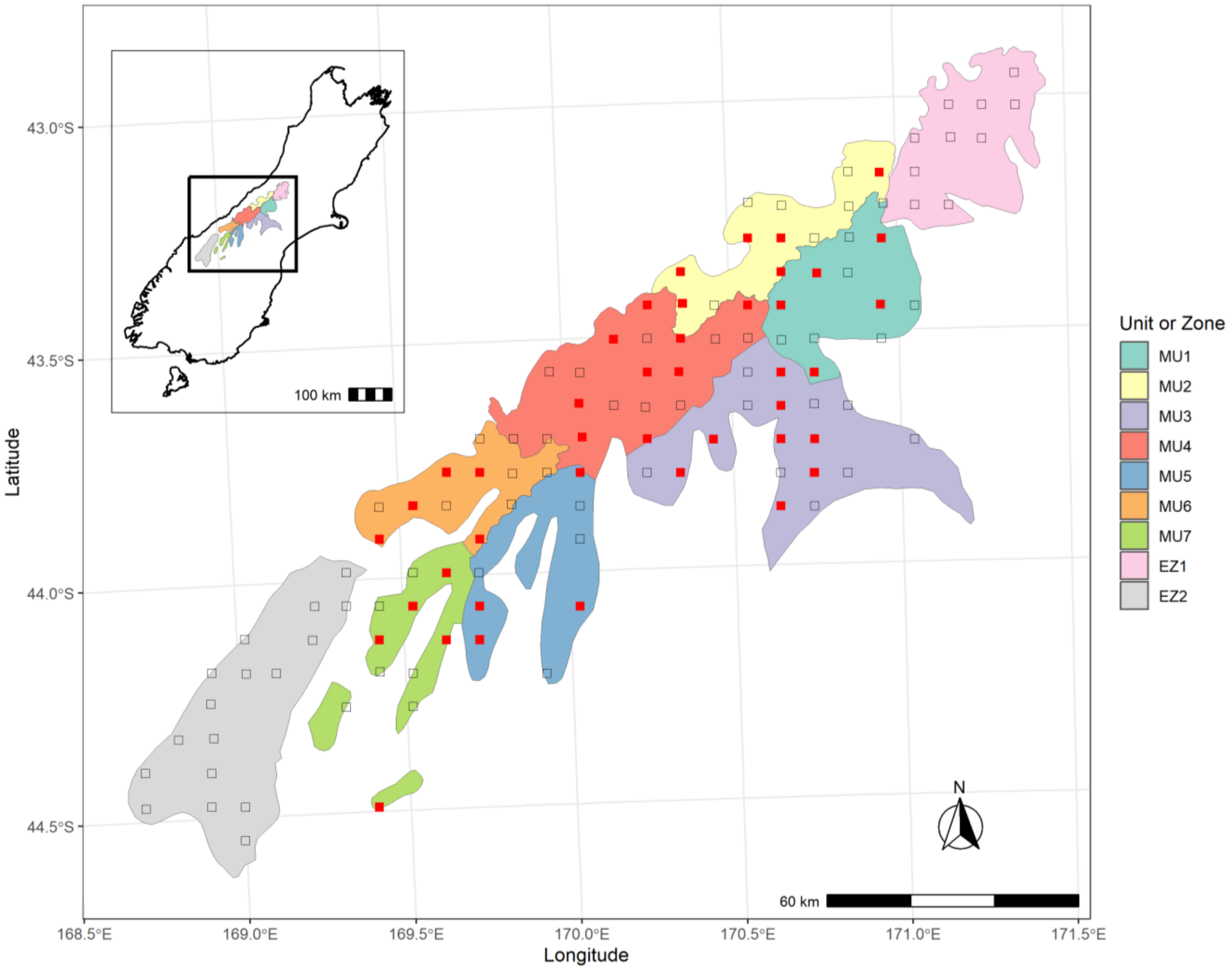

Figure 1. Location of the seven tahr management units (MUs) and two exclusion zones (EZs) in the Southern Alps of New Zealand. Squares show the locations of the 117 plots surveyed during 2016–2019, with the red squares showing the 42 randomly selected plots used for the current survey. Plot size was 2 km x 2 km.

