A survey of the wild horse population in Kosciuszko National Park, NSW, October–November 2024

Report to the NSW Department of Climate Change, Energy, the Environment & Water, November 2024

[redacted]

[redacted]

Abstract

1. The NSW National Parks and Wildlife Service requested that we repeat the 2020, 2022 and 2023 horse survey methods in four priority management areas of the Kosciuszko National Park (KNP), to estimate the 2024 horse populations. This report presents the methods and results of this survey, conducted in October–November 2024.
2. The amount of aerial survey effort (the number of kilometres of transect needed to be flown) was calculated to contain random estimation errors below provided thresholds. This analysis used survey data from 2020, 2022 and 2023, and was adjusted for assumed horse population sizes in 2024 following recent aerial horse control operations. The analysis showed it was necessary to increase sampling intensity in 2024, achieved by reducing the distance between flown transects in the two largest survey blocks.
3. Surveys were carried out in a ParkAir Eurocopter (B3 Squirrel), with flying height and speed kept consistent with the 2023 survey. In 2024 flight times were largely limited to 3 hours from sunrise and 3 hours from sunset. Using electronic key pads, observers recorded horse numbers, the sighting distance zone where they were seen, and habitat structure (open, medium, or dense vegetation obstructing sightability).
4. A total of 938.5 km of transect line was flown in the Southern survey block, 901.6 km in the Northern block, 156.8 km in the Cabramurra block, and 233.0 km in the Snowy Plains block.
5. Previous surveys used two aerial observers, one on each side of the aircraft. In 2024 a third observer was seated in the front position to allow an independent analysis to be undertaken using the two left observers' data, called mark-recapture (MR). In this report, consistent with past years, conventional distance sampling (CDS) and multiple-covariate distance sampling (MCDS) have been undertaken using only rear observers' counts to enable these results to be directly compared with results from previous years. Separately, mark-recapture distance sampling (MRDS) was undertaken using data from all three observers. The adjustment for perception bias using the MRDS count data revised the population density estimates for each survey blocks upwards by about 50% compared to the MCDS estimates. This suggest that a negative perception bias is likely to be present in past years' survey data based on MCDS analysis of the two-observer counts.
6. Horse abundance estimates were much lower than expected in 2024, regardless of modelling method. Taking the highest estimate (MRDS for adult horses) for the survey areas combined, the estimated population in 2024 was 3,949 horses, rather than the anticipated 13,050. One possibility is that horses may be avoiding areas where aerial control operations recently took place, or they may have become averse to the presence of the helicopter. The other possibility is that survey lines have been too close together in past surveys and double-counting may have occurred, elevating past population estimates. The report discusses these possible reasons and suggests ways to approach the survey in future.

This report may be cited as:

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[redacted]

Introduction

Background

Kosciuszko National Park (KNP) is a 689,000 ha (6,890 km^2) reserve system in eastern New South Wales (NSW). It forms the largest portion of the broader Australian Alps National Parks (AANP) network within the Great Dividing Range, which straddles eastern NSW, Victoria, and the Australian Capital Territory (ACT).

Wild horses (*Equus caballus*) occupy various parts of KNP. Periodic population monitoring is necessary to manage the size and distribution of the horse population in compliance with the Kosciuszko National Park Wild Horse Heritage Management Plan (Environment & Heritage Group, 2021; amended 2023).

Under the Management Plan, there are different goals for horse management in different parts of KNP. In designated removal areas there is a requirement that the National Parks and Wildlife Service (NPWS) NSW remove all horses. In retention areas, horse populations are to be retained, but maintained at reduced numbers. The target population size in all the retention areas combined is 3,000 horses by 30th June 2027.

Because there are distinct horse management goals for different portions of the park, this report includes population density estimates and population size estimates for:

- Three of the four aerial survey blocks separately (see Figure 1) (the fourth had insufficient data to calculate)
- Three of the four survey blocks combined, covering 2,536 km^2 (the fourth had insufficient data to calculate)
- Three of the four retention areas separately; one (Tom Groggin) was excluded due to its small size
- Three of the four retention areas combined, covering 2,181 km^2.

Compatibility with previous surveys

Aerial surveys of horses have been carried out in various parts of the AANP region since the early 2000s. The three most recent surveys [redacted] 2020; 2022; 2023) have focused on four defined survey blocks within KNP. For consistency, the present survey focuses on the same survey blocks, while noting that horses also occur in other areas of the park.

Previous survey methods have been based on the commonly-used techniques of Conventional Distance Sampling (CDS) and Multiple-Covariate Distance Sampling (MCDS), both of which use horse count data from two aerial observers (Thomas *et al*. 2006).

The 2024 survey design aimed to maintain compatibility with the previous three survey results by continuing to use distance sampling and multiple-covariate distance sampling, while simultaneously trialling an additional method – Mark-Recapture Distance Sampling (MRDS; Thomas *et al*. 2006) using a third observer (see *Methods*). Population density estimates obtained using each method are presented separately for comparison, including separate density calculations for the survey blocks and retention areas.

Methods

Study area

Four survey blocks of the of the KNP Wild Horse Heritage Management Areas have previously been identified by NPWS NSW as key areas that support populations of wild horses: the Northern Block, Snowy Plains, Cabramurra Block, and Southern Block (see Figure 1). The Northern (1,229 km^2) and Southern (1,146 km^2) blocks are an order of magnitude larger than the Snowy Plains (161 km^2) and Cabramurra (139 km^2) blocks.

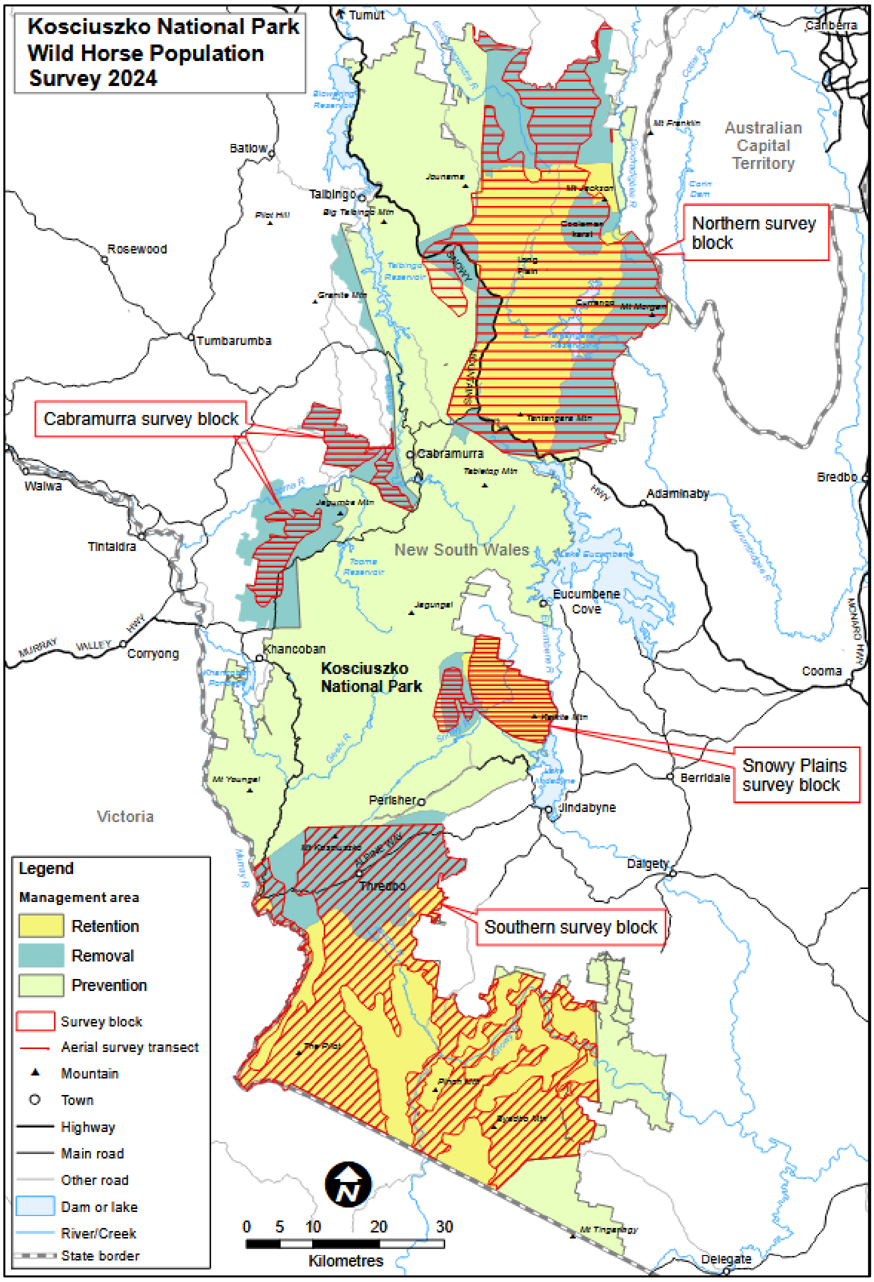

__Figure 1:__ Map of the Kosciuszko National Park Wild Horse Heritage Management Areas, showing the four management areas surveyed for this report. Map supplied by NSW NPWS.

These four blocks have been surveyed repeatedly in recent years (2020, 2022 and 2023), and as requested by the NSW NPWS, the 2024 survey was designed to align with these same areas. Horses are known to be present in other areas of the park, outside the survey blocks, typically in areas that are too steep to survey safely from the air. It is important to note, therefore, that the population estimates in this report for the combined survey areas do not comprise an estimate of the total horse population for KNP as a whole.

Survey design

For consistency and comparability of survey results with those from previous years, the 2024 survey was designed to follow a similar format to [redacted] (2020; 2022; 2023), with amendments to the amount of survey effort in some of the blocks based on analysis of previous years' survey data.

Flying operations

Aerial survey work was conducted between 27th October and 10th November 2024. The methodology is consistent with the October 2023 survey in terms of flying height, aircraft type, and flying speed. All survey transects were flown in a Park Air Eurocopter (B3 Squirrel) single-engine helicopter with the rear doors open to improve sightability. Ground speed was held at 93 km/h (50 kts) at a height of 61 m (200 ft) above ground level. The pilot used a GPS receiver to keep on track.

Following earlier surveys, two aerial observers were seated on opposite sides at the rear of the aircraft, counting horses on their side of the helicopter only. The counts from these two observers were used for the CDS and MCDS analyses (described later). In 2024 a third observer was added in the front left position.[1] This observer's counts were integral to the MRDS analyses (see *Methods*). Observers were rotated through the three seating positions systematically for each flight.

To ensure surveys coincided with the times of day when horses were thought to be most active, all flights were scheduled to be completed within 3 hours of first light and last light. Surveying was avoided when weather conditions would negatively affect visibility of animals or it was deemed unsafe to fly by the pilot. Observers were instructed not to discuss their counts during flying operations so as to maintain the independence of their counts.

Sighting poles divided into five sighting zones were used, consistent with past surveys. The marked zones on the poles corresponded with distance classes of 0–20 m, 20–40 m, 40–70 m, 70–100 and 100–150 m away from the aircraft, assuming the specified flying height of 61 m above ground.

Counting practices & electronic keypad recording

In 2024, electronic keypads were provided to the observers by the authors to replace the use of voice recorders. These had the advantage that the locations of all sightings were GPS-tagged. The keypads, which are designed so observers do not have to look away from their field of view to enter data, have been used regularly for aerial wildlife surveys in WA, Tasmania, SA, Victoria and the NT

[1] Addition of a third observer in the front seat of the aircraft, alongside the pilot, meant that a dedicated Air Observer, who normally provides situational awareness for the aircraft, could not be used. This departed from NSW NPWS standard operating procedures for low-level flying, and required an additional risk assessment and alternative risk mitigation procedures to be put in place to ensure adequate safety. Executive level approval was given for the specific operation to be carried out under the revised procedures on a one-off basis.

since 1996. A centralised computer tablet and software stores the keypad data and GPS positions for up to four observers in a secure database. A training flight was conducted prior to the survey to ensure observers were comfortable with using the keypads.

On the keypads, the aerial observers recorded:

- The sighting distance zone (numbered 1–5, corresponding with the distance classes marked on the sighting poles) in which each animal was sighted; when multiple animals were seen together, the keys were hit repeatedly for the relevant zone.
- Habitat variables where horses were sighted, classified into one of three classes: *Open* (i.e. open area with unobstructed view); *Medium* (view partially obstructed by terrain and/or vegetation); or *Closed* (heavy obstruction of view).
- The species/stage: as a priority, adult horses and foals were counted, but pigs and deer were also recorded.

