A survey of the wild horse population in Kosciuszko National Park, November 2022

December 2022

Abstract

1. Aerial surveys of the wild horse populations in the Australian Alps National Parks and adjacent State forests have been conducted periodically over the past two decades with the aim of estimating population size and determining trends in abundance over time. The most recent two of these surveys were conducted in four survey blocks within Kosciuszko National Park in October-November 2020 and November 2022; the latter which is reported on here.
2. These surveys were designed using the automated survey design engine of DISTANCE 7.3, and were conducted using helicopter line transect sampling. The results were analysed using DISTANCE 7.3.
3. In the present survey, a total of 1,490 km of transect was surveyed using helicopters flown at a ground speed of 93 km h^{-1} (50 kts) at a height of 61 m (200 ft). Two observers were seated in the rear on either side of the aircraft. Sightings of clusters of horses were recorded into five distance classes in a 150 m wide survey strip on either side of the aircraft.
4. A total of 419 clusters of horses were sighted in three of the four survey blocks. Individuals were classified as either adults or foals. No horses were detected in the fourth (Cabramurra) block.
5. A single global detection function model was fitted to the data and was used to estimate horse population densities and abundances. This was also done to estimate separately the numbers of adult horses and foals.
6. The estimated population densities of horses in the survey blocks were in the range 4.38-10.39 km^{-2}, with an overall density estimate of 7.03 km^{-2} (95%CI: 5.42-8.80). This compared to an overall density of 5.38 km^{-2} (95%CI: 3.47-8.89) estimated from a survey conducted in 2020.
7. The total number of horses in the combined 2,675 km^2 of the survey blocks was estimated to be 18,814 (95% CI: 14,501-23,535). This compared to an overall population abundance of 14,380 (95% CI: 8,798-22,555) estimated from the survey conducted in 2020.
8. As an indicator of relative recruitment in the population, foal-adult ratios were determined from the survey data. The overall value of this index was 0.191, i.e. for every 100 adult horses in the population, there were almost 20 foals. This compared to a foal-adult ratio of 0.102 estimated from the survey conducted in 2020; this representing a possible doubling in the rate of recruitment between the two surveys.
9. A number of sightings were made of other, non-native herbivores, namely feral pigs (10) and introduced deer (71). The estimated total number of deer in the combined 2,675 km^2 of the survey blocks was 6,323 (95% CI: 3,624-9,454). This compared to an overall population abundance of 2,565 (95% CI: 1,713-3,842) estimated from a survey conducted in 2020.

1. Introduction

Found within the boundaries of the Kosciuszko National Park (NP) is a number of populations of wild horses (*Equus caballus*). As part of the development and execution of evolving plans to manage horse populations, a number of surveys have been conducted initially under the combined auspices of the Australian Alps National Parks Cooperative Management Program and later separately by the NSW National Parks and Wildlife Service (NPWS). To this end, there is a substantial history of monitoring the wild horse populations within the broader Australian Alps National Parks (AANP). The wild horse populations of the AANP have been surveyed using helicopter line transect sampling in 2001, 2003 and 2009 (Walter 2002, 2003; Dawson 2009). Also, an adjacent area of State forest was surveyed in 2004 (Montague-Drake 2004). An expanded survey was carried out in April-May 2014 over an area encompassing both national parks and adjacent areas of State forest (Cairns 2014, 2019a). The timing of the conduct of this survey and the decision to expand the survey area was in response to recommendations that were made by Dawson (2009) with regard to future surveys. Five years later, this survey was repeated in April-May 2019, using the same survey design as that used in 2014. The results of this survey was that the horse population had increased in size by more than 175% over the intervening five-year period; or by a compound annualised rate of 22.5% over the period between surveys (Cairns 2019a).

Further to the results of the 2019 survey (Cairns 2019a), the NSW NPWS decided to undertake a follow-up survey of parts of the Kosciuszko NP in 2020. The principal reason for undertaking this survey so soon after the 2019 Alps survey was to investigate whether there had been any marked changes in the wild horse population in the Kosciuszko NP given that parts of the park had been impacted in the devastating bushfires of the summer of 2019-2020 (https://knowledge.aidr.org.au/resources/black-summer-bushfires-nsw-2019-20/; https://www.climatecouncil.org.au/resources/summer-of-crisis/). The survey was conducted in designated survey areas that were identified as the Northern Kosciuszko, the Snowy Plains, the Cabramurra and the Southern Kosciuszko blocks, all within the Kosciuszko NP. The locations of these survey blocks are shown in Fig. 1. The development of the survey designs used is outlined in Cairns

(2020a). The results of the survey, which was conducted in October-November, 2020, are reported in Cairns (2020b).

As a follow-up to the 2020 survey, another survey was planned for the spring of 2022. This survey was essentially a repeat of the 2020 survey, having been conducted in the four survey blocks that were used for that survey, but with some minor changes being made to the survey design. This report presents the results of the survey conducted in November 2022.

2. Study Area and Survey Design

The survey of the wild horse population in Kosciuszko NP was conducted in four survey blocks that were identified by NSW NPWS as being in areas known to support wild horses. The four survey blocks are identified as the Northern Kosciuszko, Cabramurra, Snowy Plains and Southern Kosciuszko blocks. The locations of these blocks within the national park estate are shown in Fig. 1. The areas of the survey blocks are given in Table 1.

Table 1. The target level of precision, the number of transects and the total survey effort for each of the realised survey designs. Given along with these values are the areas of the survey blocks and the reference surveys used to determine the required survey effort using the method given in Buckland *et al.* (2001).

Survey block	Area (km^2)	Target precision (%)	No. of transects	Survey effort (km)	Reference survey
Northern Kosciuszko	1,299	20.0	34	663	KNP (2020b)*
Snowy Plain	161	40.0	23	232	AALC (2019)**
Cabramurra	139	25.0	34	157	AALC (2019)**
Southern Kosciuszko	1,146	20.0	25	444	AALC (2019)**

*Cairns (2020b)
**Cairns (2019b)

For each of the four blocks, a systematic random sampling survey design comprising a randomly-placed grid of parallel lines was drafted using the survey design algorithm of DISTANCE 7.3 (http://distancesampling.org/Distance/#download-latest-version).

These surveys were designed with the aim of achieving levels of survey precision ranging from 20% in relation to the two large survey blocks and 25% and 40% in relation to the Cabramurra and the Snowy Plains survey blocks, respectively. There was, from the onset, logistical constraints to setting these levels of survey precision. A level of precision of 20% was considered to be reasonable and logistically manageable for the two larger blocks. However, the lower levels of precision used for the Cabramurra and Snowy Plains blocks which were essentially an order of magnitude smaller in area than the two larger blocks, were constrained by the logistics of conducting aerial surveys on these two blocks, mainly the placement of sufficient transects for the conduct of surveys of a higher precision.

The original design process involved the testing of the selected design against alternatives (Cairns 2020a). Survey effort was determined using the method outlined in Buckland *et al.* (2001, p. 243). The survey effort for the Northern Kosciuszko block was determined using survey effort and precision information from a survey conducted in this block in 2020 (Cairns 2020b). The survey efforts for the other three blocks were determined using survey effort and precision information from surveys conducted in similar areas of the Australian Alps in 2019 (Cairns 2019a, 2020a). The details of these surveys are given in Table 1, with diagrammatic representations of them being shown in Figs. 2-5. The transects in the Northern Kosciuszko, Cabramurra and Snowy Plains blocks were all orientated in an east-west direction, while the transects in the Southern Kosciuszko block were orientated in a northeast-southwest direction. To visualise the relative sizes of the survey blocks, refer to Fig. 1.

In the two larger Northern Kosciuszko and Southern Kosciuszko blocks, adjacent transects were 1.85 km and 2.63 km apart, respectively. This meant that it was possible to survey these blocks using the sequential traversing of adjacent transects. In the Cabramurra block, in order to achieve the required survey effort, adjacent transects were placed 900 m apart, while in the Snowy Plains block, they were placed 700 m apart. The closeness of adjacent transects in these two smaller blocks constrained the conduct surveys in these blocks to sequentially surveying every second rather than adjacent transects during a single survey session.