2.1 Aerial survey protocol

The aerial survey protocol is described in detail elsewhere (Ramsey et al. 2022). Briefly, each 4 km^2 plot was subject to two separate counts (three counts in previous surveys) undertaken from a helicopter (either 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 count at that plot. Counts were undertaken during February – May 2023.

On each of the two 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 sex and age classes where possible. A third person, seated in the rear behind the primary observer, recorded the location (with a GPS) and the sex/age composition for each tahr group.

2.2 Abundance estimation

The total number of tahr counted within each plot, on each of the two sampling occasions, was used to estimate abundance at 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; Ramsey et al. 2022). Since a subset of the same plots used for the 2016–2019 survey were monitored, we added the monitoring data for the 42 plots monitored during 2023 to the time series of monitoring data collected on the same plots surveyed in 2016–2019 and conducted an analysis of the joint data. The advantages of this approach were that the combined monitoring data allowed the trend in abundance estimates between the 2016–2019 and 2023 periods to be estimated and compared. Hence the time series of data for the 42 plots monitored during 2023 consisted of a total of five sampling occasions (three during 2016–2019 and two during 2023), with the remaining 75 plots consisting of data from three sampling occasions from 2016–2019.

The abundance of tahr in each MU from the 2023 surveys were estimated from the mean abundance of tahr from the two surveys in each of the 42 monitored plots (plus their standard error) using a design-based approach (Ramsey et al. 2022). Abundance estimates only included tahr on PCL with total abundance equal to the sum of the abundances from the seven MUs. The change in tahr abundance in each MU was determined by comparing the 2023 abundance estimates with the abundance estimates from the 2016–2019 surveys and calculating the relative change as follows:

$$C = \left(\frac{N_{23}}{N_{16}} - 1\right) \times 100\%, \qquad \text{Eq. 1}$$

Where C is the relative change (%) in abundance estimates between the 2016–2019 (N_{16}) and 2023 (N_{23}) surveys. This statistic was calculated separately for each MU as well as total abundance. A standard error for C was calculated using the delta method, from which 95% asymptotic confidence intervals were derived. A z-test and corresponding p-value for the one-tailed hypothesis test that $C < 0$ (i.e., a relative decrease between 2016–2019 and 2023) was also undertaken for each MU to determine the level of statistical support for any reductions in estimated tahr abundance.

3 Results

3.1 Summary of aerial survey counts

The number of tahr counted at each of the 42 plots sampled during 2023 for each sampling occasion ranged from an average of 2 tahr for MU7 to 24 tahr for MU1 (Table 2). The average number of tahr seen on each occasion was higher during the 2023 survey for MU1, MU2 and MU7 compared with during the 2016–2019 survey and was lower for the remaining MUs (Table 2).

Table 2. Summary of the counts of tahr on plots within each management unit (MU) during the current survey (2023) and the surveys conducted during 2016–2019. Mean count is the average count over the replicate surveys for each plot. SD – standard deviation.

	2016–2019 survey		2023 survey	
MU	Mean count	SD	Mean count	SD
1	18	17.2	24	14.1
2	12	15.6	15	10.8
3	23	25.4	21	26.0
4	11	10.6	6	8.2
5	24	37.0	7	4.7
6	10	12.2	6	5.6
7	1	1.1	2	2.8

3.2 Tahr density and abundance

The fit of the *N*-mixture model to the counts of tahr on the 42 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 mean density of tahr on each plot varied widely, from 0 to 27 tahr/km^2 (Figure 3). Precision of the plot density estimates was generally acceptable, with an average CV of 13%.

The corresponding average density of tahr within each MU varied from 0.8 tahr/km^2 in MU7 to 10.2 tahr/km^2 in MU1 (Table 3). The estimate of total tahr abundance for the current survey was 29,800 (95% CI: 22,100–40,150) (Table 4). The precision of the total abundance estimate achieved with the current survey (15%) was within the desired target range (i.e., ≤ 20%), and similar to that achieved during the 2016–2019 surveys (13%) (Ramsey et al. 2022). The total tahr abundance on PCL equates to a 13% decline compared with the equivalent estimate from the 2016–2019 survey (34,400 – excluding the two EZs – Ramsey et al. 2022). However, the difference was not statistically significant (Table 5). Declines in the number of tahr were most pronounced in MU4, MU5 and MU6 where tahr abundances were reduced by an average of 38%, 60% and 44%, respectively (Figure 4 and Table 5). However, there were also corresponding increases in tahr abundances for MU1 (28%) and MU2 (27%) compared with the estimates from the 2016–2019 survey (Figure 4, Table 5). The relative declines in abundance (Eq. 1) for MU5 and MU6 were statistically significant at the conventional 5% level of significance ($P < 0.05$), while for MU4, the hypothesis of no decrease was rejected at the 10% level of significance ($P < 0.1$). None of the relative changes in the other MUs were statistically noteworthy (Table 5).