Survey methods & data analysis

Helicopter line transect surveys

Target survey effort (i.e. number of kilometres of transect needed to be flown) was set for each survey block individually (see design report; [redacted], 2024). This report was peer-reviewed before logistics for the survey were planned. The survey effort for three of the four blocks were each calculated to meet the target Coefficients of Variation (CVs), set by NSW NPWS (Table 1). For the Northern KNP, Southern KNP and Snowy Plains survey blocks, the target survey effort was calculated, based on an analysis of the previous three years' data combined (see [redacted] 2024). There was insufficient data to determine the survey effort in the Cabramurra Block.

Table 1: *Target coefficients of variation (CV_Ds) set by NSW National Parks and Wildlife Service for horse population density estimates in Kosciuszko National Park survey blocks.*

	Northern block	Snowy Plains	Southern block
CV_D	13%	40%	20%

Due to an expected reduction in horse population size in 2024 compared with 2023 due to aerial control operations, an increased survey effort (i.e. an increase in kilometres of flown transect) was needed in 2024 to produce sufficiently precise population density estimates in the Northern and Southern blocks of KNP (Table 2).

Layout of regularly-spaced parallel transects was calculated automatically using software, avoiding areas of steep terrain, consistent with previous surveys [redacted] 2020; 2022; 2023). Maps showing the layout of transect lines are shown below, for the Northern Block (Figure 2), Snowy Plains (Figure 3), Southern Block (Figure 4) and Cabramurra Block (Figure 5). Orientation of the transects matched those used in previous surveys, east-west in the Northern, Cabramurra and Snowy Plains blocks, and northeast-southwest in the Southern block.

Increased survey effort meant that for the larger Southern and Northern blocks the transect lines were spaced more closely together than in 2023. This altered the Southern Block transects to now be

1.23 km apart and the Northern KNP block transects to now be 1.37 km apart. Given that the minimum distance between transects was set at 1.5 km by [redacted] (2023), this meant that the order in which the transects were flown needed to be staggered every second transect, with the aircraft returning on a separate day to fly the transects that were missed. [redacted] (2023) (following the findings of Linklater and Cameron, 2002) suggests that this is necessary to prevent double-counting (or worse) of horses that may have been flushed into the path of the next parallel transect line from the first pass, and so on. Spacing of the Snowy Plains and Cabramurra transects remained unchanged. As these were already spaced less than 1.5 km apart (0.7 km), the survey order was staggered as in the past.

[redacted] (2024) arrived at new survey effort estimates (transect spacings), based on the following table. No changes were deemed necessary for the Snowy Plains and Cabramurra blocks (see planning report). The assumed population increases and 2023 removal numbers were provided by NSW NPWS.

The maps in Figures 2–5 show the layout of the 2024 transects, based on survey effort in Table 2.

Table 2: *Survey block size, horse population sizes, survey effort, & transect spacing (from design report;* [redacted] *2024)*

	Northern	Snowy Plains	Southern	Cabramurra
Survey block area (km^2)	1,229	161	1,146	139
Abundance estimate 2023	13,212	363	3,769	-
Removal numbers 2023	5,016	8	1,360	-
Likely abundance after removals	8,196	355	2,409	-
Assumed population increase	22.5%	15%	8%	-
Expected abundance Oct 2024	10,040	408	2,601	-
Expected density (horses per km^2), Oct 2024	8.169	2.535	2.270	-
Survey effort (km of flown transect), 2023	**794 km**	**231.9 km**	**765 km**	**156 km**
Transect spacing for 2023	1.5 km	0.7 km	1.5 km	0.9 km
Minimum survey effort for 2024	**880 km**	**231.9 km***	**925 km**	**-**
Final transect length for 2024	**901 km**	**232 km**	**938 km**	**156 km**
Transect spacing for 2024†	**1.37 km**	**0.7 km**	**1.23 km**	**0.9 km**

**Note: The target precision for the Snowy Plains block could have been met with less survey effort in 2024 than in 2023, but effort was maintained at the same level as previously for consistency & comparability of the data; †Transects were flown in a staggered alternating sequence to minimise risk of flushing horses into the path of the next transect; the transects that were skipped on the first past were flown on a different day.*

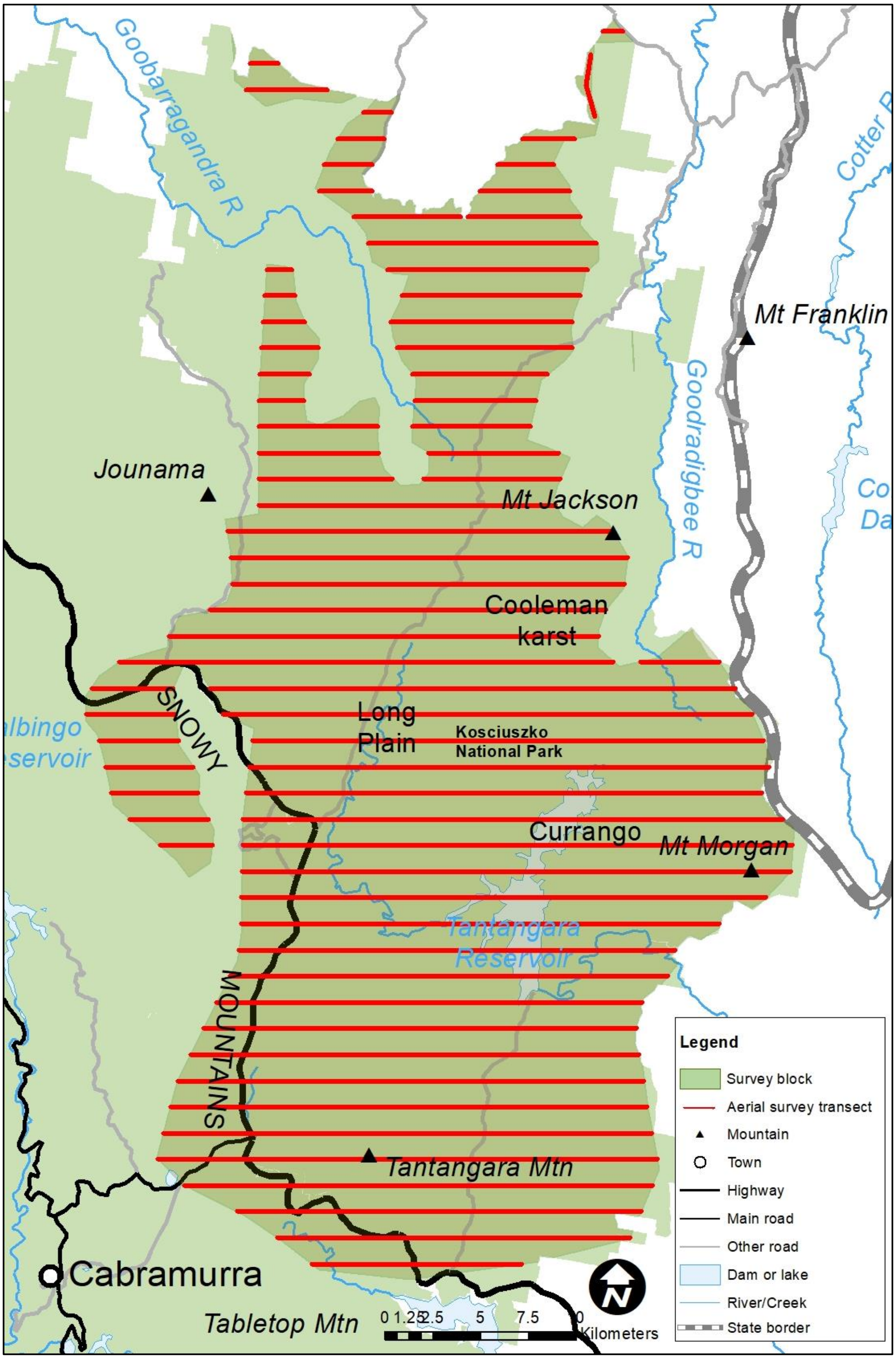

Figure 2: *Layout of aerial transects in the Northern Block of Kosciuszko National Park, 2024. Map supplied by NSW NPWS.*

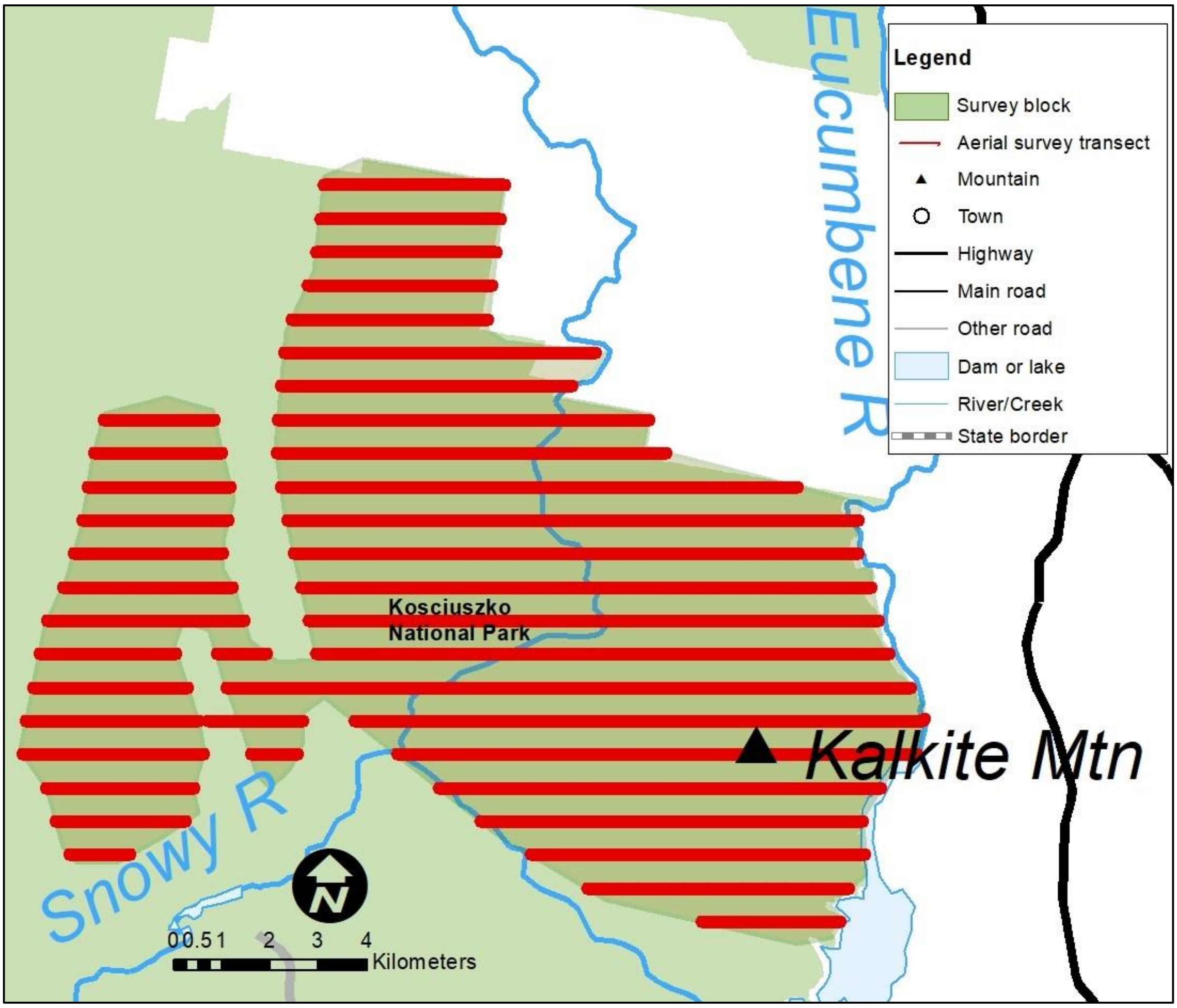

Figure 3: *Layout of aerial transects in the Snowy Plains block of Kosciuszko National Park, 2024. Map supplied by NSW NPWS.*