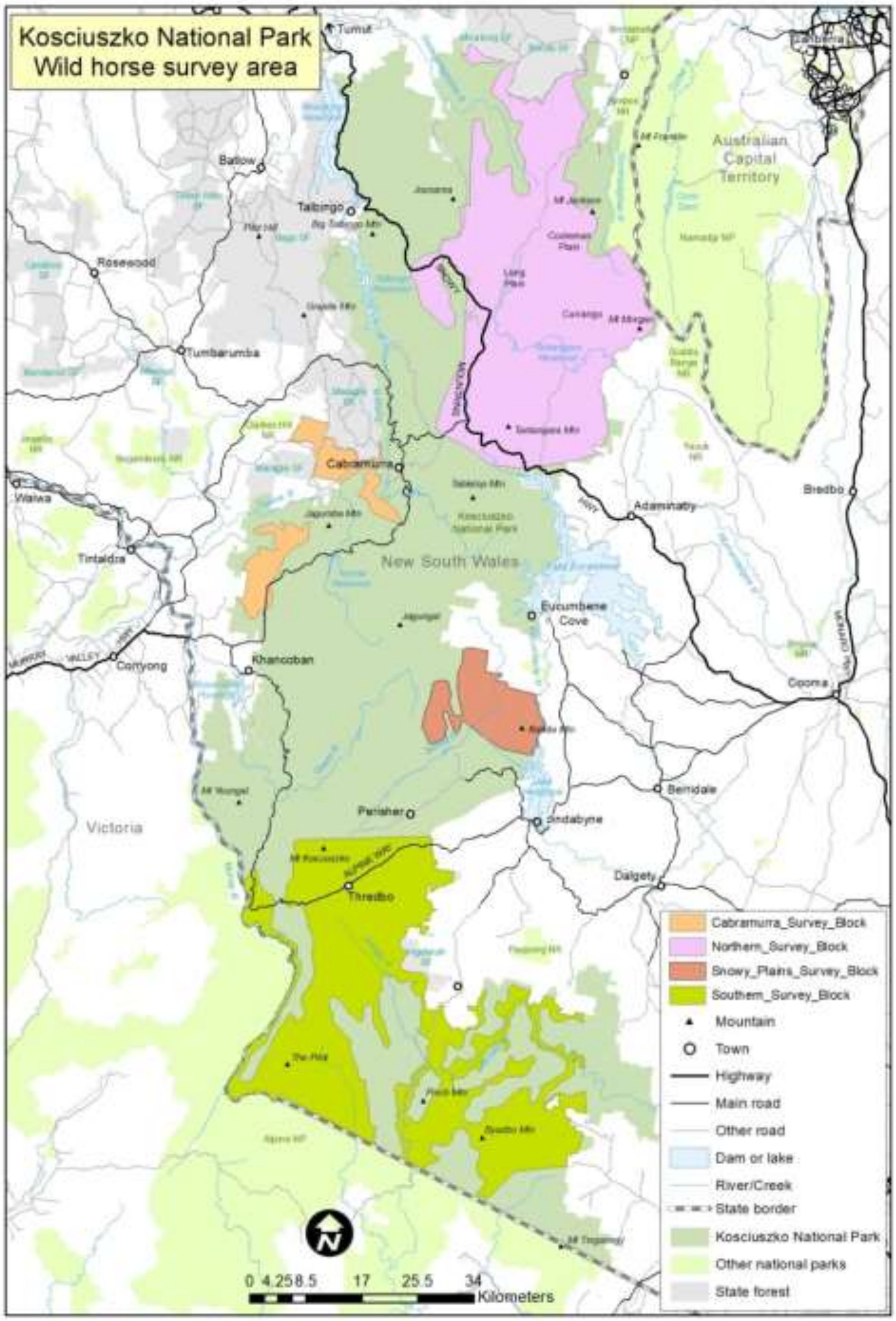

Fig. 1. The wild horse survey blocks in Kosciuszko NP. To identify each block, see the legend in the bottom right-hand corner.

3. Survey and Data Analysis Methods

For the conduct of these surveys, a standard aircraft configuration was used. It included a pilot seated in the front right-hand seat of the helicopter who was responsible for flying the aircraft, maintaining a constant height and speed along the survey transect; an air safety observer seated in the front left-hand seat of the aircraft who was responsible for assisting with navigation and maintaining situational awareness for the aircraft; and two experienced observers (counters) seated on either side in the rear of the aircraft who were responsible for using a calibrated sighting boom to record animal sightings during a survey (see Fig. 6). This configuration has been used for the present survey.

The aircraft used was the NSW NPWS ParkAir Eurocopter AS350 Écureuil (*Squirrel*) single-engine light helicopter. The seating of the observers in relation to the left-hand and right-hand side of the aircraft was allocated randomly for each survey session.

3.1 Helicopter Line Transect Surveys

Surveys were carried out during daylight hours, with there generally being two sessions each day, one in the morning and one in the afternoon. The conduct of the surveys was such that for the two larger survey blocks (Fig. 1) transects were flown sequentially during each survey session. The parallel transect lines being 1.85 km apart in the Northern block and 2.63 km in the Southern block allowed this to be undertaken with reasonable degree of confidence that there would be no double counting of horses on adjacent transects during any survey session. Because this could not be guaranteed for the two smaller blocks, every second transect was therefore flown during a survey session, with a 24-h time cycle between the surveying of adjacent transects. Flying every second transect during a survey session ensured that there was at least 1.4 km between the designated adjacent transects for that session, greatly reducing the likelihood of double-counting horses that might move between adjacent transects in response to the helicopter (see Linklater & Cameron 2002).

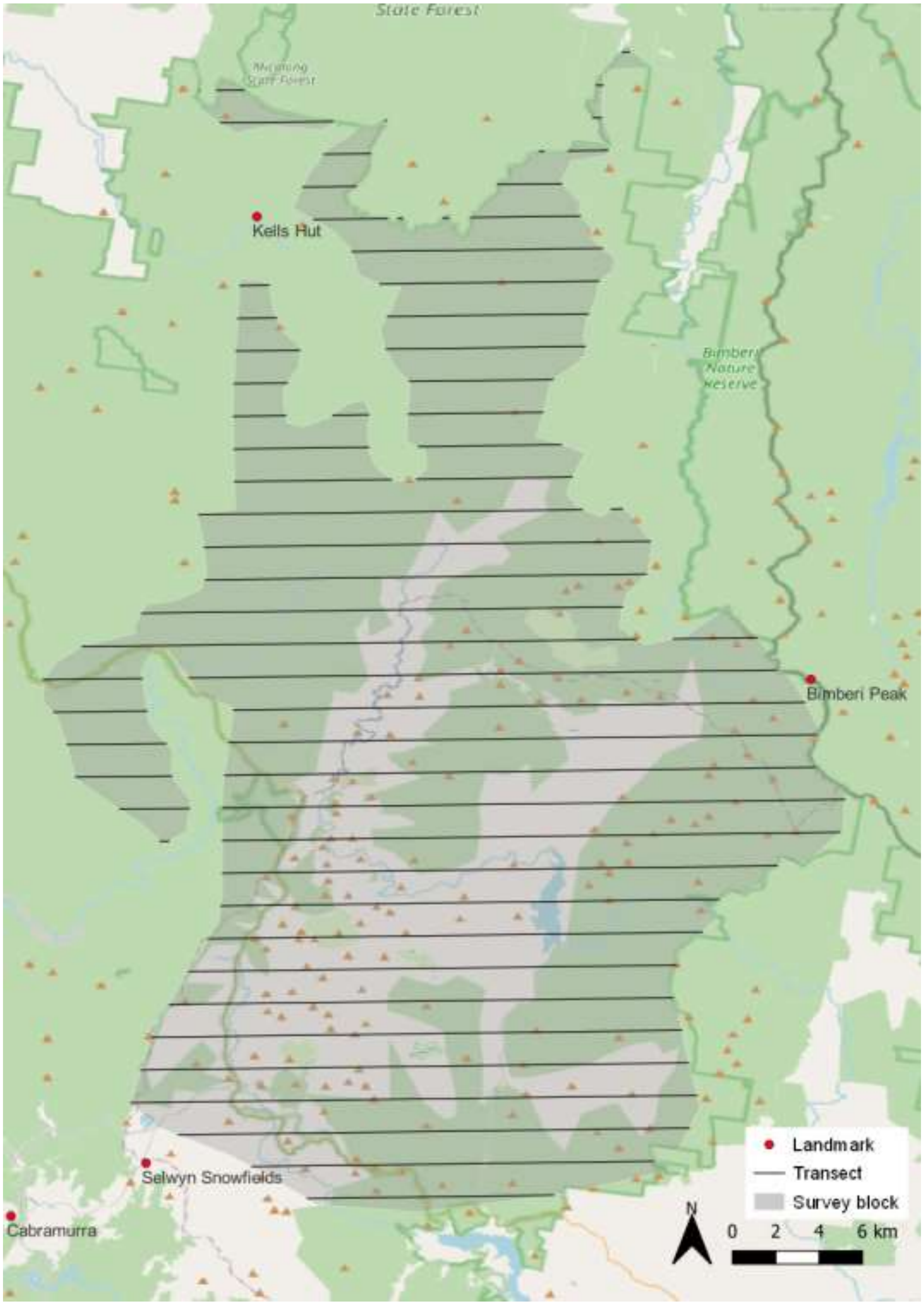

Fig. 2. The planned systematic random (parallel) survey design for the Northern Kosciusko block with an estimated survey effort of 665 km and a total trackline length of 843 km. High points in the landscape are indicated by the orange triangles. For the geolocation of this survey block, see Fig. 1.