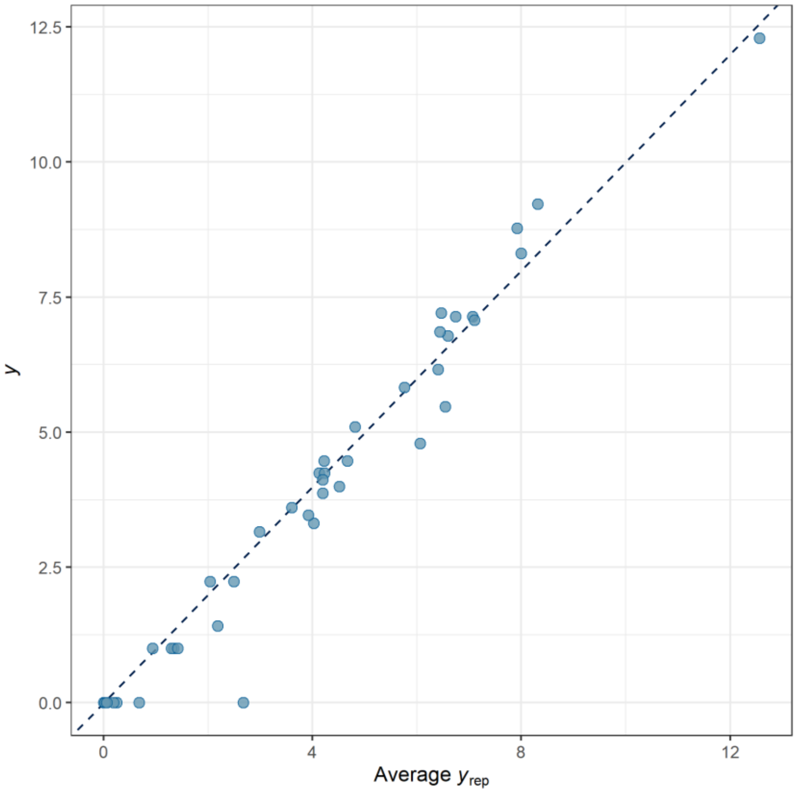

Figure 2. Posterior mean of the total counts of tahr on each plot predicted by the *N*-mixture model (average y_{rep}) versus the observed total counts of tahr (y). Predicted and observed counts have been square root transformed for clarity.