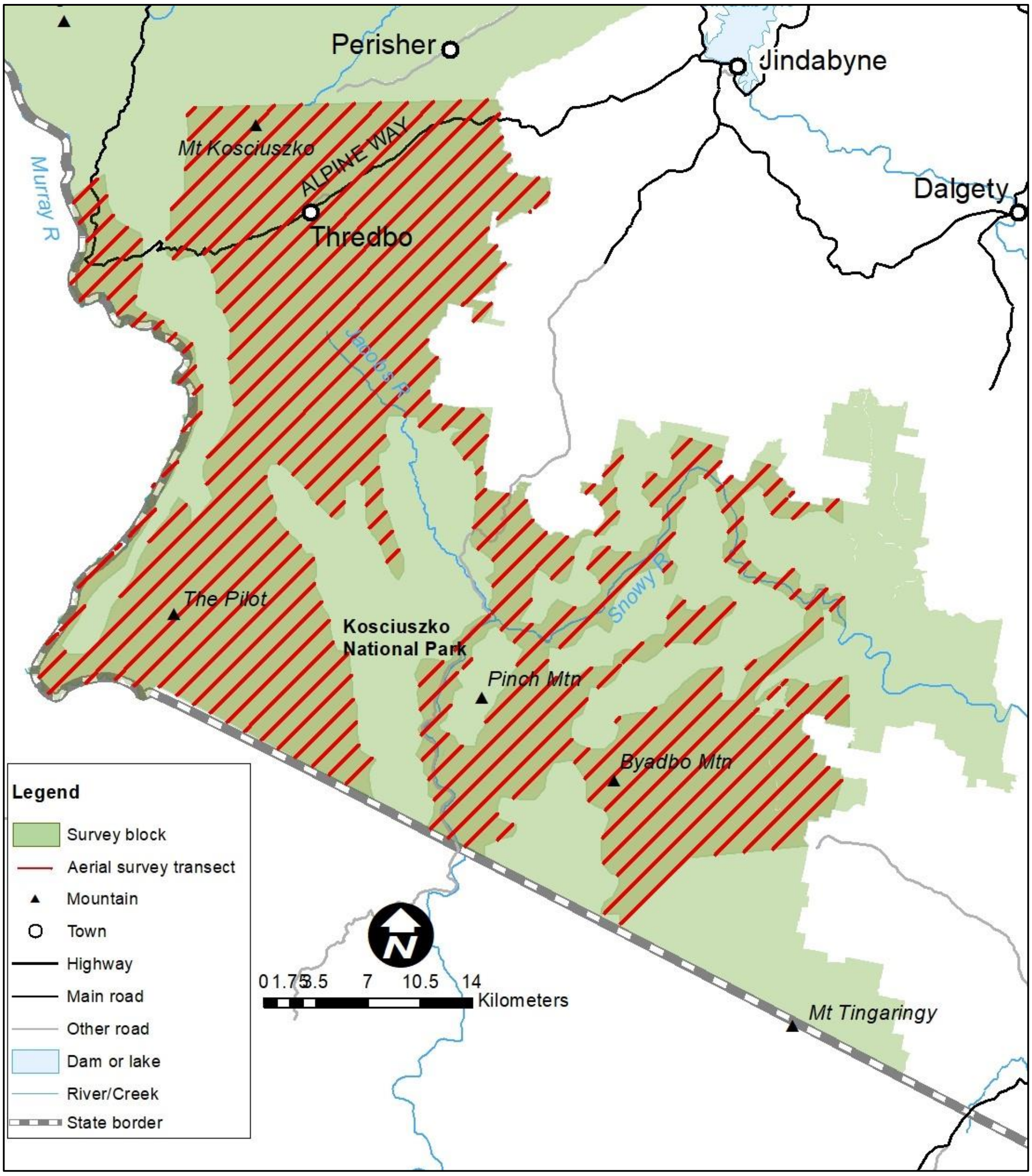

Figure 4: Layout of aerial transects in the Southern Block of Kosciuszko National Park, 2024. Map supplied by NSW NPWS.

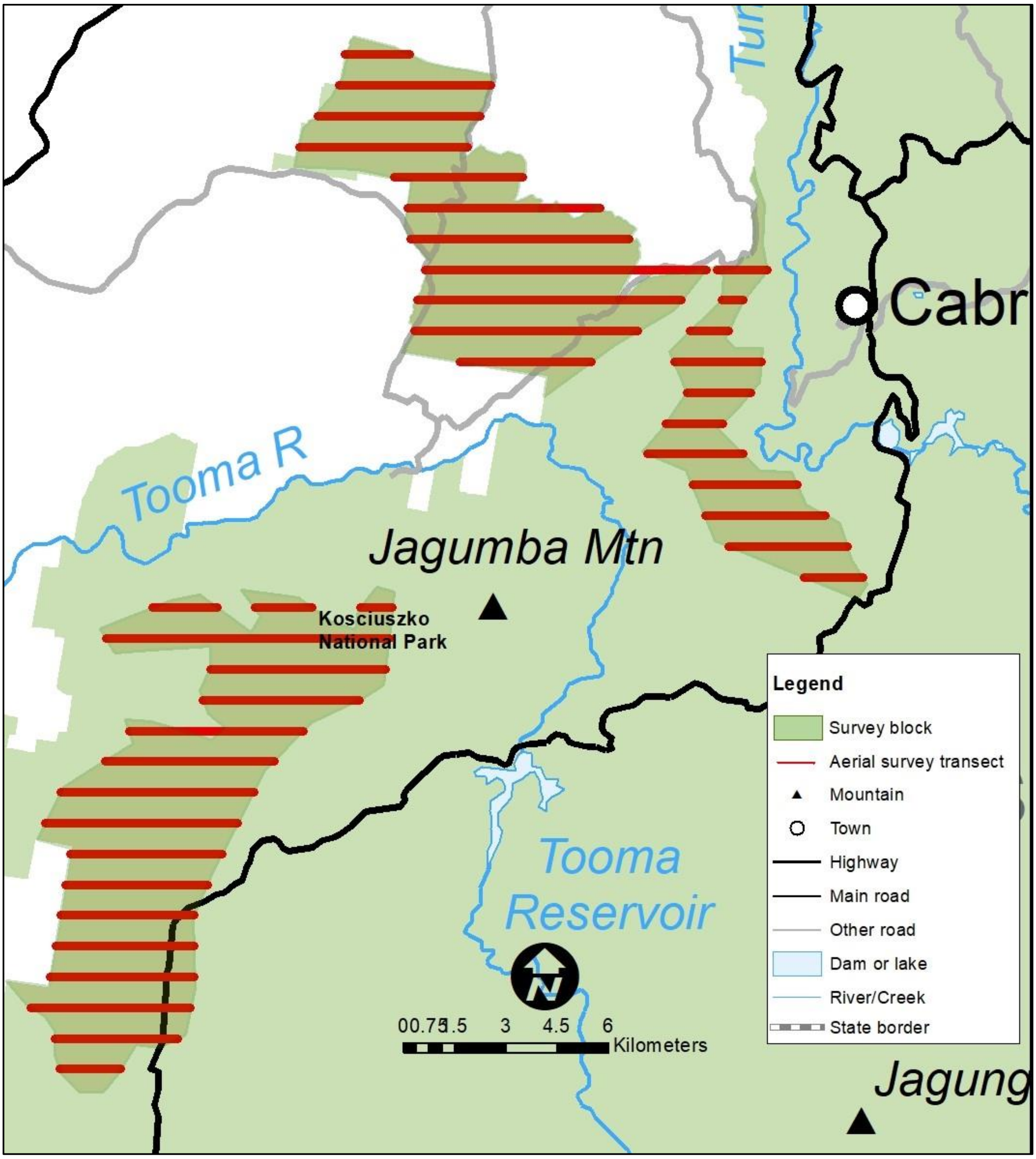

Figure 5: *Layout of aerial transects in the Cabramurra Block of Kosciuszko National Park, 2024. Map supplied by NSW NPWS.*

Data analysis

Three methods were used to model the horse count data in 2024: CDS, using rear observer data; MCDS, again using rear observer data, and MR using left-front and left-rear observer data. These were later combined in a method called Mark-Recapture Distance Sampling (MRDS), combining the MR and MCDS models.

Population density estimates and population size estimates were also calculated separately for three of the four survey blocks. There was insufficient data in the Cabramurra block to model any estimates. A single [global] detection function *g(x)* from the combined-areas analysis was used for all calculations because sample size was too small in the smaller survey blocks to derive their own statistically meaningful detection functions. This is identical to the approach taken by [redacted] (2023).

Horses were the primary species of interest for the survey of KNP. Separate analyses were conducted for adult horses only, and for adults and foals combined.

Distance sampling (DS)

Following previous years, horse count data from the rear-left and rear-right observers was first analysed in program *Distance 7.5* (Thomas *et al.* 2006) using CDS.

The DS method produces population estimates that account for the influence of a decline in probability of sighting (or being able to identify) an animal at increasing distances away from the observer. The equation that describes this decay in sightability is known as the detection function, or *g(x)*.

With distance sampling, the final population density equation for aerial observations collected on both sides of the aircraft along a transect line is given by Equation 1, where $\widehat{D}$ is estimated density, *n* is the observed number of groups of animals, *L* is the total length of transects, *E(s)* is group (cluster) size, and ESW is the effective strip width, a statistically derived metric based on the collection of perpendicular distances to each group of animals sighted. The ESW is the distance at which the same fraction of animals is missed inside the ESW as observed beyond the ESW (Buckland *et al*. 1993).

$$\widehat{D} = \frac{n}{L} . E(s) . \frac{1}{2\,ESW} \qquad \textbf{Equation 1}$$

Each of the above three components in Equation 1 has its own associated coefficient of variation (CV). The CVs of each component were combined to provide an overall CV of the population density estimate using the delta method (Thomas *et al.* 2006). Using propagation of uncertainty theory (Ku 1966), the final CV of the population density estimate (CV_D) is calculated by Equation 2, which assumes that the three constituent components (transect length, group size and strip width) are independent of each other.

$$CV_D^2 \approx CV_{n/L}^2 + CV_{E(s)}^2 + CV_{ESW}^2 \qquad \textbf{Equation 2}$$

Multiple-covariate distance sampling (MCDS)

The count data from the rear left and rear-right aerial observers was then modelled in *Distance 7.5* using MCDS, consistent with previous years [redacted] 2020; 2022; 2023). Compared to distance sampling, MCDS considers unmodeled heterogeneity in the data that might bias the results. It takes into account additional factors (called covariates) that might influence the variability in detectability of animals.

Our analysis tested various combinations of covariates, including the direction of the sun, habitat (better labelled visibility obstruction from vegetation) at each individual sighting, keyed in by the observer as 1=*Open*, 2=*Medium*, or 3=*Dense*, seating position of the observer in the aircraft, and time since sunrise/time to sunset. The models were tested in *Distance* to produce a series of population density estimates with associated measures of statistical variability. We favour the use of coefficients of variation (CVs) for reporting and comparing population estimates, and have reported these where relevant. However, as requested, for consistency with past reports we have also added 95% confidence intervals in places. In general, we do not support the use of 95% CIs in aerial surveying, particularly in temporal analysis because the population estimates from year to year are not statistically independent. Models were ranked in order of parsimony, with the most parsimonious model being that with the lowest Akaike's Information Criterion (AIC) score.

Mark-recapture (MR)

Count data from the front and rear left-side observers were separately analysed using MR. This assesses the degree of consistency between the counts of two observers who are counting animals out of the same side of the aircraft (in this case the left), who have the same field of view and are counting the same animals. In MR, the degree of agreement or disagreement in these counts can be used to calculate perception bias. Perception bias is expressed as a probability *p(0)* (the probability of detection on the transect line) and acknowledges that not all animals that are available (i.e. in view) to the observers are seen, even when they are close to the aircraft where there is more certainty of sighting them. Providing all observers are rotated systematically, it is reasonable that a '*combined p(0)*' applies generally to all seat positions. MRDS density outputs can then be adjusted using the invert of the '*combined p(0)*'.

Detection probability curves with increasing distance (i.e., sightability decay) were calculated for both left observers individually, and these results were used to calculate the conditional probabilities of both observers sighting the same horse(s) – that is, the likelihood of Observer 1 sighting a horse at a particular distance, given Observer 2's detection probability at the same distance, and vice versa (expressed as $p_{1|2}(x)$ and $p_{2|1}(x)$). The conditional probabilities between the two left-sided observers' counts (i.e. the probability of Observer 1 sightings, given the probability of Observer 2 sightings, $p_{1|2}(x)$ and vice versa, $p_{2|1}(x)$) are taken into account to ensure independence between the left observer counts. Where same-side observers' counts depart from the individual probably functions $p_1(x)$ and rear $p_2(x)$, there may be reason to believe there is common dependency. In this situation a point independence modelling approach is recommended (Laake and Borchers 2004), because a full independence approach would be biased. Here the MR sub-model should have distance as a covariate, and by default the *g(x)* sub-model in MRDS will also depend on distance.

'Apparent' animal movement (often due to aircraft roll) can result in the front observer seeing a group of individuals closer to one viewing zone and the rear observer seeing the same group in an adjacent zone. We allowed for this and applied the commonly-used practice of taking the first observer's distance as the distance of the object from the aircraft (Burt *et al.* 2014).