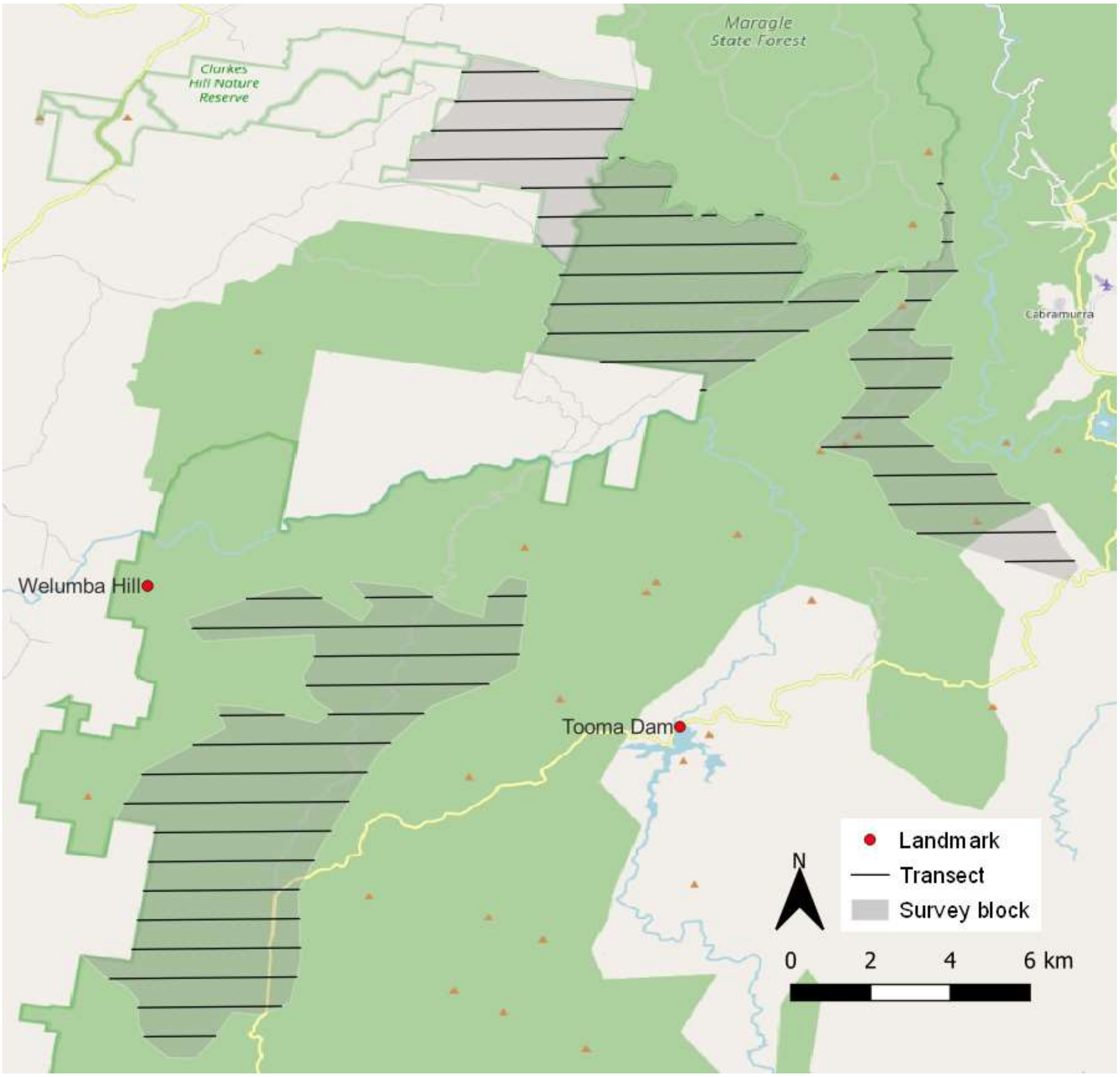

Fig. 3. The planned systematic random (parallel) survey design for the Cabramurra survey block with an estimated survey effort of 176 km and a total trackline length of 309 km. High points in the landscape are indicated by the orange triangles. For the geolocation of this survey block, see Fig. 1.

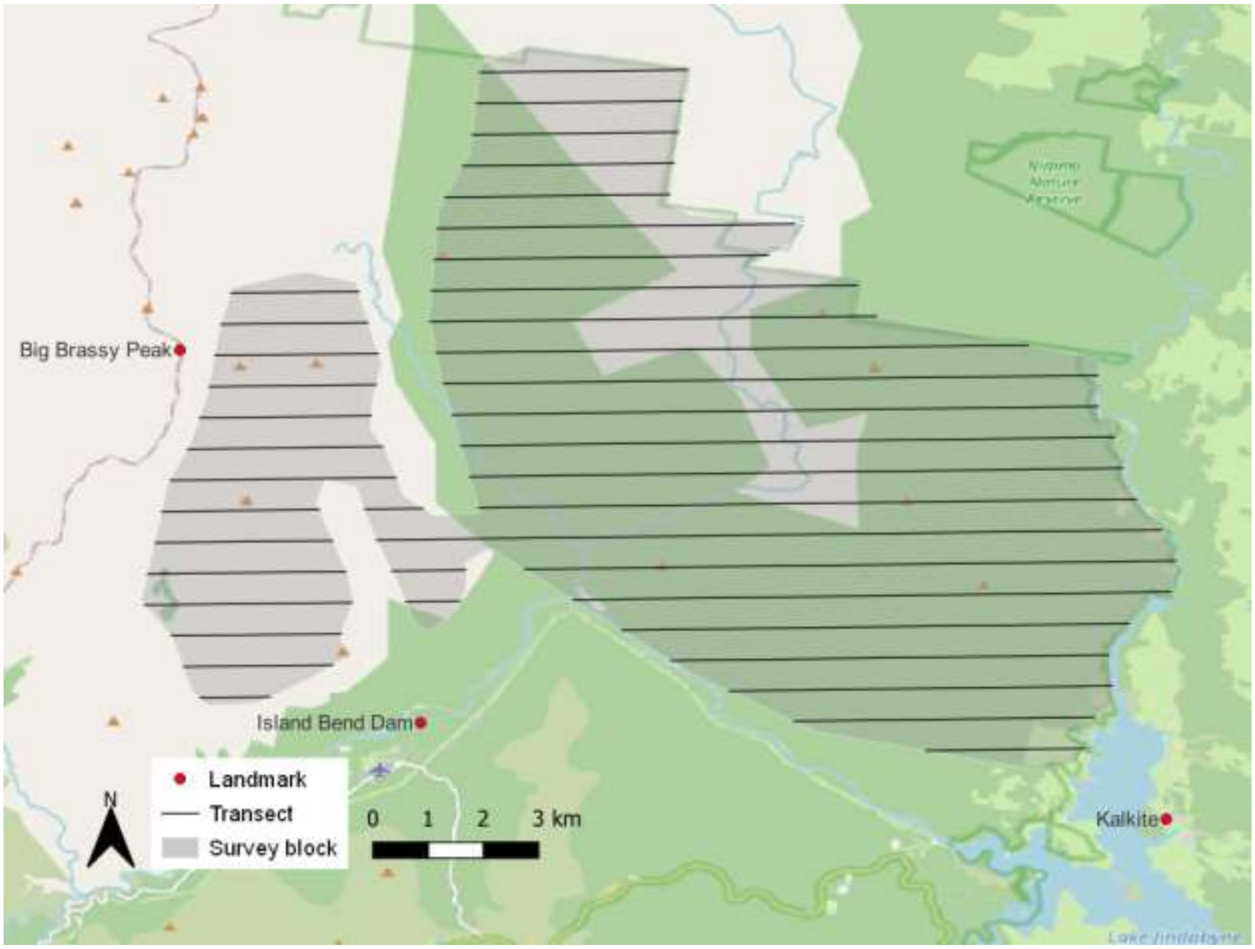

Fig. 4. The planned systematic random (parallel) survey design for the Snowy Plains survey block with an estimated survey effort of 232 km and a total trackline length of 291 km. High points in the landscape are indicated by the orange triangles. For the geolocation of this survey block, see Fig. 1.