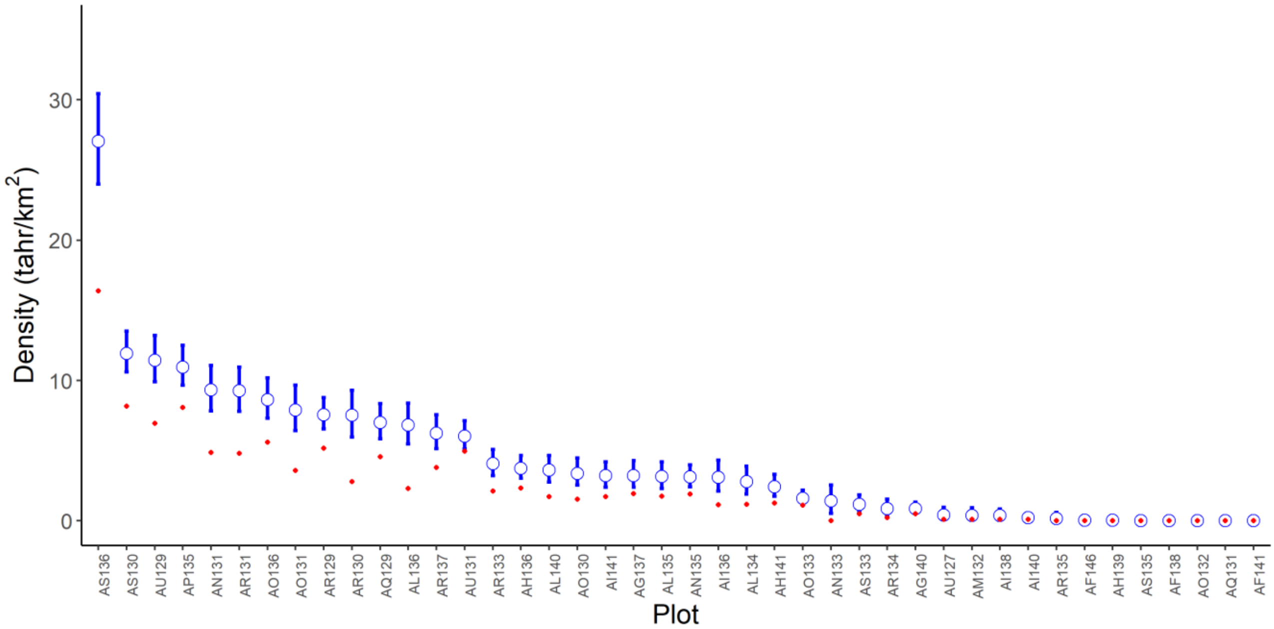

Figure 3. Estimated mean tahr density (open circles) and associated 95% Bayesian confidence intervals (solid lines) on each of the 42 plots sampled by aerial surveys during 2023. The plots are shown in descending order of mean tahr density. Red circles indicate the naïve density estimate obtained by dividing the (average) observed count by the plot area.

Table 3. Average densities of tahr (tahr/km^2) on PCL within each of seven management units (MUs) estimated from plots subject to aerial surveys during 2023. SD – standard deviation; LCL – lower 95% confidence limit; UCL – upper 95% confidence limit; *n* – number of plots

MU	Density	SD	LCL	UCL	n
1	10.2	2.00	7.0	14.9	6
2	6.6	1.82	3.9	11.2	5
3	9.1	4.05	4.0	21.0	8
4	3.0	1.14	1.4	6.2	9
5	4.3	1.60	2.1	8.7	4
6	2.7	1.00	1.3	5.4	5
7	0.8	0.55	0.2	2.7	5

Table 4. Design-based estimates of total abundance (*N*) of tahr on PCL within seven management units (MUs) estimated from 42 plots subject to aerial surveys during 2023. SE – standard error; CV (%) – percent coefficient of variation; LCL – lower 95% confidence limit; UCL – upper 95% confidence limit.

MU	*N*	SE	CV (%)	LCL	UCL
1	7,750	1,518	20	5,300	11,350
2	5,450	1,508	28	3,200	9,250
3	7,900	3,501	44	3,450	18,100
4	4,400	1,694	38	2,150	9,150
5	1,950	738	37	950	4,000
6	1,800	682	38	900	3,700
7	500	335	69	150	1,650
Total	29,800	4,564	15	22,100	40,150

Table 5. The difference in abundance estimates between the 2016–2019 and 2023 surveys (difference), the percent relative change (*C* %), the standard error of the change (SE %), and the Z statistic and corresponding p-value for the hypothesis test that the difference was less than zero.

MU	Difference	*C* (%)	SE (*C*)	LCL	UCL	Z	P
1	-1700	28	36.4	-43.4	99.4	0.77	0.78
2	-1150	27	56.4	-83.5	137.5	0.48	0.68
3	750	-9	45.1	-97.5	79.5	-0.20	0.42
4	2700	-38	26.8	-90.5	14.5	-1.42	0.08
5	2950	-60	23.1	-105.3	-14.7	-2.60	0.01
6	1400	-44	26.2	-95.4	7.4	-1.68	0.05
7	-300	150	192.0	-226.2	526.2	0.78	0.78
Total	4600	-13	16.4	-45.2	19.2	-0.79	0.21