Results

Survey data summaries

Only one horse was sighted in the Cabramurra Block during the 2024 surveys. As a consequence this block has been left out of population density modelling. The results presented below relate to the remaining three blocks only.

Figure 6 shows variation in average group sizes for the three blocks where this could be analysed. Lowest average group size was seen in the Southern Block (2.3 horses per group), and highest in the Northern Block (3.8 horses per group).

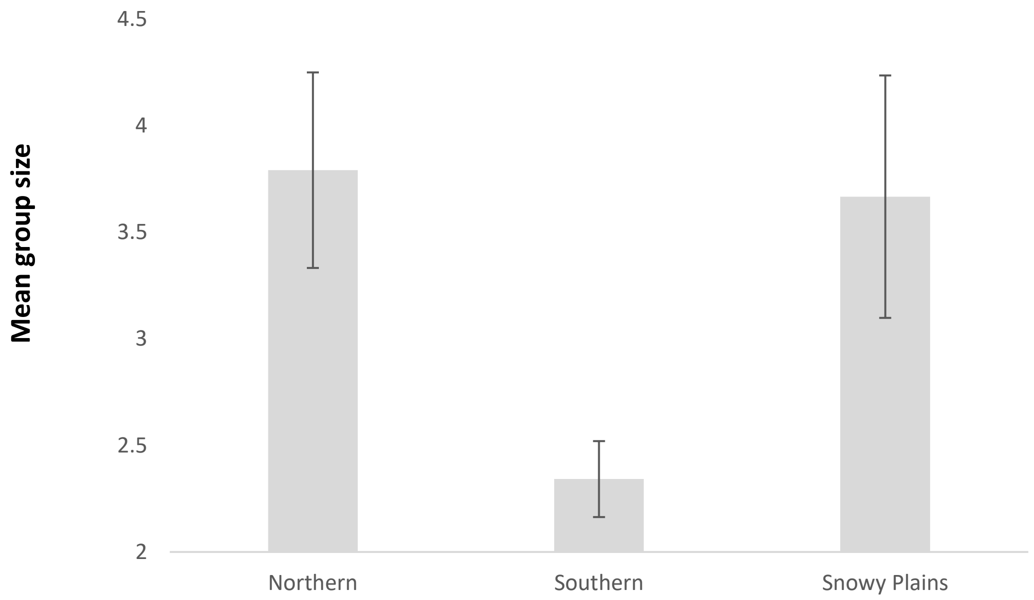

Figure 6: *Mean sizes of horse groups in the Northern, Southern & Snowy Plains survey blocks, Kosciuszko National Park. Cabramurra is excluded due to only one horse being sighted in 2024.*

Larger groups (11–22 animals) were sighted between 70 and 150 m out. This is likely due to a combination of greater sightability of larger groups at a distance, and each observer's perspective view. Observed at a greater distance, animals are seen over a larger area and at a shallower angle, and are inevitably lumped more easily, while close to the aircraft they tend to be counted in smaller groups as they pass close to the aircraft. Animals close to the aircraft also disperse faster, thus are less likely to be lumped as groups.

As group sizes (clusters) ranged from 1 to 22, this potential group size bias (i.e. a bias towards larger groups at larger distances) needed to be accommodated. This was found in the estimation of cluster size across the transect width in the Southern block and Snowy Plains block ($P < 0.15$). In these blocks, instead of the mean cluster size, population density was estimated using an expected value of cluster size based on the relationship between observed cluster size and the estimated probability of detection *g*(x). This was not the case for the Northern block, where the mean cluster size was used.

The number of horse groups sighted per kilometre length of transect (*n/L*) varied considerably between survey blocks (Figure 7), with more groups per unit distance sighted in the Southern block, and fewest in the Snowy Plains. Most variability in the number of groups/km was seen in the Southern block. Summary data for groups per transect kilometre are shown in Appendix 1.

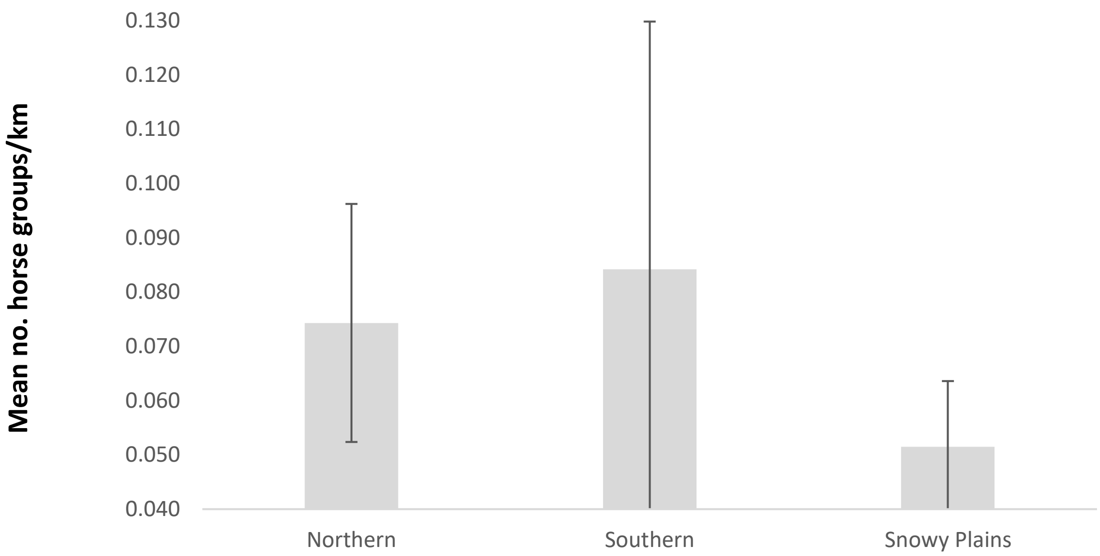

Figure 7: *Mean number of horse groups sighted per kilometre length of transect in the Northern, Southern & Snowy Plains survey blocks, Kosciuszko National Park. Cabramurra is excluded due to only one horse being sighted in 2024. Error bars show the coefficient of variation as a percentage.*

Akaike's Information Criterion (AIC) (Akaike 1974) was used to rank all the models within a model set from 'best' to 'worst' relative to each other. The lowest AIC score indicates the best fitting model for the fewest parameters (known as model parsimony), and the results of this model were then selected for use in the combined mark-recapture distance sampling model (see below).

Conventional distance sampling (DS) for adult horses only

Four models were tested and compared using AIC scores, with the lowest AIC score indicating the most parsimonious model fit. Decay in sightability (the probability detection function) with increasing distance of horses from the aircraft is shown in Figure 8. The equivalent decay curve for horses plus foals is provided in Figure 9 for comparison.

The best fitting model (lowest AIC) for adult horses was a negative exponential model (Table 3). This produced an effective strip width (ESW) of 115.1 m, and a population density estimate (i.e., number of horses per square kilometre) of 0.658, with a Coefficient of Variation (CV) of 22.7% across all survey areas.

Following [redacted] (2023), *g(x)* was calculated as a global model for all three survey blocks. As *n/L and* average groups sizes vary significantly between blocks, these are calculated individually for each block in the post-stratification, following [redacted] (2023).

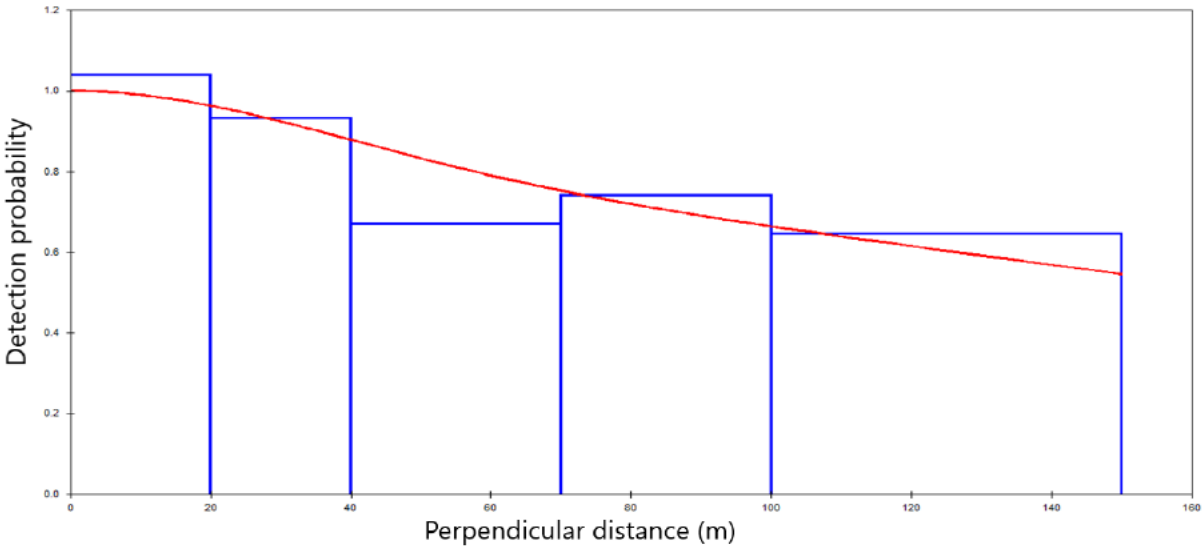

Figure 8: *The global half-normal/cosine detection function for adult horses across the four survey blocks of Kosciuszko National Park, 2024 (calculated in Distance 7.3).*

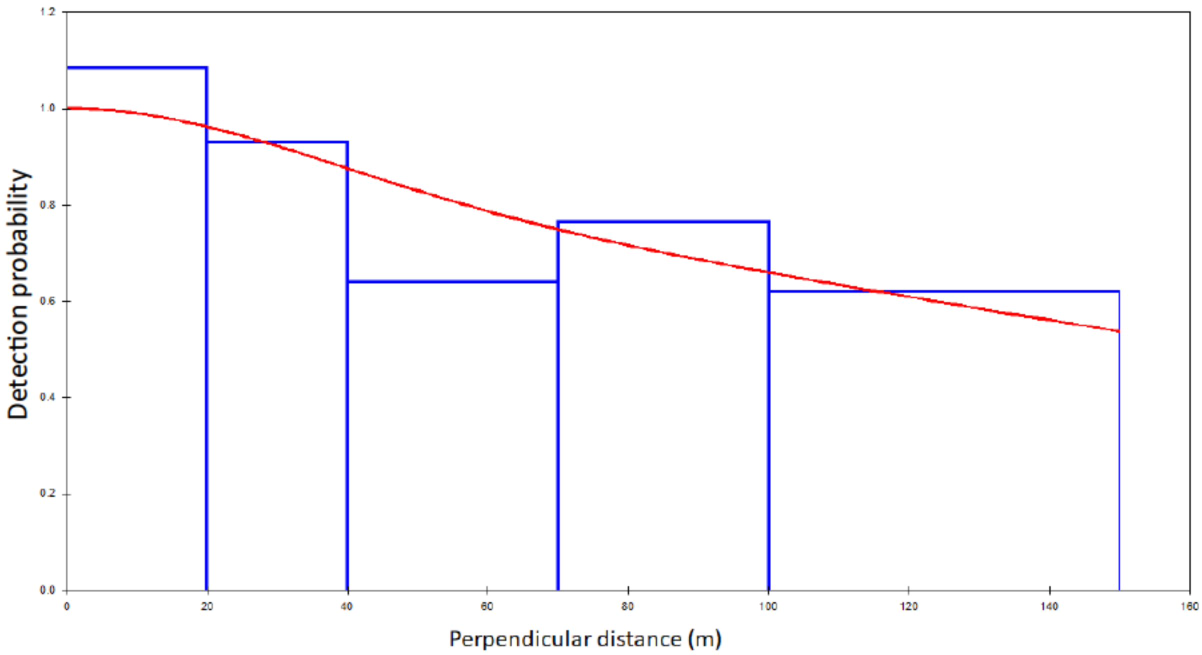

Figure 9: *The global half-normal/cosine detection function for horses & foals across the four survey blocks of Kosciuszko National Park, 2024 (calculated in Distance 7.3).*

The UCL and LCL headings in Table 3 (and tables that follow) are the upper and lower 95% confidence limits around the densities. We have shown these to remain consistent with [redacted] (2020, 2022, 2023).