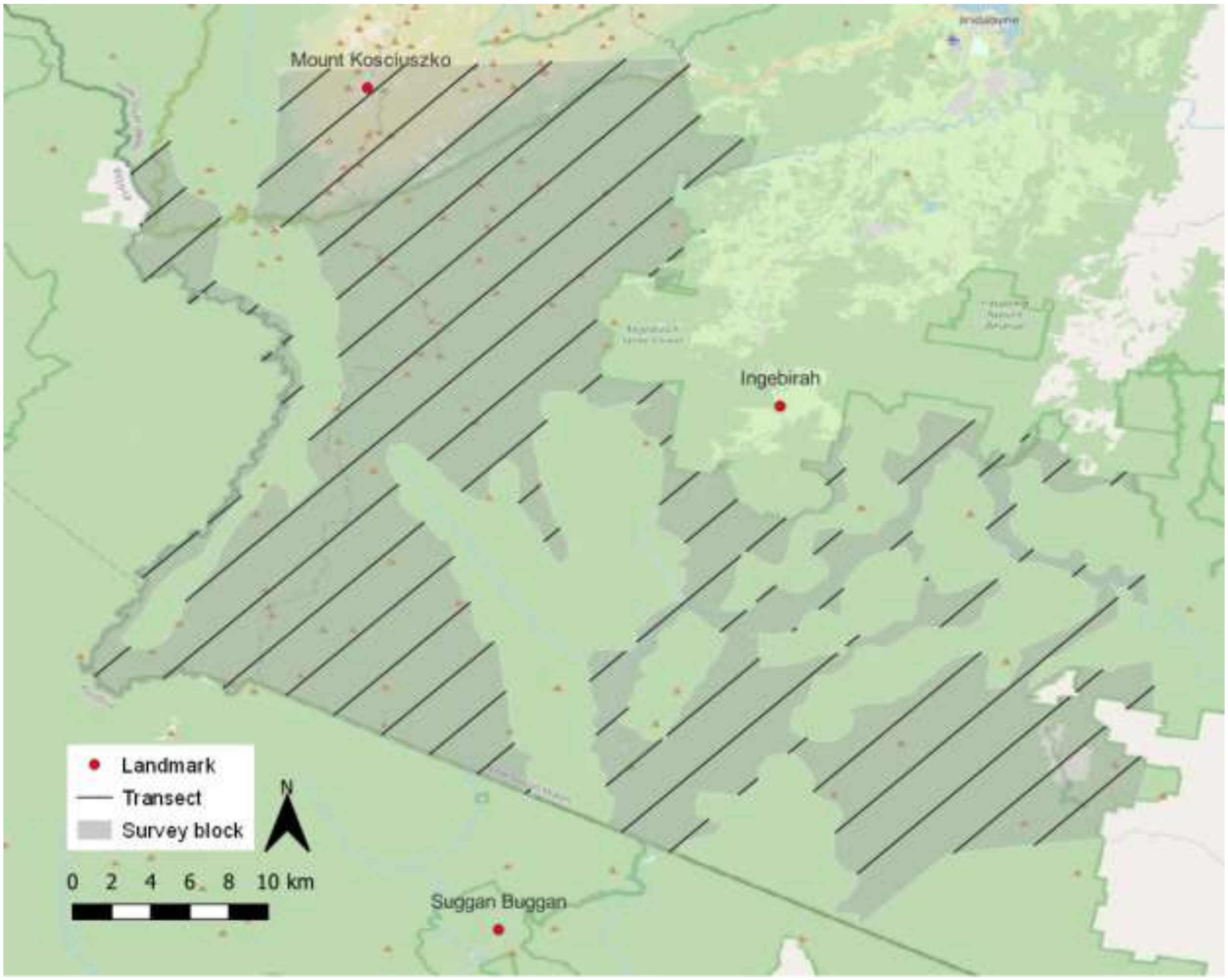

Fig. 5. The planned systematic random (parallel) survey design for the Southern Kosciuszko survey block with an estimated survey effort of 445 km and a total trackline length of 740 km. . High points in the landscape are indicated by the orange triangles. For the geolocation of this survey block, see Fig. 1.

The survey transects (samplers) varied widely in nominal length, ranging from 2 km up to 44 km. A number of transects were broken into segments in relation to landscape features (Figs. 2-4), with the data collected in these segments being combined for analyses.

In conducting the surveys of the four blocks, the helicopter was flown with the two rear doors open along each straight transect line at a ground speed of 93 km h^{-1} (50 kts) and a height of 61 m (200 ft) above ground level. Navigation was by a global positioning system (GPS) receiver. The two observers counted horses seen on either side of the aircraft, recording the sizes of the clusters observed within specified perpendicular distance classes from the transect centreline, designated by the inner edge of the delineated survey strip on either side of the aircraft. Sightings of clusters of horses were recorded into 0-20 m, 20-40 m, 40-70 m, 70-100 m and 100-150 m distance classes, perpendicular to the transect centreline. These distance classes were delineated on metal booms extending from either side of the helicopter (Fig. 6).

Data in the form of the numbers of clusters (groups of one or more) of horses observed within the different delineated distance classes across the transect were voice-recorded, along with sightings of any other large mammal species (kangaroos, wild dogs and wombats excluded). The numbers of adult horses and foals in each cluster were also recorded. In addition, ancillary information that could affect detection probability was also recorded. This information included observer identification, survey aspect in relation to the side of the aircraft and the direction flown, and the proportion of cloud cover during a survey session.

The seating positions of the observers and the direction flown on each transect were also recorded to determine survey aspect (north-facing or south-facing). Voice-recorded information was transcribed at the end of each survey session. No rest breaks were taken by the observers on any transect during the survey sessions. Hence, for the purpose of data analysis, the exact transect lengths were equal to the allocated lengths in the survey designs.

Fig. 6 Sighting boom mounted on the left-hand side of the Eurocopter AS350 Écureuil helicopter. The perpendicular distance classes used in the surveys (0-20 m, 20-40 m, 40-70 m, 70-100 m and 100-150 m) are indicated by the black bands on the boom.

3.2 Data Analysis

The analysis of distance sampling data such as those collected here initially involves the estimation of the detection probability of animals within the covered area (usually a designated survey strip). Following this, the density of animals within the covered area can be estimated given this detection probability, after which the number of animals in the survey region can be estimated given the density of animals in the covered area (Borchers & Burnham 2004). With a properly designed survey, inferences can be safely made about the survey region using information obtained from sample units (Thompson 2002). Density ($\widehat{D}$) in the covered area is estimated from:

$$\widehat{D} = \frac{n_a \hat{E}(c)}{2wLP_a} \qquad \text{eqn. 1}$$

where, n_a is the number of clusters observed, $\hat{E}(c)$ is the expected cluster size (see later), L is the survey effort (total transect length) and P_a is the probability of detecting a cluster of the animals within w, the half-width of the designated survey strip (Buckland *et al.* 2001).

In order to estimate the probability (P_a) of detecting a cluster of the animals within w, the detection function g(x), the probability that a cluster of animals at perpendicular distance x from the survey transect centreline is detected (where, $0 \leq \mathrm{x} \leq \mathrm{w}$ and $g(0) = 1$) needs to be modelled and evaluated at $x = 0$, directly on the transect centreline (Thomas *et al.* 2002). To do this, the sampling data, the counts of clusters of animals (horses) within each of the five distance bins used in these surveys, were analysed using DISTANCE 7.3 (Thomas *et al.* 2010). Basing the analysis on the sightings of clusters in preference to the sightings of individual animals has been found to ensure against the overestimation of the true variances (Southwell & Weaver 1993).

In analysing the results of surveys such as those undertaken here, it is important that the recommended minimum sample sizes of both transect lines and observations are at least attained. According to Buckland *et al.* (2001), the recommended minimum number of samplers (replicate transect lines) should be 10-20 in order to ensure reasonably reliable estimation of the variance of the encounter rate, and the recommended number of observations, clusters of horses in this instance, should be 60-80 for reliable modelling of the detection function. The numbers of replicate transects flown across each survey block are given in Table 1.

The analysis program DISTANCE 7.3 has three different analysis engines that can be used to model the detection function (Thomas *et al.* 2010). Two of these, the conventional distance sampling (CDS) analysis engine and the multiple-covariate distance sampling (MCDS) analysis engine, were used here. In analysing survey results using the CDS analysis engine, there is no capacity to include any covariates other than the perpendicular distance of a cluster of horses from the transect centreline in the modelling process. Hence, an assumption is made of pooling robustness, i.e. it is assumed that the models used yield unbiased (or nearly unbiased) estimates when distance data collected under variable conditions are pooled (Burnham *et al.* 1980). Using MCDS allows the inclusion of additional covariates in the analysis. Doing this relaxes, to some extent (but not entirely), reliance on the assumption of pooling robustness that characterises the use of CDS (Burnham *et. al.* 2004).

The results of the analyses conducted using detection function model options available within both the CDS and MCDS analysis engines were compared serially in order to determine the most parsimonious model and, hence, which population density and abundance estimates were the most likely and accurate. The model with the lowest value for a penalised log-likelihood in the form of Akaike's Information Criterion (*AIC= -2 x log-likelihood + 2[p +1]*; where *p* is the number of parameters in the model) was selected as the most likely detection function (Burnham & Anderson 2002; Thomas *et al.* 2010). In selecting the most parsimonious model, along with comparing AIC values, some secondary consideration was given to goodness-of-fit and the shape criterion of the competing detection functions; with any model with an unrealistic spike at zero distance, rather than a distinct 'shoulder' near the transect line, being likely to be rejected in favour of a model that better meets the selection criteria. Although available as an option to improve goodness-of-fit, no manipulation of the grouping intervals was undertaken.

Five detection function models were considered in the analyses using the CDS analysis engine. Each model comprised a key function that, if required, can be adjusted by a cosine or polynomial series expansion containing one or more parameters. The different models considered were a Uniform key function with an optional Cosine or Simple Polynomial series expansion, a Half-normal key function with an optional Cosine or Hermite Polynomial series expansion, and a Hazard-rate key function with an optional Cosine or Simple Polynomial series expansion. The number of adjustment terms incorporated into a model was determined through the sequential addition of up to three terms.

Because horse sighting were recorded as clusters, estimation of expected cluster size for use in the determination of density (see eqn. 1) of horses can be problematic. The obvious estimator, the mean size of detected clusters, may be subject to group size bias. If larger clusters are more detectable at greater distances from the survey transect than are small clusters, then mean size of detected clusters will become a positively-biased (rather than an unbiased) estimator of expected cluster size (Buckland *et al.* 2001). A regression method was used to ameliorate this potential bias, whereby the expected cluster size ($\hat{E}(c)$) is determined using the regression of the logarithm of observed cluster size ($ln(c)$) against the estimated probability of detection ($g(x)$) at the distance (x) from the transect centreline. Significance of this relationship is determined in relation to $\alpha = 0.15$ rather than the conventional value of 0.05. By doing this, the likelihood of Type I error in relation to testing the null hypothesis of no association between $ln(c)$ and $g(x)$ is increased, and the likelihood of Type II error decreased. Here, increasing the likelihood of accepting an association between $ln(c)$ and $g(x)$ may represent a “false positive” in outcome (Type I error), but it has a precautionary advantage in case this association really exists.