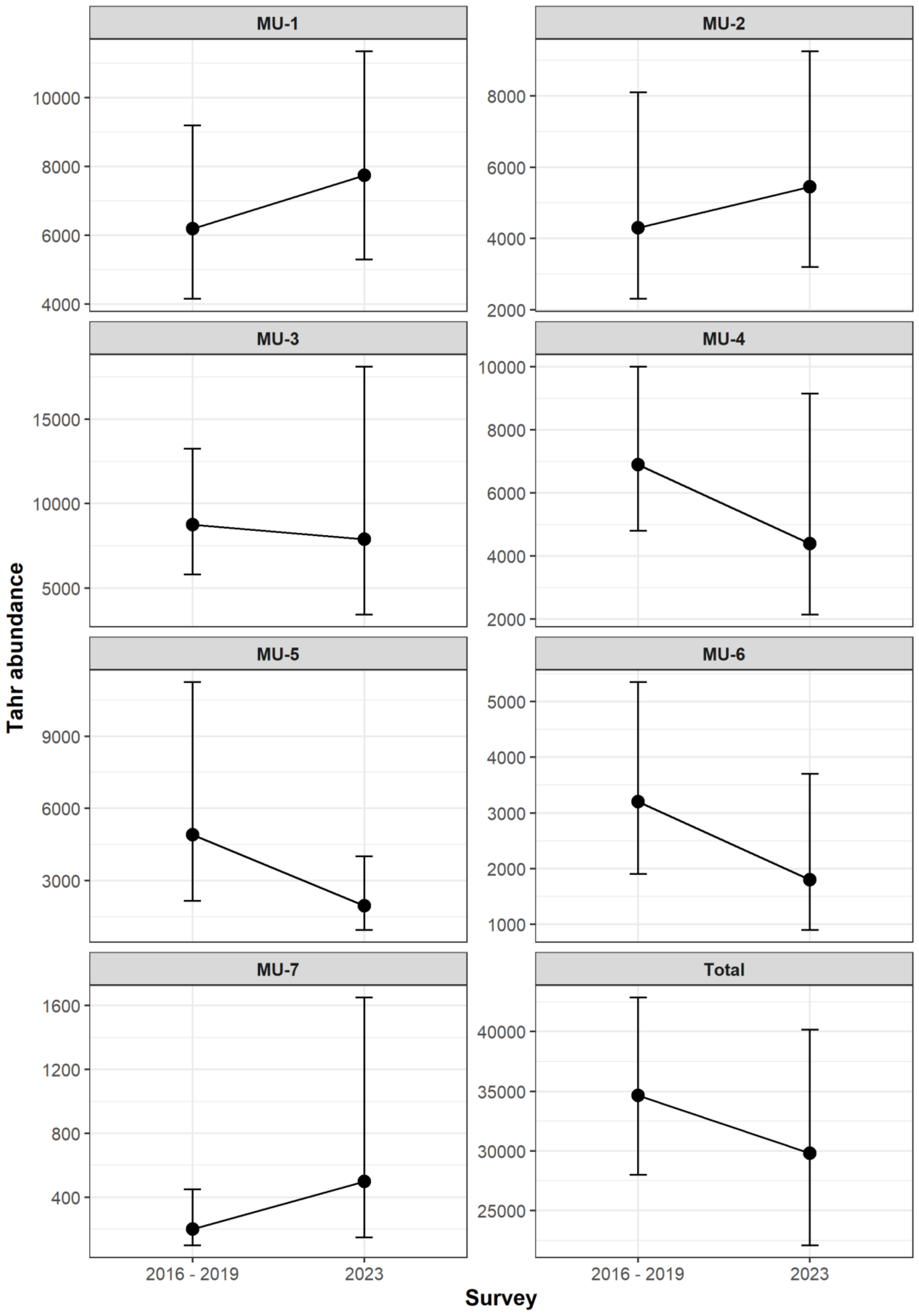

Figure 4. The difference (D) in tahr abundance estimates for each management unit between the 2016–2019 and 2023 surveys. Vertical lines indicate the 95% confidence intervals. Note scales on the y-axis differ for each management unit (MU).

3.3 Tahr culling data

The numbers of tahr culled during control programs led or directed by the Department of Conservation in each MU from July 2019 to June 2023 are presented in Table 6. Most tahr were culled during operations within MU4, where an average of 21.4 tahr were shot per 10 km^2 of PCL per year. This was followed by MU6, where an average of 21.6 tahr per 10 km^2 of PCL per year. In contrast, around 8–10 tahr per 10km^2 per year were culled in most other MUs, but very few tahr were culled in MU7 (Table 6).

Table 6. The number of tahr culled each year within each management unit (MU) between 1 July 2019 and 30 June 2023 for control programs led or directed by the Department of Conservation and the number culled per 10 km^2 of PCL per year (Density).