Table 3: *Conventional distance sampling models tested for adult horse density estimates in all survey blocks of Kosciuszko National Park, 2024 (excluding Cabramurra, where there was insufficient data). The most parsimonious model (lowest AIC score) is shown in bold.* ***Abbreviations:*** *AIC – Akaike's Information Criterion; ESW – effective strip width; LCL – 95% lower confidence limit; UCL – 95% upper confidence limit; CV – coefficient of variation; NE – negative exponential; HN – half-normal; HR – hazard rate.*

Model	Delta AIC	AIC	ESW (m)	Density (horses per km^2)	Density (LCL)	Density (UCL)	Density CV
CDS_Horse (NE Cos)	**0**	**505.4**	**115.1**	**0.658**	**0.424**	**1.021**	**22.7%**
CDS_Horse (HN Cos)	0.9	506.3	128.4	0.684	0.459	1.019	20.5%
CDS_Horse (Post-stratify Region HN Cos)	0.9	506.3	128.4	0.717	0.475	1.083	21.2%
CDS_Horse (HR Cos)	2.8	508.2	124.6	0.698	0.443	1.099	23.4%

Multiple covariate distance sampling (MCDS) for adult horses only

A range of models that included multiple covariates were tested (Table 4). In addition to sightability decay (CDS), the MCDS models allowed us to assess the effects of habitat (open, medium or dense), sun glare, observer position in the aircraft, and time of day. Time of day may have affected observer fatigue. However, it may also affect horse behaviour, which is technically not a sightability covariate.

The most parsimonious MCDS model with the lowest AIC score (in bold red text in Table 4) showed that habitat class (recorded at three levels, open, medium and dense vegetation obstruction) for each group of sightings) had the greatest effect on horse counts. The probability of observers sighting horses in the landscape under open conditions remains close to 100% even at a distance of 150 m, whereas in habitats where there was medium obstruction or more, the likelihood of observers sighting a horse a 140 m away from the aircraft decayed to around 50% (see Figure 10). There were not enough sightings of horses in areas with dense habitat for this to be explicitly shown in Figure 10.

The best-performing MCDS model, with habitat as a covariate (in bold red text in Table 4), calculated an ESW of 114.4 m, very similar to that in the best-performing conventional DS ESW (115.1 m; Table 3). This model estimates a population density for the entire survey area of 1.030 horses per km^2. This is more than 56% higher than the estimate obtained with conventional distance sampling (0.658; see Table 3). The confidence interval of the MCDS estimate (19.5%) is also narrower than the DS estimate (22.7%), and the MCDS population density estimate in Table 4 can therefore be considered more reliable.

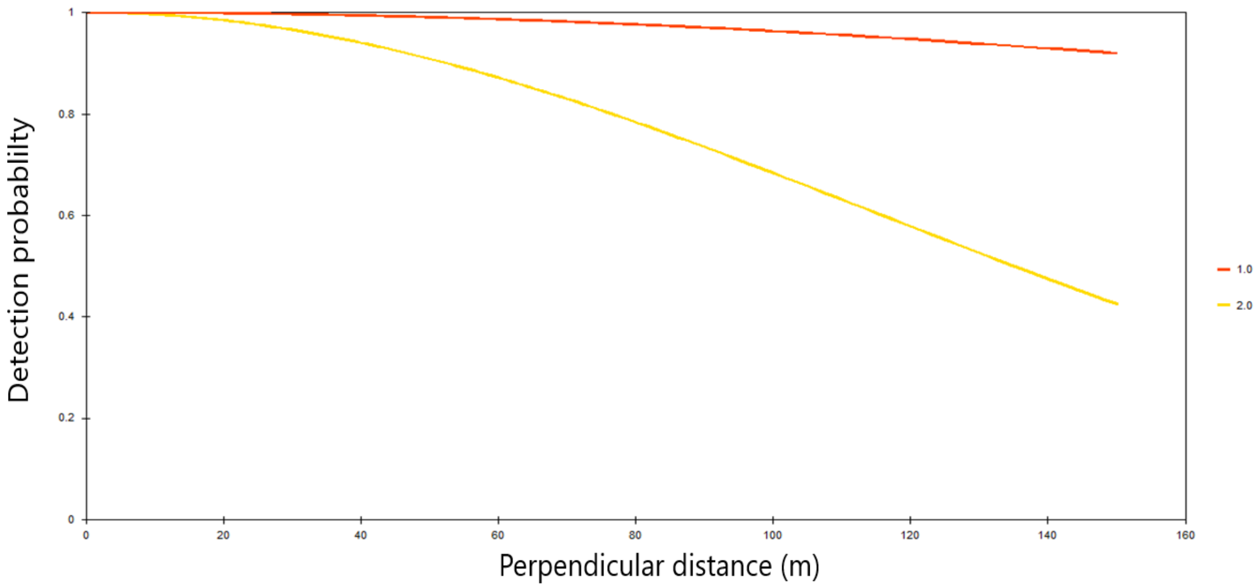

Figure 10: *Decay in the probability of detecting horses with increasing distance from the aircraft under two habitat types (red = open; yellow = medium)*

Following [redacted] (2023), the best performing global MCDS model in Table 4 was then post-stratified over three of the four survey blocks (Cabramurra was excluded) (bold black text in Table 4). This has the same AIC and ESW as the unstratified model, but separately calculates the number of horse groups sighted per km of transect (n/L) for each survey block individually, and recalculates density using a weighted mean. Following [redacted] (2023), *g(x)* was determined globally. This is completely valid, given that the covariate *habitat*, recorded for each individual group, already accounts for variations in the vegetation obstruction in these land systems. The post-stratified model is shown in bold black text in Table 4. Resultant population density estimates calculated for the three included survey blocks are shown in Table 5.

Table 4: *Multiple covariate distance sampling (MCDS) models tested for adult horse density estimates in three survey blocks of Kosciuszko National Park, 2024 (Cabramurra block was excluded due to insufficient data). The most parsimonious model (lowest AIC score) is shown in bold red text. The best-performing model post-stratified over the survey blocks is shown in bold black text.*
Abbreviations: *AIC – Akaike's Information Criterion; ESW – effective strip width; LCL – lower confidence limit; UCL – upper confidence limit; CV – coefficient of variation; NE – negative exponential; HN – half-normal; HR – hazard rate; SR – sunrise; SS – sunset.*

Model	Delta AIC	AIC	ESW (m)	Density (horses per km^2)	Density (LCL)	Density (UCL)	Density CV
MCDS_Horse ~ Habitat (HN Cos)	**0.0**	**490.6**	**114.4**	**1.030**	**0.704**	**1.505**	**19.5%**
MCDS_Horse ~ Habitat (Post-stratify_Region HN Cos)	**0.0**	**490.6**	**114.4**	**1.012**	**0.679**	**1.508**	**20.4%**
MCDS_Horse ~ Habitat + Sun (HN Cos)	1.5	492.2	114.4	1.035	0.706	1.516	19.6%
MCDS_Horse ~ Habitat + Sun + Position (HN Cos)	3.1	493.7	114.0	1.037	0.706	1.524	19.8%
MCDS_Horse ~ Sun+To_SR_SS+Habitat (HN Cos)	3.5	494.2	114.4	1.035	0.705	1.519	19.7%
MCDS_Horse ~ To_SR_SS+Position+Habitat (HN Cos)	3.8	494.4	114.3	1.031	0.702	1.513	19.7%
MCDS_Horse ~ Habitat + Sun + Position + To_SR_SS (HN Cos)	5.1	495.7	114.0	1.038	0.704	1.530	19.9%
MCDS_Horse ~ Sun+To_SR_SS+Habitat+Position (HN Cos)	5.1	495.7	114.0	1.038	0.704	1.530	19.9%
MCDS_Horse ~ To_SR_SS+Habitat (HN Cos)	5.2	495.8	108.4	1.098	0.734	1.642	20.7%
MCDS_Horse ~ To_SR_SS (HN Cos)	16.4	507.1	128.6	0.731	0.506	1.057	18.9%
MCDS_Horse ~ Sun+To_SR_SS+Position (HN Cos)	16.8	507.4	129.8	0.819	0.562	1.193	19.3%
MCDS_Horse ~ Sun (HN Cos)	17.4	508.0	127.7	0.718	0.497	1.038	18.9%
MCDS_Horse ~ Position (HN Cos)	17.6	508.2	128.3	0.692	0.479	1.000	18.9%
MCDS_Horse ~ To_SR_SS+Position (HN Cos)	18.3	508.9	129.0	0.739	0.511	1.068	18.9%
MCDS_Horse ~ Habitat (HR Cos)	19.6	510.2	124.8	0.697	0.482	1.008	18.9%

Table 5: *Post-stratified adult horse population density estimates for three survey blocks of Kosciuszko National Park, 2024, using MCDS. There were too few data to model for the Cabramurra block.* ***Abbreviations:*** *CV – coefficient of variation; df – degrees of freedom; CI – confidence interval; DS – Density of groups; D – density. Population estimates have been rounded to the nearest whole number.*

Model	**Density estimate** (adult horses per km^2)	**CV**	**Estimated population (adult horses)** (upper & lower CIs)	**df**	**95% CI** (density)
	Northern Block				
DS	0.32473	30.03%		81.43	0.181 – 0.583
D	1.2311	31.92%	**1,513** (809 – 2,830)	101.80	0.658 – 2.302
	Snowy Plains				
DS	0.22499	54.52%		41.86	0.080 – 0.629
D	0.73899	57.15%	**119** (41 – 346)	48.57	0.254 – 2.151
	Southern Block				
DS	0.3679	24.18%		177.77	0.230 – 0.590
D	0.86148	25.35%	**987** (603 – 1,614)	210.51	0.526 – 1.409

MCDS analysis of horses & foals combined

The addition of foals to the MCDS analysis amounted to a small change in the results of conventional and multiple covariate distance sampling results (Table 6). The same model, with habitat as a covariate, had the lowest AIC score as the adult horse model in Table 4, and foals contributed to only a marginal increase in the post-stratified population density estimate with the most parsimonious model, from 1.030 (adult) horses per km^2 to 1.055 (adults + foals) horses per km^2. As for the MCDS analysis for adult horses (see above), the most parsimonious model for adults and foals (see bold black text in Table 6) was post-stratified for three of the survey areas. Densities are shown in Table 7.

***Table 6**: Multiple covariate distance sampling (MCDS) models tested for horses & foals combined, in three survey blocks of Kosciuszko National Park, 2024 (Cabramurra block was excluded due to insufficient data). The most parsimonious model (lowest AIC score) is shown in bold red text. The best-performing model post-stratified over the survey blocks is shown in bold black text.*
***Abbreviations:** AIC – Akaike's Information Criterion; ESW – effective strip width; LCL – lower confidence limit; UCL – upper confidence limit; CV – coefficient of variation; NE – negative exponential; HN – half-normal; HR – hazard rate.*

Model	AIC	ESW (m)	Density (horses + foals per km^2)	Density (LCL)	Density (UCL)	Density CV
MCDS_Horse_Foal ~ Habitat (HN Cos)	**570.4**	**113.4**	**1.055**	**0.720**	**1.545**	**0.196**
MCDS_Horse_Foal ~ Habitat (Post-stratify_Region HN Cos)	**570.4**	**113.4**	**1.037**	**0.692**	**1.554**	**0.207**
MCDS_Horse_Foal ~ Habitat + Sun (HN Cos)	572.0	113.4	1.062	0.724	1.558	0.197
MCDS_Horse_Foal ~ Habitat + Sun + Position (HN Cos)	572.9	112.7	1.071	0.727	1.578	0.199
MCDS_Horse_Foal ~ To_SR_SS+Position+Habitat (HN Cos)	573.8	113.2	1.056	0.719	1.553	0.198
MCDS_Horse_Foal ~ Sun+To_SR_SS+Habitat (HN Cos)	574.0	113.5	1.061	0.722	1.559	0.198
MCDS_Horse_Foal ~ Habitat + Sun + Position + To_SR_SS (HN Cos)	574.9	112.7	1.071	0.726	1.581	0.200
MCDS_Horse_Foal ~ Sun+To_SR_SS+Habitat+Position (HN Cos)	574.9	112.7	1.071	0.726	1.581	0.200
MCDS_Horse_Foal ~ Sun+To_SR_SS+Position (HN Cos)	585.8	126.8	0.921	0.621	1.367	0.203
CDS_Horse_Foal (NE Cos)	586.9	110.9	0.730	0.474	1.125	0.223
CDS_Horse_Foal (HN Cos)	588.1	125.2	0.745	0.501	1.109	0.204
CDS_Horse_Foal (Post-stratify Region HN Cos)	588.1	125.2	0.776	0.512	1.177	0.214
MCDS_Horse_Foal ~ To_SR_SS (HN Cos)	588.8	125.8	0.787	0.542	1.142	0.191
MCDS_Horse_Foal ~ Sun (HN Cos)	589.5	124.9	0.774	0.533	1.123	0.191
CDS_Horse_Foal (HR Cos)	589.8	119.9	0.762	0.486	1.197	0.233
MCDS_Horse_Foal ~ Position (HN Cos)	589.9	125.1	0.752	0.519	1.092	0.191
MCDS_Horse_Foal ~ To_SR_SS+Position (HN Cos)	590.5	127.2	0.805	0.555	1.169	0.191
MCDS_Horse_Foal ~ Habitat (HR Cos)	591.8	119.9	0.762	0.525	1.107	0.191

Table 7: *Post-stratified population density estimates for horses + foals, for three survey blocks of Kosciuszko National Park, 2024, using MCDS. There were too few data to model for the Cabramurra block.* ***Abbreviations:*** *CV – coefficient of variation; df – degrees of freedom; CI – confidence interval; DS – Density of groups; D – density. Population estimates have been rounded to the nearest whole number.*

Model	**Density estimate** (horses & foals per km^2)	**CV**	**Estimated population (horses + foals)** (upper & lower CIs)	**df**	**95% CI** (density)
	Northern Block				
DS	0.38643	31.67		80.24	0.209 - 0.715
D	1.316	33.82	**1,617** (842 – 3,106)	102.25	0.685 - 2.527
	Snowy Plains				
DS	0.28384	52.27		41.82	0.105 - 0.765
D	0.78140	55.77	**126** (44 – 357)	51.06	0.275 - 2.221
	Southern Block				
DS	0.41828	23.52		176.43	0.265 - 0.661
D	0.91645	24.68	**1,050** (650 – 1,690)	209.84	0.567 - 1.475

Mark recapture (MR) - adult horses only

As previously mentioned, the mark-recapture (MR) component assesses the degree of agreement between the aerial counts of the front and rear left-side observers, to determine detection probability on the transect line.