If required, this method is able to correct for size-biased detection and the underestimation of the size of detected clusters, provided that neither of these effects occur at the transect centreline (Buckland *et al.* 2001). If the observed sizes of detected clusters are independent of distance from the transect centreline (i.e., if $g(x)$ does not depend upon c), then the sample mean cluster size ($\bar{c}$) is taken as an unbiased estimator of the mean size of the *n* clusters in the covered area. If, however, the observed sizes of detected clusters are found to be dependent upon $g(x)$, then, $\bar{c}$ is replaced by an expected value determined from the above-described regression of this relationship (Buckland *et al.* 2001).

The MCDS analysis engine allows for the inclusion in the detection function model of covariates other than the perpendicular distance from the transect centreline (Thomas *et al.* 2010). The key functions available in this analysis engine are the Half-normal and the Hazard-rate functions. However, only the Half-normal function was used in these analyses because the addition of a covariate to a model based on the Hazard-rate function risked over-parameterisation. The covariates can be either factor (i.e. qualitative or categorical) or non-factor (i.e. continuous), and have the effect of altering the scale but not the shape of the detection function. That is, covariates can affect the rate at which detectability decreases with perpendicular distance from the transect line, but do not alter the overall shape of the detection curve (Marques & Buckland 2004; Thomas *et al.* 2010). The covariates used in these analyses were related to individual detections of clusters of horses and were identified as observer, survey aspect and cloud cover score. All these covariates were categorical. There were two observers, two survey aspects (nominally northerly and southerly) and three grades of cloud cover (1 = clear to light, 2 = medium, 3 = overcast to dull). To avoid model over-parameterisation, the three covariates were included in the analysis singly. Cluster size could have been included in the analysis as a non-factor covariate. However, if this had been done, it would preclude the use of stratification in the analyses; stratification being required with the use of a single detection function model with four survey blocks. Possible bias associated with cluster size was therefore dealt with in the same manner as it was in relation to the use of the CDS analysis engine.

The methods of determination of the density estimates of clusters of horses, the density estimates of individual horses and the estimates of population abundance in relation to the most parsimonious detection function model using the CDS analysis engine are described in Buckland *et al.* (2001). The methods of determination of these statistics in relation to the most parsimonious detection function model using the MCDS analysis engine are described in Marques & Buckland (2004). The detection function models derived using these analysis engines can be compared using AIC, so long as the dataset analysed remains unchanged.

While densities and abundances, and their associated statistics of variation were, in most instances, determined empirically, confidence limits (LCL and UCL) and coefficients of variation (cv_{boot} %) were also determined by bootstrapping the data. If confidence intervals are calculated using the conventional, empirical method of estimation, then it is assumed that the data being analysed have been drawn from a population of values that is log-normally distributed (Buckland *et al.* 2001). This may be the case, but is often not. If it is not, in which case, the calculation of confidence intervals using the conventional method of estimation fails to truly represent the uncertainty associated with the point estimate in question. Bootstrapping the data can circumvent this problem.

Once the most likely detection function model had been determined, the data were bootstrapped 999 times in relation to all model options in the analysis engine and not just the model selected to determine the empirical estimates. The 95% confidence limits were presented as the 2.5% and 97.5% quantiles of all respective bootstrap estimates. This approach is advantageous because with bootstrap resampling of the data, the variance and associated interval estimates will include a component due to model selection uncertainty (Thomas *et al.* 2002). This is expected to improve the robustness of the interval estimation of density and abundance (Buckland *et al.* 2001). Bootstrap confidence intervals are essentially distribution-free and because their calculation is based only on the data in the sample, if the data were drawn from a population with a skewed distribution, this asymmetry will be represented in the confidence interval.

Similar analyses were also undertaken to determine separately the respective abundances of adult horses and foals. The results of these analyses were used to evaluate the extent of recruitment into the population in the form of the foal-adult ratios for the blocks surveyed.

4. Results and Discussion

The aerial survey of the four survey blocks was completed over 8-12 November 2022. Two survey sessions were flown on three of these days, with only morning sessions being flown on the other two. A total of 1,490 km of transects were flown across the four survey blocks which had a total area of 2,675 km^2. Although the blocks varied considerably in size, the number of transects flown across each survey block were in the range 23-34 (Table 1).

A total of 419 clusters of horses were sighted, compared to 236 sightings during the survey conducted in 2020 (Cairns 2020b). As was the case in 2020, most sightings in the present survey (69%) occurred in the large Northern Kosciuszko block and no horses were sighted in the Cabramurra block (see Table 5).

The method of analysis used to estimate the population densities and abundances of the wild horses in the survey blocks conformed to a general and well-understood framework for analysing distance sampling data, as presented in Buckland *et al.* (2001). Key to the analysis is the modelling of the detection of clusters of horses in relation to at least one covariate, the perpendicular distance from the transect centreline. In relation to this, a global detection function model was fitted to the combined results from the four survey blocks. The analysis involved the use of both the CDS and the MCDS analysis engines of DISTANCE 7.3 (Thomas *et al.* 2010) with a number of detection function models being compared (see Section 3.2).

With an analysis such as this, the most parsimonious (specific) detection function is usually selected principally on the basis of it being the one that yields the smallest value of the AIC statistic. The overall model selection process is comparative, being based upon the difference between the AIC statistics for competing models (ΔAIC). In comparing any two models, when ΔAIC >2.00, the interpretation is that there is increasing evidence that it is increasingly less plausible that the fitted model with the larger AIC could be considered the better of the two models, given the data. The converse of this is that when ΔAIC <2.00 then it can be thought that there can be some level of empirical support for the model with the larger AIC in comparison with the one associated with the smaller AIC, given the data. For further information on the use of AIC in model selection, see Burnham & Anderson (2002).

The result of the comparative model selection process is given in Table 2. The most parsimonious global detection function model was found to be a multiple-covariate model that had a Half-normal key function and included along with the perpendicular distance of a cluster from the transect centreline, the added factor covariate of observer. For all the other models tested it was found that comparison with this model resulted in ΔAIC >>2.00 (Table 2). The general form of the preferred detection function is shown in Fig. 7. The inclusion of a covariate such as observer in the model has the effect of altering the scale of the detection function, but not its general form (Marques &

Buckland 2004). The probability of detecting an object (cluster of horses) in the nominal survey strip therefore differs between observers.

Table 2. Comparison of the top five detection function models generated using the conventional distance sampling (CDS) and multiple-covariates distance sampling (MCDS) analysis engines in DISTANCE 7.3. Model selection was based upon comparison of the AIC statistics for the models. For details of the models and the selection process, see text.

Analysis engine	Model	Covariates	AIC	ΔAIC
CDS	Uniform/Cosine	–	1337.79	12.90
	Half-normal	–	1338.10	13.21
MCDS	Half-normal	Observer	1324.89	**0.00**
	Half-normal	Aspect	1338.45	13.56
	Half-normal	Cloud	1336.92	12.03

Associated with the survey results and detection function modelling are a small number of informative, ancillary statistics. Two of these are listed in Table 3 in relation to each survey block. These are the encounter rate (n/L) and the probability (P_a) that a randomly selected cluster of horses in the surveyed area will be detected. The encounter rate is a useful statistic from a comparative point-of-view. It is considered to be a more informative statistic than is n itself, the number of clusters detected (Buckland *et al*. 2001). Encounter rate variance is usually the dominant component of the overall variance of object (horse) density. The encounter rate in the Northern Kosciuszko block was over twice as high as it was in the Snowy Plains block and the Southern Kosciuszko block. It was also twice as precise (cv = 11.6%).