Year	MU1	MU2	MU3	MU4	MU5	MU6	MU7
2019/20	2113	246	1603	3675	1278	1332	58
2020/21	555	1038	641	3299	241	1697	10
2021/22	0	873	187	3007	111	1572	0
2022/23	406	832	334	2706	116	1277	0
Total	**3074**	**2989**	**2765**	**12687**	**1746**	**5878**	**68**
Density	**10.1**	**9.0**	**8.0**	**21.4**	**9.5**	**21.6**	**0.3**

4 Discussion

Estimates of the abundance of tahr on PCL within seven MUs were generated from monitoring data collected on a subset of 42 plots from the 117 that were sampled during 2016–2019. Despite the lower number of plots, which were also monitored only twice, the estimate of total abundance (29,800) had adequate precision, with a coefficient of variation (CV) of 15%. Hence, this estimate is within the desired precision range (< 20%) predicted for this sample size by Ramsey and Forsyth (2019). Although not a statistically significant difference, this estimate was 13% lower than the equivalent estimate from 2016–2019 (34,400). Despite this change, the lower 95% confidence interval in 2023 is still more than double the maximum of 10,000 tahr specified in the Himalayan Tahr Control Plan (Department of Conservation 1993).

The majority of the change in the total abundance of tahr since 2016–2019 can be attributed to declines in tahr abundance of around 40–60% in MU4, MU5 and MU6 between the two survey periods. However, this was tempered by corresponding increases in estimated tahr abundance of around 28% in MU1 and MU2. Due to the lower number of monitored plots, estimates for individual MUs had lower precision than the estimates from the 2016–2019 survey. This means our power to detect significant change in total abundance, and for specific MUs, was relatively low. The exception to this was the relative decreases in abundance observed for MU5 and MU6, where the hypothesis that the abundance had not decreased in those MUs was rejected at the conventional 5% level of significance. Similarly, for MU4, the hypothesis of no decrease was rejected at the 10% level of significance.

Collation of the number of tahr culled during management operations led by the Department of Conservation from July 2019 to June 2023 indicated that tahr were more heavily culled in MU4 and MU6 compared with other MUs, so the observed decrease in tahr abundance in those MUs is not surprising. However, relatively fewer tahr were culled in MU5, which also recorded the largest decrease in abundance. It remains to be investigated whether this apparent decrease in MU5 is an anomaly or due to some other unknown process such as increased recreational hunting activity or differential movement of tahr away from this MU.

Despite the unexplained decrease in abundance in MU5, the rates of culling recorded within MU4 and MU6 suggest that relatively high culling rates, around 20 tahr per 10 km^2 per year are required to effect substantial reductions in tahr abundance, at least initially. The minimum number of tahr required to be removed annually to mitigate population growth can be calculated theoretically from the intrinsic rate of increase (r_m). Estimates of r_m for tahr can be derived from ground counts of female tahr in MU3 conducted between 1984 and 1996, which revealed that female tahr in the North Branch were increasing at a rate of 32% per year (i.e., r_m = 0.28) (Forsyth 1999). As female tahr are relatively sedentary, and the initial population was relatively low, tahr populations were likely increasing in this area at their maximum rate (Forsyth 1999). The minimum fraction of the population that must be culled each year (p) to reduce the growth rate to zero is given by $p = 1 - 1/\exp(r_m)$ (Hone et al. 2010). Assuming a maximum rate of increase 0.28 per year, then p = 0.24 or 24% of the population would need to be culled, per annum. Applying this rate to the population estimate for MU1, for example, suggests that 1860 tahr or 25 tahr per 10 km^2 per year would need to be culled to halt further population increase. However, this level of culling applies when tahr populations are increasing at their maximum rate. Since the current tahr population is not at low density, the actual rate of increase of the tahr population and the population response to culling is unknown. Hence, the actual amount of culling required to reduce or reverse population growth would require more detailed demographic modelling. Hence, it is recommended that such demographic models of tahr populations be developed and used to determine the level of annual culling required to reduce the tahr population in each MU to the respective intervention densities. Such modelling would need to be supported by periodic monitoring across the seven MUs to determine the actual level of population reduction achieved. This may require additional monitoring effort to increase statistical power if a more precise estimate of population reduction is required for specific MU.

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