Figures 11–13 show the probabilities and conditional horse detection probabilities when comparing the front and rear observers. The conditional probabilities between observers $p_{1|2}(x)$ and $p_{2|1}(x)$ are relatively flat lines and depart from the individual probably functions $p_1(x)$ and rear $p_2(x)$. They are however, very close in magnitude at $p(0)$. This shows that there is some dependency between front and rear positions with distance out from the aircraft because they do not follow the same shapes as $p_{1|2}(x)$ and $p_{2|1}(x)$. This suggests that a point independence (PI) modelling approach, rather than a full independence modelling approach, is most appropriate because while there appears to be independence, the flatter lines for $p_{1|2}(x)$ and $p_{2|1}(x)$ show a positive correlation between observers, thus a full independence approach would be biased at larger distances (Laake and Borchers 2004).

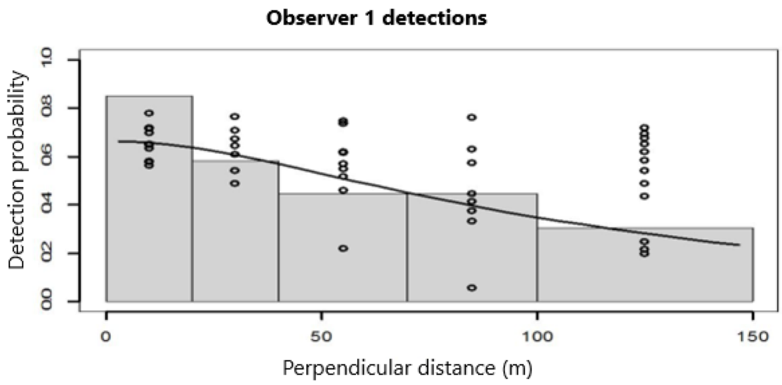

Figure 11: *Horse detection probabilities of Observer 1 in the mark-recapture sub-model*

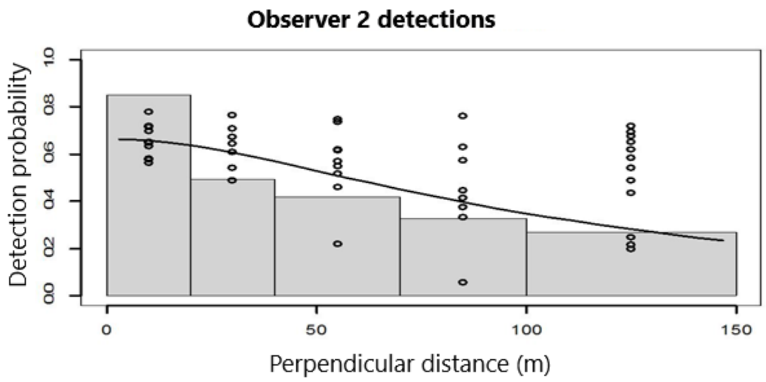

Figure 12: *Horse detection probabilities of Observer 2 in the mark-recapture sub-model*

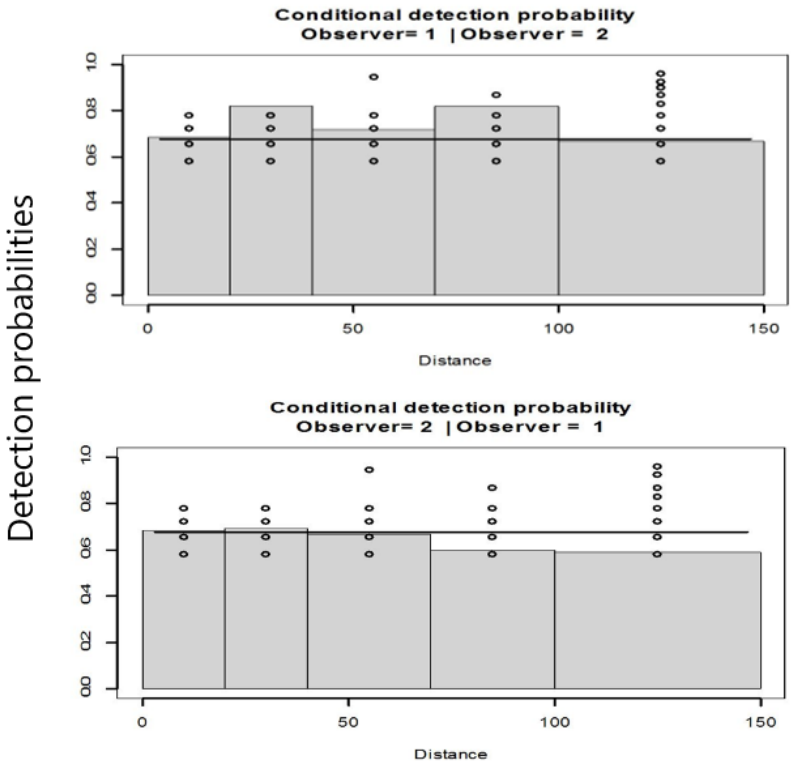

Figure 13: *Conditional detection probabilities of Observer 1 & Observer 2*

A point independence (PI) modelling approach was therefore adopted. Table 8 shows the relative performance of the left observer models with each combination of covariates. For the MR component, distance is only treated as a linear covariate of sighting probability (Becker and Christ 2015). While we are only interested in the probabilities that emerge from the mathematics in the MR component *mr()* below, by way of comparison it was prudent to see what covariates explained variation in the left observer *g(x)*. In other words, the left observer's probability detection function *g(x)* ~ is tested alongside of the MR model, to check how well the counts of the two left observers agree with the counts of the two rear observers, but this also ensures that there is no unaccounted-for heterogeneity in the MR model.

A range of covariates were therefore tested for their contribution to the MR and *g(x)* components. The best-fitting MR and *g(x)* combination model with the lowest AIC score is shown in bold in Table 8. The detectability of horses in the MR component *mr()* ~ was found to be a function of group size (cluster size). As group size increased, the difference between the counts of the front and rear observers decreased. Not surprisingly, the sightability curve *g(x)* agrees with the MCDS for rear observers (see above), that is, in addition to the perpendicular distance out from the aircraft, habitat type (open, medium and dense canopy) also affects detectability.

Table 8: *Mark-recapture (MR) modelling results, showing the relative performance of front & rear left-side observers under a point-independence modelling approach. The most parsimonious model (lowest AIC score) is highlighted in bold.* ***Abbreviations:*** *MR – mark-recapture; g(x) – detection probability function; AIC – Akaike's Information Criterion*

Model	AIC
MR Horse g(x)~ habitat; mr() ~ size	**508.8011**
MR Horse g(x)~ size + habitat; mr() ~ distance + size	509.357
MR Horse g(x)~ size; mr() ~ size	513.4148
MR Horse g(x)~ size; mr() ~ distance + size	513.4984
MR Horse g(x)~ size; mr() ~ size + position	513.6807
MR Horse g(x)~ size; mr() ~ size + habitat + distance	514.6898
MR Horse g(x)~ size; mr() ~ size + habitat + distance + position	514.9557
MR Horse g(x)~ size; mr() ~ size + habitat	515.0271
MR Horse g(x)~ size; mr() ~ position	517.2847
MR Horse g(x)~ size; mr() ~ distance + position	518.9299
MR Horse no g(x) mr() ~ size	524.6561

Using the best model from Table 8 (lowest AIC score), the combined detection probability on the transect line from both observers *p(0)* was 0.66297 (the average secondary *p(0)* in bold red text in Table 9). This is the overall fraction of animals seen by a secondary (or rear left) observer, even at distance = 0 out from the aircraft (perception bias). This model had a very low coefficient of variation (CV) of 0.073 (i.e., +/- 7.3% estimated error). As observers were systematically rotated through all seat positions in the aircraft from flight to flight, it is assumed that *p(0)* applies to both rear seats. The invert of the global detection probability, 1/0.66297 = 1.50835, is the multiplication factor that is applied to the MCDS population density estimates (see MRDS results below).

Table 9: *Output of best mark-recapture (MR) model from Table 8.* ***Abbreviations:*** *SE – standard error; CV – coefficient of variation; p(0) – detection probability.*

Conditional detection function parameters			
	Estimate	SE	CV
Intercept	0.01341833	0.3988846	-
Size	0.31153910	0.1454619	-
Average primary *p(0)*	0.6629735	0.04828794	0.07283540
Average secondary *p(0)*	**0.6629735**	**0.04828794**	**0.07283540**
Average combined *p(0)*	0.8788341	0.03559976	0.04050794

Mark recapture distance sampling (MRDS) - adult horses only

Using the invert of the global detection probability from the MR results (1.508; see above) as the multiplication factor, combined with the best-performing MCDS model, Table 10 gives the final combined MR + DS horse population density estimate for 2024 of 1.553 horses per km^2. This is the average population density across the three included survey blocks combined. The final coefficient of variation (21.1%) uses the delta method to combine all contributing estimated errors into a single figure. The adjustment for perception bias using the MRDS correction factor revised the overall population density estimate for the three survey blocks combined upwards by about 50% compared to the MCDS estimate (Table 10). This suggest that a negative perception bias is likely to be present in past years' survey data based on MCDS analysis of the two-observer counts.

Table 10: *Horse population density estimate for three survey blocks of Kosciuszko National Park, 2024, using the combined mark-recapture distance sampling (MRDS) model (red text).* ***Abbreviations:*** *D (MCDS) – Horse population density from multiple covariate distance sampling; p(0) – mark-recapture derived probability of sighting an animal at x = 0; n/L CV – coefficient of variation associated with the count distribution and effort; E(s) CV – the coefficient of variation associated with cluster size; ESW CV – the coefficient of variation associated with the effective strip width; CV P(0) – the coefficient of variation associated with the mark-recapture probability.*

Unweighted average density (MCDS)	***p(0) combined***	***MRDS density*** *(Horses/km^2)*	***n/L CV***	***ESW CV***	***E(s) CV***	***CV P(0)***	***Final CV***
1.030	0.6629	**1.553**	17.6%	5.6%	7.3%	7.2%	**21.1%**

The same procedure was applied to the three survey blocks separately, to produce separate population density estimates for each of these blocks (Table 11). The multiplication factor from the MR model above (1.508) was multiped by the density estimates from the MCDS modelling stratified by block, and using the delta method to combine the CVs from the MR component (see Table 8). These densities are subdivided into densities in each stratum (survey block) using weighted averages, where the weighting depends on transect length (effort) flown (hence the sample area), not the area of the block.