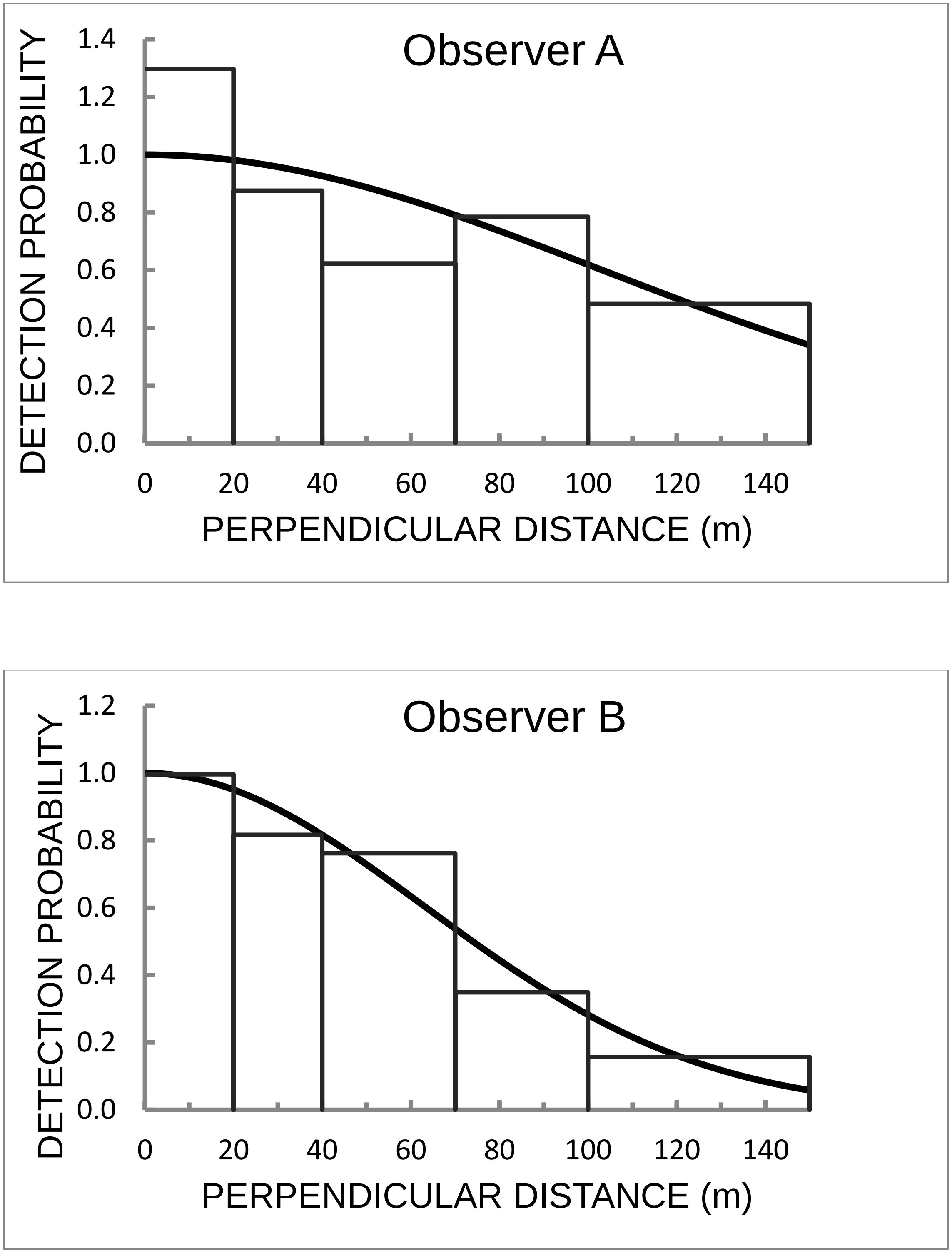

Fig. 7. The Half-normal detection function for wild horses in the survey blocks. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 with observer as a covariate (for further details regarding covariates, see Table 2).

Table 3. The encounter rates ($n/L \pm SE$) and probabilities of detecting a cluster of horses within the nominal (150 m) survey strip ($P_a \pm SE$) for the surveys conducted in 2022 in the four survey blocks.

Survey block	n/L	P_a
Northern Kosciuszko	0.43 ± 0.05	0.61 ± 0.02
Snowy Plains	0.20 ± 0.04	0.57 ± 0.05
Cabramurra	–	–
Southern Kosciuszko	0.19 ±0.04	0.56 ± 0.04

While P_a is required as part of the estimation process (see eqn. 1), it can be viewed as indicators of the interaction between the subjects of the survey, the landscape they occupy and the observers and conditions on the survey platform. Like the encounter rate, this parameter has some comparative value. The probability (P_a) that a cluster of horses in the survey strip will be detected was marginally higher for the Northern Kosciusko than it was for the Snowy Plains and Southern Kosciuszko blocks (Table 3). This is a reversal of the situation that was found with the 2020 survey where P_a was found to be some 30-40% higher for the Southern Kosciuszko block than it was for the Northern Kosciuszko and Snowy Plains blocks (Cairns 2020b). The change from a post-drought, post-bushfire landscape in 2020 to one that has been enhanced by substantial rainfall in the period leading up to the present survey might have had some influence on this apparent shift in detectability in the Southern Kosciuszko block. It is important, where possible, to be able to model survey- and location-specific detection functions. Although this was not specifically done in relation to this survey, the use of stratification in relation to fitting a global detection function partially achieves this aim.

As well as P_a, another parameter determined from the survey data that is required for density estimation is an estimate of the expected (mean) cluster size ($\hat{E}(c)$ – see eqn. 1). Details regarding the determination of this parameter are given in Table 4. The overall size range of the clusters counted was 1-30, with, in most instances, larger groups being encountered wider out on the survey strip, at distances >70 m. In relation to this, size bias was found in the estimation of cluster size across the transect width in both the Northern Kosciuszko and Snowy Plains blocks (P <0.15). For these two survey blocks an expected value of cluster size based on the relationship between observed cluster size and the estimated probability of detection ($g(x)$) was used to estimate density instead of the mean cluster size (see Section 3.2). This was not the case for the Southern Kosciuszko block where the mean cluster size was used as the expected cluster size (Table 4). Although some large clusters of horses were observed, the expected cluster sizes across all survey blocks were in the range 3.66-4.36 horses. The relationship between cluster size and detectability was the same in 2020 and 2022. However, cluster sizes in the 2020 survey were in the wider range of 1.25-4.41 horses (Cairns 2020b), with the smaller cluster size of the range occurring in the Southern Kosciuszko block. In relation to this, it needs to be noted here that these clusters are defined by the distance bins used in the survey process and are general measures of aggregation. They do not necessarily represent social groupings, although that might be the case with larger clusters observed wide on the survey strip.

Table 4. The expected sizes ($E(c) \pm SE$) of the clusters of horses counted on the survey transects with each of the four survey blocks. Given along with the estimates of $E(c)$ are the size ranges of the clusters sighted, the correlation coefficient (r) and the P-values for the assessment of the significance of the linear relationship between $ln(c)$ and estimated $g(x)$. Where P < 0.15, $E(c)$ was adjusted for size bias in cluster detection. For further details, see text.

Survey block	$E(c)$	Range	r	P-value
Northern Kosciuszko	4.36 ± 0.25	1 – 30	-0.262	<0.001
Snowy Plain	3.67 ± 0.32	1 – 12	-0.298	0.021
Cabramurra	–	–	–	–
Southern Kosciuszko	4.06 ± 0.31	1 – 11	0.118	0.857

The densities of clusters of horses and the corresponding population densities in each survey block are given in Table 5. The corresponding estimates of population abundance are given in Table 6. Across the four survey blocks, there was estimated to be a total population of 18,814 (14,501-23,535) horses which was equivalent to an average density of 7.03 km^{-2}. This density estimate was for the total area surveyed, including the Cabramurra block, in which no horses were detected.

Table 5. Results of the helicopter line transect surveys of wild horses conducted in the four survey blocks in November, 2022. Given for each block is the number of clusters of horses detected (n), the estimated density of clusters of horses (D_c) and the horse population density (D) along with their 95% bootstrap confidence intervals and coefficients of variation (cv%). Note that there were no horses detected in the survey of the Cabramurra block.

Survey block	n	Cluster density (km^{-2})			Population density (km^{-2})		
		D_c	95% confidence interval	cv (%)	D	95% confidence interval	cv (%)
Northern Kosciuszko	288	2.38	1.75 – 3.02	13.5	10.39	7.63 – 13.20	14.0
Snowy Plains	47	1.19	0.66 – 1.95	27.9	4.38	2.13 – 7.59	32.3
Cabramurra	–	–	–	–	–	–	–
Southern Kosciuszko	84	1.15	0.72 – 1.68	29.5	4.66	2.60 – 7.32	26.7
Kosciuszko NP	419	1.66	1.32 – 2.04	11.4	7.03	5.42 – 8.80	12.4

Table 6. The population estimates (N) for each of the survey blocks. Given along with these estimates of abundance are their 95% bootstrap confidence intervals and coefficients of variation (CV %). Given also are the areas surveyed, including the total area of the four blocks.

Survey block	Area (km^2)	N	95% confidence interval	cv %
Northern Kosciuszko	1,229	12,774	9,379 – 16,862	14.0
Snowy Plain	161	705	343 – 1,222	32.3
Cabramurra	139	–	–	–
Southern Kosciuszko	1,146	5,335	2,979 – 8,384	26.7
Kosciuszko NP	2,675	18,814	14,501 – 23,535	12.4

Over the past 14 years, three surveys similar to the present one have been conducted throughout the park (Dawson 2009; Cairns 2019; Cairns 2020b). Of these, the one survey that is of most immediate relevance here is the one conducted in the spring of 2020 over the four survey blocks that were used in the present survey (Cairns 2020b). A direct comparison can be made between the results of that survey and the present one, both on an overall basis and between survey blocks.

From the 2020 survey was that total population of horses in the four blocks surveyed was estimated to be 14,381 (95% CI: 8,798-22,555), which was equivalent to an average density of 5.38 km^{-2} (Cairns 2020b). This population estimate and that from the present (2022) survey were compared using the method given in Buckland *et al.* (2001, pp 84-86). While there appeared to be an increase in the size of the total population over the two years between these successive surveys, this increase proved not to be statistically significant ($z = 1.06$; $P = 0.289$). Although there was no overall difference between the total population estimates obtained from this and the previous survey, further comparisons can be made between the population estimates for each survey block in order to assess possible population changes at a finer scale.

The highest density of horses was in the Northern Kosciuszko block, where it was more than twice the density estimates for the other two survey blocks in which horses were detected (Table 5). This is similar to the findings of the previous surveys which were conducted either within these four survey blocks (Cairns 2020b), or within the general vicinities of these blocks (Dawson 2009: Cairns 2019).