Table 11: *Horse (adults) population density & abundance estimates for three survey blocks of Kosciuszko National Park, 2024, using mark-recapture distance sampling (MRDS). The population density estimates from the best multiple covariate distance sampling (MCDS) estimates in Table 4 were multiplied by the mark-recapture (MR) multiplication factor (1.508). Population estimates are shown rounded to the nearest whole number.*

Survey block	**Area km^2**	**Density (MCDS)** (horses/ km^2)	**CV (MCDS)**	**Estimated population (MCDS)** (LCL – UCL)	**Density (MRDS)** (horses/ km^2)	**CV (MRDS)**	**Estimated population (MRDS)** (LCL – UCL)
Northern	1,229	1.231	32%	**1,513**	1.857	33%	**2,282**
Snowy Plains	161	0.739	57%	**119**	1.115	57%	**179**
Southern	1,146	0.861	25%	**987**	1.299	26%	**1,488**
Totals	**2,536**			**2,619** (1,535 – 3,703)			**3,949** (2,261 – 5,637)

MRDS analysis of horses & foals combined

When the MRDS analysis above was repeated for adult horses and foals combined, the average secondary *p(0)* increased from 0.6629 to 0.7189 with a CV of 9.5%. The invert of 0.7189 (1.391) was multiplied by the estimated population MCDS density of horses and foals. Across all survey areas combined, the unweighted MRDS density was 1.467 horses and foals per km^2 (Table 12). Counterintuitively, this is lower than the 1.553 horses per km^2 when only adults were included (Table 10). This a mathematical artefact resulting from a slight difference in *g(x)* curve (i.e. sightability) when foals were included in the analysis compared to when only adults were included (see Figures 8 and 9). This pushed the multiplication factor downwards rather than upwards when the foals were included. The final coefficient of variation for the adult/foal estimate (22.4%) uses the delta method to combine all contributing estimated errors into a single figure.

Table 12: *Horse & foal population density estimate for three survey blocks of Kosciuszko National Park combined, 2024, using mark-recapture distance sampling (MRDS).*

Unweighted average density (MCDS)	***p(0) combined***	***MRDS density*** *(Horses & foals/km²)*	***n/L CV***	***ESW CV***	***E(s) CV***	***CV P(0)***	***Final CV***
1.0547	0.7189	**1.467**	18.0%	6.0%	7.3%	9.5%	**22.4%**

The procedure was repeated for horses and foals for the three survey blocks individually (Cabramurra excluded due to lack of data), giving the population density estimates shown in Table 13. These are slightly higher than the equivalent estimates based on adult horse counts alone, as would be expected. The numerical differences are relatively small, but these differences are multiplied over large geographical areas and therefore affect the population size estimates (see Table 13).

Table 13: *Horse & foal population density & abundance estimates stratified by survey block, 2024, comparing multiple covariate distance sampling (MCDS) and mark-recapture distance sampling (MRDS) estimates. Population estimates are shown rounded to the nearest whole number.*

	Area km²	**Density (MCDS)** (horses & foals/ km²)	**CV (MCDS)**	**Horse+Foal Population (MCDS)** (LCL – UCL)	**Density (MRDS)** (horses & foals/ km²)	**CV (MRDS)**	**Horse+Foal Population (MRDS)** (LCL – UCL)
Northern	1,229	1.316	34%	**1,617**	1.831	35%	**2,249**
Snowy Plains	161	0.781	56%	**126**	1.086	57%	**175**
Southern	1,146	0.916	25%	**1,050**	1.274	27%	**1,461**
Totals	**2,536**			**2,793** (1,579 – 4,007)			**3,885** (2,131 – 5,639)

MCDS & MRDS population density estimates for the Kosciuszko National Park horse retention management areas

Population density estimates for horses and foals were calculated for a sub-set of the KNP horse retention areas as identified in the Kosciuszko National Park Wild Horse Heritage Management Plan (Environment & Heritage Group, 2021; amended 2023), post-stratifying the best-performing MCDS model in the same way as for the survey blocks. Included retention areas were those in the Northern, Snowy Plains, and Southern blocks, with a combined area of just over 2,000 km^2. The Cabramurra Block has no retention area. A fourth retention area (Tom Groggin) was excluded from the analysis due to its small size (7.31 km^2). The MCDS population density was estimated to be highest in the retention area within the Northern block (1.7838 horses/foals per km^2), with lower densities in the retention areas within the Snowy Plains and Southern survey blocks (Table 14).

Note that for the Southern Block Retention Area, the density/population estimates were calculated for the entirety of the Retention area (see map in Figure 1) including areas of steep terrain that were not surveyed; hence the total area (and population estimate) is higher than for that of the Southern Block overall.

Table 14: *Post-stratified population density estimates for horses + foals, for three retention areas of Kosciuszko National Park, 2024, using MCDS. There were too few data to model for the Cabramurra block.* ***Abbreviations:*** *CV – coefficient of variation; df – degrees of freedom; CI – 95% confidence interval; DS – Density of groups; D – density. Population estimates have been rounded to the nearest whole number.*

Model	**Density estimate** (horses & foals per km^2)	**CV**	**Estimated population (horses + foals)** (upper & lower CIs)	**df**	**95% CI** (density)
	Northern Block retention area				
DS	0.66283	30.25		24.21	0.36003 – 1.2203
D	1.7838	32.14	**1,269** (669 – 2,406)	30.71	0.94076 – 3.3821
	Snowy Plains retention area				
DS	0.62005	37.62		5.48	0.24925 – 1.5425
D	1.0605	42.10	**137** (54 – 347)	8.18	0.41930 – 2.6823
	Southern Block retention area				
DS	0.58896	25.47		73.33	0.35735 – 0.97069
D	1.1208	26.55	**1,502** (894 – 2,523)	85.95	0.66716 – 1.8830

As would be expected, the MRDS estimates for horses/foals were considerably higher than the MCDS estimates (see Table 15), estimating nearly 1.4 times more horses/foals in the retention areas overall.

Table 15: *Multiple covariate distance sampling (MCDS) and mark recapture distance sampling (MRDS) estimates of horse + foal population density & abundance, post-stratified for three horse retention areas of Kosciuszko National park, 2024. Estimates are shown rounded to the nearest whole number. Note that summed totals are based on rounded whole numbers.*

Retention Area	**Area km²**	**Density (MCDS)** (horses & foals/ km²)	**CV (MCDS)**	**Horse + Foal Population (MCDS)**	**Density (MRDS)** (horses & foals/ km²)	**CV (MRDS)**	**Horse + Foal Population (MRDS)**
Northern block retention	711	1.784	32%	**1,269**	2.481	33%	**1,765**
Snowy Plains retention	130	1.061	42%	**137**	1.475	43%	**191**
Southern block retention	1,340	1.121	27%	**1,502**	1.559	29%	**2,089**
Totals	**2,181**			**2,908** (1,766 – 4,050)			**4,045** (2,373 – 5,717)

Other species

A total of 43 feral pigs *Sus scrofa* were counted in the Northern Block, and 5 in the Southern Block. This was insufficient data with which to calculate a population density estimate or population size estimate.

Many more deer were present, allowing calculation of population density estimates. Deer population density and population size were estimated using conventional distance sampling (Table 16) and multiple-covariate distance sampling (MCDS) (Table 17). Relative model performance was evaluated using Akaike's Information Criterion (AIC), with the lowest AIC score indicating the best performing model.

Table 16: *Conventional distance sampling (CDS) population density estimates for deer in four survey blocks of Kosciuszko National Park, 2024.* ***Abbreviations:*** *AIC – Akaike's Information Criterion; ESW – effective strip width; LCL – lower confidence limit; UCL – upper confidence limit; CV – coefficient of variation. HN – half normal distribution; NE – negative exponential distribution; HR – hazard ratio distribution. Best performing models are shown in bold.*

Model	**AIC**	**ESW (m)**	**Density** (deer per km²)	**Density (LCL)**	**Density (UCL)**	**Density CV**
CDS_Deer (HN Cos)	**316.51**	**55.88**	**0.82**	**0.60**	**1.13**	**16.1%**
CDS_Deer(Post-stratify Region HN Cos)	**316.51**	**55.88**	**0.84**	**0.63**	**1.14**	**15.3%**
CDS_Deer (NE Cos)	317.72	45.96	0.99	0.66	1.47	20.5%
CDS_Deer (HR Cos)	317.82	54.86	0.84	0.59	1.20	18.0%

For conventional DS of deer, the most parsimonious global detection function was a half-normal cosine model (AIC of 316.51) regardless of whether results were combined or post-stratified. This gave an estimated population density of between 0.82 (unstratified) and 0.84 (post-stratified) deer per square kilometre (Table 16). This was lower than in 2023, when the density estimate was 1.96 animals per km^2 [redacted] 2023). The coefficients of variation of the two joint-best performing models (15.3–16.1%) were lower than in 2023, when the CV was 28.4% [redacted] 2023). The effective strip width (ESW) for deer was narrow in 2024, at around 55 m. This is likely due to deer being small and relatively difficult to detect or identify relative to horses. A similar ESW was found using MCDS (Table 17).

When testing with MCDS, similar results were obtained as with CDS, with the most parsimonious models (in bold in Table 17) producing a population density estimate for deer of 0.85 animals per square kilometre, for an estimated population of ~2,153 deer, again with low CVs of around 16%. The covariate with the greatest influence on deer sightability was the observer's position within the aircraft.

Table 17: *Multiple covariate distance sampling (MCDS) population density estimates for deer in four survey blocks of Kosciuszko National Park, 2024.* ***Abbreviations:*** *AIC – Akaike's Information Criterion; ESW – effective strip width; LCL – lower confidence limit; UCL – upper confidence limit; CV – coefficient of variation. HN – half normal distribution; NE – negative exponential distribution; HR – hazard ratio distribution. SR – time to sunrise; SS – time to sunset; The best performing model is shown in bold.*

Model	AIC	ESW (m)	Density (deer per km^2)	Density (LCL)	Density (UCL)	Density CV
MCDS_Deer ~ Position (HN Cos)	**313.96**	**54.41**	**0.85**	**0.62**	**1.17**	**16.3%**
MCDS_Deer ~ To_SR_SS+Position (HN Cos)	314.11	53.71	0.85	0.61	1.17	16.4%
MCDS_Deer ~ To_SR_SS (HN Cos)	314.21	54.23	0.83	0.61	1.15	16.4%
MCDS_Deer~ Sun+To_SR_SS+Position (HN Cos)	315.60	53.48	0.85	0.62	1.18	16.5%
MCDS_Deer ~ To_SR_SS+Position+Habitat (HN Cos)	316.10	53.71	0.85	0.61	1.17	16.4%
MCDS_Deer ~ To_SR_SS+Habitat (HN Cos)	316.97	53.96	0.84	0.61	1.16	16.4%
MCDS_Deer ~ Habitat + Sun + Position (HN Cos)	317.44	54.21	0.85	0.62	1.18	16.4%
MCDS_Deer ~ Sun+To_SR_SS+Habitat+Position (HN Cos)	317.60	53.49	0.85	0.62	1.18	16.5%
MCDS_Deer ~ Habitat + Sun + Position + To_SR_SS (HN Cos)	317.60	53.49	0.85	0.62	1.18	16.5%
MCDS_Deer ~ Sun+To_SR_SS+Habitat (HN Cos)	317.76	54.08	0.84	0.61	1.16	16.4%
MCDS_Deer ~ Sun (HN Cos)	318.37	55.83	0.83	0.60	1.13	16.3%
MCDS_Deer ~ Habitat (HN Cos)	318.40	55.84	0.83	0.60	1.14	16.2%
MCDS_Deer ~ Habitat (Post-stratify_Region HN Cos)	318.40	55.84	0.85	0.62	1.15	15.5%
MCDS_Deer ~ Habitat (HR Cos)	319.96	57.36	0.81	0.59	1.11	16.3%
MCDS_Deer ~ Habitat + Sun (HN Cos)	320.24	55.80	0.83	0.60	1.14	16.3%

Raw data summary and data checks

Based on the rear-observer only counts, a total of 512 horses and foals were seen in the five sighting zones on both sides of the aircraft in 2024. Foals accounted for ~5.79% of all sightings of horses, based again on counts from the two rear observers. Group sizes ranged from 1–22 in size, similar to [redacted] (2023). The front-left position saw 193 horses and foals, while the rear left position saw 214 horses and foals. Conversely, the front left position saw 115 deer and the rear left position saw 93 deer. The two rear seat positions collectively saw 220 deer.

A number of quality management checks from field to the final report were undertaken. An example of these checks is described below.