In the present survey, the population in the Northern Kosciuszko block was found to comprise in excess of 68% of the total number of horses estimated in all four blocks combined (Table 6). In 2020, this proportion was much higher at 85% (Cairns 2020b), which suggests that some proportional change may have occurred in numbers among the four survey blocks since the 2020 survey. However, the population in the Northern Kosciuszko block had remained essentially unchanged over the last two years; being estimated to be 12,511 (7,111-20,761) in 2020 and 12,774 (9,379-16,862) in 2022 ($z = 0.07$; $P = 0.944$). As well as this, numbers in the Snowy Plains block also remained essentially unchanged over the two years between surveys, being estimated to 436

(176-851) in 2020 and 705 (343-1,222) in 2022 ($z = 0.95$; $P = 0.342$). However, where a change in numbers had occurred at this finer scale was in the Southern Kosciuszko block. In this block, the population had increased substantially in size from an estimated 1,433 (949-2,038) in 2020 to an estimated 5,335 (2,979-8,384) in 2022 (z = 0.2.60; $P = 0.009$). While there was a significant change in the number of horses in the Southern Kosciuszko, there was no significant change in the total population. This is likely due to the dominance of the large population in the Northern Kosciuszko block as a component of the total population in both 2020 and 2022.

To draw some inferences regarding what is happening in terms of changes in horse numbers in the park, some discussion can be directed at what is happening in the north of the park. Conducting surveys in the northern parts of Kosciuszko NP (Fig. 1) has been a common practice with regard to attempts to estimate the size of the wild horse population in the Australian Alps (Dawson 2009; Cairns 2019). In terms of encounters, only 26 clusters of horses were sighted in north Kosciuszko in 2009, although it needs to be noted these sightings were made on only one side of the aircraft (Dawson 2009), so it could possibly have been higher if an observer on either side of the aircraft had been used. In 2014, 104 clusters were sighted in the north Kosciuszko block that was surveyed. This number increased to 269 clusters when the same block was surveyed in 2019 (Cairns 2019). The density of the horse population has increased accordingly over the ten-year period from 2009 to 2019. Between the 2014 and 2019 surveys, density of the horse population in the block that was surveyed increased substantially from 2.38 km^{-2} to 11.48 km^{-2} ($z = 4.12$; $P < 0.001$; Cairns 2019).

The block surveyed in 2014 and 2019 in north Kosciuszko was 1,366 km^2 in area and overlapped with the Northern Kosciusko block surveyed in 2020 and 2022, which is 1,229 km^2 in area. Given this, a cautious but useful exercise that can be undertaken is to compare the current estimated density of horses in the Northern Kosciuszko block with the density estimate obtained for north Kosciuszko in 2019. In 2020, 164 clusters of horses were observed and the density of wild horses was estimated to be 10.18 km^{-2}, which was found not to be different from the density estimate for the region of 11.48 km^{-2} obtained in 2019 ($z = 0.40$; $P = 0.689$). This could be interpreted as meaning that there have been no discernible changes in the wild horse population in the north of Kosciuszko NP between 2019 and 2020, nor between 2020 and 2022.

The situation in the south of the park is a little more complicated to interpret. In 2014 and 2019, surveys were conducted over a large area identified as the Byadbo-Victoria block which comprised an area of 3,237 km^2 that straddled the NSW-Victoria border. In 2014, there were 159 clusters of horses observed during the survey of this large block. In 2019, there were 157 clusters of horses observed in this block. These detections translated into two substantially and significantly different densities of horses: 1.33 km^{-2} in 2014 and 2.63 km^{-2} in 2019 ($z = 2.41$; $P = 0.008$). The density of horses in the Southern Kosciuszko block, which overlaps with the northern (NSW) part of the Byadbo-Victoria block, was found to have substantially increased from 1.25 km^{-2} in 2020 to 4.66 km^{-2} in 2022 ($z = 0.2.60$; $P = 0.009$). Direct comparisons cannot be made here between the population surveyed in the Southern Kosciuszko block in 2020 and 2022, and that surveyed in the Byadbo-Victoria block in 2014 and 2019. A possible explanation for these apparent sharp increases and decreases in numbers that are occurring over relatively short periods of time could be movement of horses within the broader southern Kosciuszko region as well as the normal demographic processes of recruitment and mortality.

During the conduct of this survey, as was done in the 2020 survey, the observers counted the numbers of foals within the observational clusters of horses recorded in the distance categories of the survey strip. The reason for this was so the counts of foals and the counts of adult horses could be analysed separately to determine an index of recruitment; i.e., a foal-adult ratio. This is an index similar to the fawn-doe ratio that is commonly used in deer management in North America (Pierce, Sumners & Finn 2012). These data were analysed using the methods outlined in Section 3.2.

In terms of detection functions, the most parsimonious (specific) model for both adult horses and foals was of the same form as that determined for all horses, a model derived using the MCDS analysis engine that has a Half-normal key function and incorporates additional covariate of observer. The probability of detection of foals on the survey strip was 0.51-0.57, the same as it was for the 2020 survey. For adult horses, P_a was 0.56-0.61, essentially the same as it was for adults and foals combined (Table 3).

The results of these analyses are given in Table 7. The estimated densities of adult horses in the three survey blocks were slightly less but broadly comparable to those determined for all horses (Table 5). The densities of foals were, of course, lower and somewhat less precise, with somewhat high coefficients of variations.

Across all four blocks, the foal-adult ratio was 0.191, ranging from 0.180 in the Snowy Plains block to 0.213 in the Southern Kosciuszko block (Table 7). This overall foal-adult ratio was significantly higher than the ratio of 0.102 estimated from the results of the 2020 survey ($z = 21.44$; $P < 0.001$). This was also the case when the ratios for all three survey blocks on which horses were detected were compared ($P < 0.001$), in particular the Southern Kosciuszko block for which the ratio was 0.075 in 2020 and 0.213 in 2022. Overall, these figures suggest that the level of recruitment in 2022 was almost twice as high as it was in 2020.

According to Dawson (2002), the average birth rate of foals in wild horses in the Australian Alps is 0.26 female foals per mare per year. Further, according to Dawson (2002), approximately 75% of the female population is likely to be mature adults. If a sex ratio of parity is assumed for the current horse population in, for instance, the Northern Kosciuszko survey block, then using the above estimated proportion of mature females in a population and double the fecundity rate for the production of both male and female offspring, gives an estimate of the number of foals in that population that is approximately 20% higher than the number determined from the density given in Table 7. Repeating this exercise with the results of the 2020 survey, the estimate of the number of foals determined using the information given in Dawson (2002) is almost twice that of the number estimated from the survey results. The discrepancy between using Dawson's (2002) fecundity rate and the survey data is possibly due to factors such as perinatal mortality of foals, differing population age structure and sex ratio, different birth rates and different timing of foaling.

Table 7. The foal-adult ratios for the four survey blocks in November, 2022. Given for each block is the numbers of clusters of adult horses and foals detected (n), respectively, and the estimated densities of adults horses and foals (D) along with their 95% bootstrap confidence intervals and coefficients of variation (cv%).

Survey block	Adult horses				Foals				Foal- adult ratio
	n	D	95% confidence interval	cv (%)	n	D	95% confidence interval	cv (%)	
Northern Kosciuszko	288	9.06	6.63 – 11.45	13.9	104	1.66	1.16 – 2.11	14.4	0.183
Snowy Plains	47	3.66	1.65 – 6.51	33.0	17	0.66	0.26 – 1.15	37.4	0.180
Cabramurra	–	–	–	–		–	–	–	–
Southern Kosciuszko	84	3.90	2.30 – 6.20	25.1	33	0.83	0.34 – 1.50	36.0	0.213
Total	419	6.06	4.62 – 7.58	12.5	154	1.16	0.79 – 1.52	16.3	0.191

These aerial surveys were designed with the intention of providing realistic and reasonably precise population estimates of wild horses in four survey blocks. For all the three survey blocks where horses were detected, the precision of the estimates as indicated by the coefficients of variation were generally near to the target level of precision. The level of precision for the Northern Kosciuszko and the Snowy Plains block exceeded the target which resulted in a high overall level of precision for the survey as a whole (Table 5). Although acceptable, the attained level of precision for the Southern Kosciuszko block was lower than the target.

Further, regarding the conduct of the surveys and the associated data analysis, two comments are warranted. The first is that ancillary data were collected for use as covariates in analyses using the MCDS analysis engine in DISTANCE. These were static data associated with the survey platform and dynamic data associated with the conduct of particular survey sessions. The static data comprised the observers used and the survey aspect (northerly or southern) associated with the detection of a cluster of horses. The dynamic data were cloud cover and habitat cover at point-of-detection. Of these covariates, observer proved to strong influencing factor (Table 2). Observer was also used as a detection function model covariate in relation to the 2020 survey (Cairns 2020b). In relation to previous survey, (Cairns 2014, 2019) observer and another covariate, habitat cover at point-of-detection, were strong competing covariates in the model selection process.