> *Example: As part of a broader range of Quality Management checks, we checked the computer outputs of MCDS for horses and foals manually. Using MCDS, and the Effective Strip Width (ESW) of 113.4 metres for foals and horses, excluding the Cabramurra block, effectively 18.53% of the total area was surveyed (a sample area of 470.1 km^2 divided by a total area of 2,535.7 km^2) for the Southern KNP, Northern KNP and Snowy Plains survey blocks combined. Ignoring group size biases and the mark-recapture corrections, a quick check using simple arithmetic suggests there would be approximately 1.1 foals and horses per km^2 on average (or N >2,760) across the three survey blocks (512 horses and foals divided by ~470 km^2, the sample area).*
>
> *After correcting for group size biases (i.e. more groups seen further out), the MCDS modelling yielded a total abundance across all three survey blocks above of 2,793 foals and horses, with CVs ranging from 25–55%. This figure is close to the approximation described above, suggesting no gross errors were made as part of the computer processing. Correcting these estimates using the mark-recapture model increased the estimate to 3,885 foals and horses, with CVs ranging from 25–56%.*

Comments & recommendations

Distance sampling & multiple covariate distance sampling

Aerial wildlife surveys are a well-established technique for estimating the population sizes of medium to large sized animal species in natural landscapes, and have been used for around 60 years, commencing in Africa in the 1960s. Scientists have been using and improving aerial survey methods ever since. This globally accepted scientific method provides vital information to decision-makers on the distribution and abundance of medium to large animals at a landscape scale, in contexts where on-ground surveys would be impractical.

In 1997, two prominent British scientists, Buckland and Borchers, significantly modernised wildlife aerial surveys by introducing the use of distance sampling. These methods have been widely adopted, and further improvements in distance sampling methods continue to be made by leading scientists in the field around the world, including practitioners such as Anderson, Marques, Hedley, Pollard and Miller. In 2024 a database search found over 2,000 peer-reviewed scientific papers on distance sampling in ecology and environment journals.

In the three most recent surveys, [redacted] (2020, 2022, 2023) chose distance sampling as the most appropriate approach for estimating wild horse (*Equus caballus*) population density in KNP. In 2024 the NSW government asked us to continue with, and further refine this methodology for surveying the wild horse populations. Aerial survey operations were conducted jointly by our staff and NSW Government staff.

Conventional distance sampling only considers one variable that may affect wildlife counts, that is, a decline in sightability the further away from the observer the animal(s) are in the landscape. To examine other influences, again following [redacted] (2020, 2022, 2023), we tested various combinations of additional covariates using Multiple Covariate Distance Sampling (MCDS). The MCDS modelling showed that habitat type (i.e. the level of vegetation cover obstructing view) was a contributor to sightability. In open areas sightability remained very high, even at 150 m away from the aircraft (Figure 10). In thicker canopy, sightability declined more rapidly. Population density estimates that compensate for this were markedly higher than those derived from conventional distance sampling and are considered to better represent population density because this heterogeneity in the data can be explained by modelling the habitat. We therefore consider that in future surveys it will remain extremely important to record habitat type associated with each sighting.

Other factors including the direction of the sun (forward or aft of the observer), and time of day were also tested. Time of day (measured as the time to sunset of sunrise) may have influenced the count due to observer fatigue. Time of day could also influence the count because horse activity may decline during the middle of the day, in which case it should not be included as a factor affecting sightability, instead being a horse availability issue. To avoid this ambiguity, in 2024 the surveys flights were timed to be within approximately 3 hours of sunrise and sunset when horses were thought to be most active and therefore more available. As a precaution we nevertheless tested how the time to sunrise and sunset affected observations in the MCDS modelling, and it did not appear as the most highly-ranked model in Table 4. This was expected, given that we largely restricted flight times to early morning and late afternoon.

Mark-recapture distance sampling (MRDS)

MRDS[2] was trialled in the KNP surveys for the first time in 2024 at the request of the NSW Government, and based on expert advice. This has recently been trialled for horses elsewhere in Australia but was unsuccessful, possibly due to low sample size [redacted] 2023b). The purpose of this technique is to provide an additional correction for perception bias to the MCDS population density estimates. In this survey, the MRDS modelling resulted in elevated horse population density estimates compared to MCDS models. For example, for foals and horses combined in the three included survey blocks, the total combined population estimate went from 2,793 using MCDS to 3,885 (Table 13).

Aerial observers were assumed to have the same level of survey experience and were systematically rotated between each seat (rear right, front-left and rear-left) during the survey. This meant we could test for any biases associated with seat position. Seat position was found to not be affecting observer horse counts but it did appear to do so for the smaller species, deer (Table 17). While not graphed in this report, it was clear the left-rear position saw fewer deer. This is likely because of the increased propellor wash affecting the rear left observers, a well-known issue in B3 Squirrel helicopters. Our analysis therefore suggests this has a greater effect for smaller animals but there was no evidence it affected foal sightings, probably because they were always found near adult horses.

[2] In the strictest sense, mark-recapture (MR) involves the front observer calling out their counts to the rear observer, and the rear observer agreeing/disagreeing or adding further counts. This is also termed a 'dependence' count. In the 2024 survey, the front and rear observers recorded data independently, so the term is used here in a loose sense.

Data security and independence

In 2024, the survey data were collected electronically in a proprietary database as part of our standard operating procedures for aerial surveys. To maintain observer independence, the daily counts were securely stored, and count data was not shared during or after flights with any of aerial observers.

Population density & population size estimates for 2024

MCDS estimates

Compared with the projections from 2023 and known removals data, the 2024 densities are significantly lower than expected densities (Table 2), where we projected that there would be 8.169 horses per km^2 (N = 10,041) in the Northern KNP block, 2.535 per km^2 (N = 408) in the Snowy Plains block, and 2.270 per km^2 (N = 2,601) in the Southern KNP block. Combining foals and horses for 2024 using MCDS (to be consistent with methodology of [redacted] 2023), the densities were instead found to be 1.316 km^2 (N = 1,617) in the Northern KNP block, 0.781 km^2 (N = 126) in the Snowy Plains block and 0.916 km^2 (N = 1,150) in the Southern KNP block. These estimates represent a significant population drop in the expected numbers (expected total: 13,050; actual estimated total: 2,793), particularly in the Northern survey block where only ~16% of the expected population was estimated.

Statistical variability in the estimates

Lower than expected counts also adversely affected the predicted 2024 survey effort required for each block, with MCDS density estimates having significantly higher associated CVs (estimated % errors) in all three survey blocks than the target CVs in Table 1 that were set before the survey. This is because for a given survey effort, any drop in population will increase the CV. Before the survey, target CVs set for the survey design were: 13% (Northern block), 40% (Snowy Plains) and 20% (Southern block). Using MCDS estimates for horses and foals, the actual estimated CVs for 2024 were: 34% (Northern block), 56% (Snowy Plains) and 25% (Southern block). This adds an unacceptable level of uncertainty to the 2024 results.

Where requested, we have added 95% confidence intervals to show statistical variability in the population estimates to be consistent with past years' reported results. We have previously stated that we do not support the use of 95% CIs in aerial survey estimates, particularly when they are used in temporal analysis because the population estimates over time are not statistically independent, thus too much can be read into any error bars in terms of population change, or stability. The recommendation in future is to use the more statistically correct approach, error estimation of the ratio of change. This is the ratio of two population estimates over an interval of time. In this case, the combined error of this ratio is not the sum of the coefficients of variation of the two population estimates because the latter is dependent on the former. Instead, the errors should be combine using the delta method (Powell 2007; Seber 1982). This assumes a Gaussian distribution exists in the ratio of the two populations.

The quadratic delta method (Equation 2) is from partial differential calculus, combining the standard error (SE) in each year (see Cochran 1977, page 155 for proof). Here σ_x and σ_y are Standard Errors of the two populations from Program Distance, for year *x* and year *y*. Note that in Cochran's (1977) original formula $\frac{1-f}{n}$ are shown, but this is accounted for in σ_x and σ_y, so it is omitted in Equation 3 (also see Lynch et al. 2021, page 4). In Equation 3, μ_x and μ_y are the population estimates for year *x* and year *y* respectively. $\sigma^2_{\hat{R}}$ is the variance of the ratio of these population estimates: $\hat{R} = \mu_y / \mu_x$.

$$\sigma^2_{\hat{R}} \approx \frac{\sigma_y^2}{\mu_x^2} + \frac{\mu_y^2 \sigma_x^2}{\mu_x^4} - 2\frac{\sigma_{xy}\mu_y}{\mu_x^3} \quad \textbf{\textit{Equation 3}}$$

Lynch et al's (2021) covariate term σ_{xy} can be re-written as $\sigma_x\sigma_y\hat{R}$ or $\sigma_x\sigma_y\mu_y/\mu_x$ The last term in Equation 3 then becomes: $-2\frac{\mu_y^2\sigma_x\sigma_y}{\mu_x^4}$, the covariance term. Its presence in Equation 3 acknowledges the population estimates from the two surveys are not independent. In future work we recommend using this approach rather than comparing years with error bars.

For the MCDS population estimates (e.g. Table 7) we have nevertheless calculated upper and lower population estimates using the 95% CIs as requested, for comparison with previous years' MCDS results. However, it should be noted that it is not possible to calculate equivalent 95% CIs for the MRDS population estimates because these estimates combine two models (MCDS and the MR model), both of which have their own 95% CIs. Mathematically there is no way of combining these two 95% CIs to obtain an 'overall' error. If the intention in future is to continue with using three-surveyor aerial surveys and MRDS analysis, the use of 95% CIs therefore becomes increasingly irrelevant for comparing results between years, in addition to our above comments about their suitability for MCDS.

Possible reasons for reduced estimates

There are a few potential explanations for the significant drop in horse numbers in 2024 from those predicted prior to the survey.

The first is that large numbers of horses that remained in these areas could have emigrated out of the surveyed areas after control operations, especially aerial shooting during 2024, and overall there may be a greater volume of movement in and out of the survey blocks than previously thought. Horse movements in and out of survey areas between years has been suggested as a possible cause of sharply different abundance shifts from year to year in some areas of KNP in the past [redacted] 2022). Three months had passed since the last aerial shooting event. It is unknown whether horses would be likely to continue to avoid the survey areas and the retention areas after this length of time.

Another possible explanation for lower than expected counts, also related to horse movements, is transect spacing. The Northern block and Southern block transects were spaced less than 1.5 km apart in 2024, and as such were flown in a staggered pattern, with every second transect skipped and surveyed on a different day, to minimise risk of double-counting due to animals flushing into the path of the next transect if flown sequentially, a rule adopted from [redacted] (2023). Due to the staggered pattern, distance between any two sequentially flown transects in the Northern block was 2.74 km in 2024, and 2.46 km in the Southern block.

Linklater and Cameron (2022) found horse flushing behaviour in response to aircraft to be significant when they used independent observers on the ground and in the air. They found that the helicopter induced running and changes in group sizes, with flushing between transect lines such that the helicopter estimates may have over-estimated horses abundance between 15% to 32% due to sequential survey lines being flown. Although we staggered transect lines on different days in 2024, it is possible that the >1.5 km sequential flight rule is too small, and in past surveys of horses a fraction may have been flushed from one line to the next, leading to over-counting. However, this does not account for the drop from an expected 408 to 126 horses in the Snowy Plains block, where transect spacing was consistent with previous years (0.7 km), suggesting that flushing may not be the only contributing factor. There is also no guarantee that that lines flown in a staggered approach with sequential flights of >2.4 km apart in 2024 has sufficiently abated the risk of flushing and double-counting. For kangaroos, goats and deer we have always recommended a sequentially flown transect spacing of >1.5km. For camels we always recommend a sequentially flown transect spacing of >5km. We therefore recommend increasing transect spacing for horses in future.

Another potential explanation for the larger than expected population drop is that remaining horses in these survey blocks have a heightened awareness and evasion response to the noise of the helicopter after recent aerial control operations and that they rapidly leave the survey area, heading quickly to cover, well before they are sighted.

In reality we have no information to support any one of the possible reasons above, or a combination of reasons, for the lower than expected count in 2024. As there is no data on horse movement to confirm whether any of the possibilities above is a contributing factor, we recommend that the NSW Government consider embarking on a horse radio collar tracking study, to track a sufficient number of horses before, during and after any form of aerial operation. This information would be of considerable value in guiding future survey design and for making informed management decisions about horses in line with the Kosciuszko National Park Wild Horse Heritage Management Plan.

Appendix 1 – Horse group size summary data

Summary data graphed in Figure 7. Strip width in all cases was 150 m. Abbreviations: *n* – total number of groups of horses for each survey block; *L* – length of transect (i.e. survey effort); CV – coefficient of variation; *df* – degrees of freedom; LCL – lower confidence limit (95% CI); UCL – upper confidence limit (95% CI).

	Estimate	CV	df	LCL (95%)	UCL (95%)
Northern Block					
n	67.0				
L	901.57				
n/L	0.074315	29.51	76	0.0417	0.1321
Snowy Plains					
n	12.0				
L	233.06				
n/L	0.051489	54.23	41	0.0184	0.14357
Southern Block					
n	79.0				
L	938.37				
n/L	0.084189	23.53	160	0.0532	0.13317

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