As acceptable as conventional distance sampling of the form used here is considered to be, there is always the possibility that population estimates produced using it could be underestimates. Laake, Dawson & Hone (2008) found that estimates of wild horse numbers determined using CDS analysis could be biased low because the assumption of certain probability of detection on the transect centreline ($P_0 = 1.00$; Buckland *et al.* 2001) is not true, i.e. $P_0 < 1.00$. Laake, Dawson & Hone (2008) suggested that analysing their small data set using CDS analysis resulted in a substantial underestimation of numbers because the value of P_0 determined using mark-recapture distance sampling (MRDS) was found to be some 25% below the assumed value of P_0 (= 1.00) used in CDS and MCDS analyses. Contrary to this, however, in analyses of thermal imagery surveys conducted on the wild horse population in Barmah NP (Victoria), MRDS estimated that the values of P_0 were equal to, or near to 1.00 (Cairns 2019b). In relation to this, the population estimates obtained from the present surveys may be underestimates, but not seriously so.

In conducting aerial surveys of wild horses, a case could be made for double-counting and analysing the results obtained using the MRDS analysis engine. However, the requirement that an Air Safety Observer occupy the seat next to the pilot precludes configuring the aircraft for double-counting unless a single larger aircraft that allowed tandem seating or two aircraft flying in tandem were used.

5. Other Species

Apart from horses, and excepting macropods, some other species of large herbivores were counted during the surveys. These included feral pigs and introduced deer. There were eight clusters of pigs sighted across all four survey blocks, which amounted to a raw count of 28 pigs. Because of the low number of sightings, no useful analysis could be undertaken using these data. Seventy-one clusters of deer which amounted to a raw count of 212 individuals were sighted across the four survey blocks. Most of these deer were detected in the southern survey block within Kosciuszko NP. Although these deer were not identified to species, it is thought, based on some local knowledge (S. Seymour and G. Robertson, pers. com.), that they were mostly sambar deer (*Rusa unicolor*), with some fallow deer (*Dama dama*) also being sighted.

The counts of deer were analysed using the CDS and MCDS analysis engines of DISTANCE 7.3, with a global detection function being fitted using all detections. Four detection function models were tested using the CDS analysis engine, while two, in association with three covariates, were tested using the MCDS analysis engine. The possible influence of cluster size on detection was also tested as part of the modelling process. For full detail on the analyse protocol, see Section 3.2. The analysis was stratified on the basis of the four survey blocks.

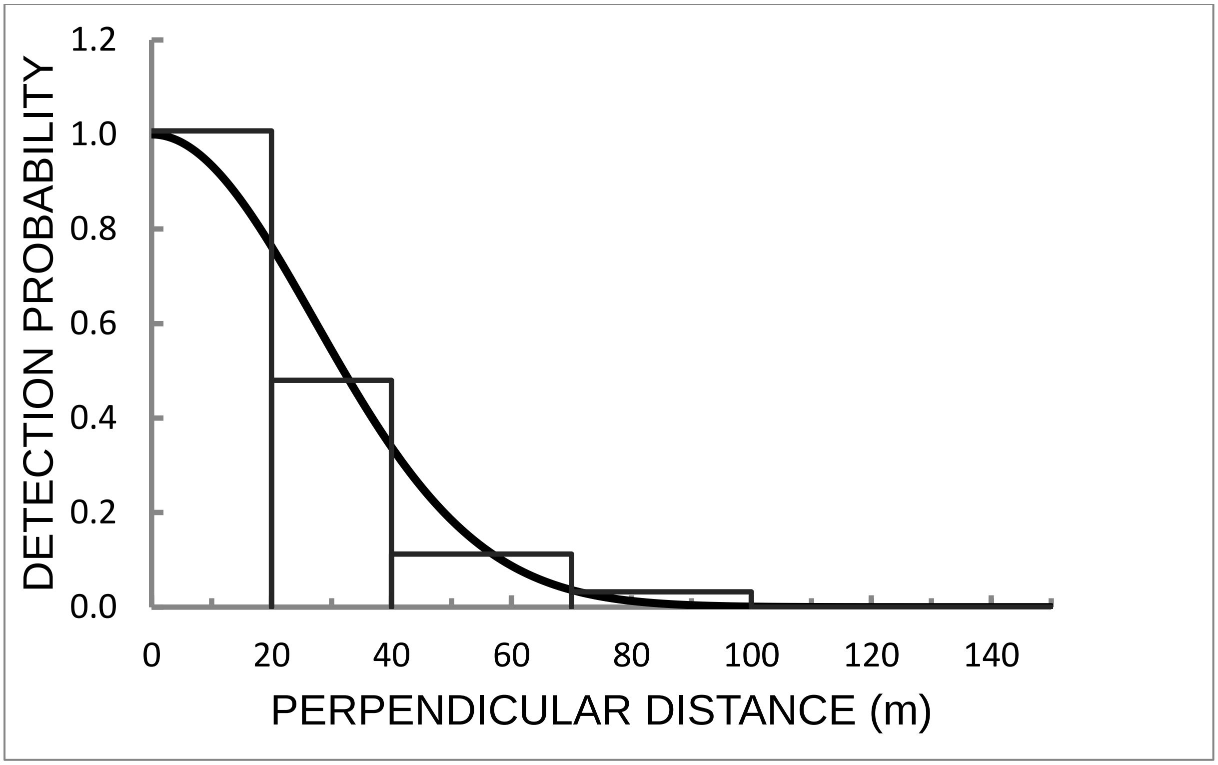

Fig. 8. The Half-normal detection function for deer in the survey, 2022. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details regarding covariates, see text).

For the analysis of the survey results, the most parsimonious global detection function was a Half-normal model (Fig. 8). The value for the probability of detection (P_a) was 0.23, which was considerably lower than the probabilities of detection for horses in this survey (Table 3). This may well be related to deer being smaller and somewhat more cryptic in the landscape than are horses.

The population densities and abundances of deer in the four survey blocks are given in Table 8. In terms of numbers, there was a strong north to south increasing trend in density across the park. Precision of estimation was rather poor in all survey blocks except for the South Kosciuszko block. This is no doubt associated with the low encounter rate (n/L ≤0.10) for deer compared with horses (Table 3).

Table 8. Results of the helicopter line transect surveys of introduced deer conducted in the four survey blocks in November, 2022. Given for each survey block are the population density (D) and abundance (N). Given in association with the two estimates are the empirically-estimated and bootstrap-estimated coefficients of variation (cv %), and the bootstrap confidence intervals.

Survey block	Deer population density (km^{-2})			Deer population abundance	
	D	95% bootstrap confidence interval	cv_{boot} (%)	N	95% bootstrap confidence interval
Northern Kosciuszko	0.27	0.06-0.62	49.6	344	76-801
Snowy Plains	1.52	0.58-3.51	46.5	245	77-458
Cabramurra	3.82	0.74-7.11	48.4	531	102-989
Southern Kosciuszko	4.54	2.27-6.91	28.6	5,202	2,597-7,916
Kosciuszko NP	2.30	1.32-3.44	25.3	6,323	3,624-9,454

Compared with the unpublished results of a survey conducted in late spring 2020 when the deer population in the park was estimated to be 2,565 (95% CI: 1,717-3,842), the population of 6,323 (95% CI: 3,624-9,454) deer estimated from the present survey represents a substantial and significant 2.5X increase in numbers ($z = 2.50$; $P < 0.012$).

6. Acknowledgements

The success or failure of exercises such as these depend so much the abilities of the observers. Thanks goes to the two experienced observers used for this survey. Thanks also goes to those who provided invaluable GIS support as well as logistical and flight planning support. Regarding the flight crews, I would like to thank them for a safe execution of what turned out to be a survey that was flown at times over some difficult terrain and occasionally interrupted by the vagaries of the weather.

7. References

Borchers, D. & Burnham, K. (2004). General formulation for distance sampling. In: Advanced Distance Sampling (eds. S. T. Buckland, D. A. Anderson, K. P. Burnham, J. L. Laake and L. Thomas). OUP, Oxford. Pp. 6-30.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L. & Thomas, L. (2001). *Introduction to Distance Sampling: Estimating abundance of biological populations*. Oxford University Press, Oxford.

Burnham, K. P & Anderson, D. A. (2002). *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*. Springer, New York.

Burnham, K. P., Anderson, D. R. and Laake, J. L. (1980). Estimation of density from line transect sampling of biological populations. *Wildlife Monographs* **72**: 1-202.

Burnham, K. P., Buckland, S. T., Laake, J. T., Borchers, D. L., Marques, T. A., Bishop, J. R. B. and Thomas, L. (2004). Further topics in distance sampling. In: *Advanced Distance Sampling* (eds. S. T. Buckland, D. A. Anderson, K. P. Burnham, J. L. Laake and L. Thomas). OUP, Oxford. Pp. 307-392.

Cairns, S.C. (2014). *Feral Horses in the Australian Alps: the Design and Analysis of Surveys Conducted in April-May, 2014.* A report to the Australian Alps Liaison Committee, September, 2014. 58 pp.

Cairns, S. C. (2019a). *Feral Horses in The Australian Alps: the Analysis of Aerial Surveys Conducted in April-May, 2014 and April-May, 2019.* A report to the Australian Alps Liaison Committee, September 2019. 51 pp.

Cairns, S. C. (2019b). *Analysis of the 2017 and 2018 aerial surveys of the feral horse population in the Barmah National, Victoria.* A report to the Parks Victoria. 18 pp.

Cairns, S. C. (2020a). *The Design of a Survey of Feral Horses in the Kosciuszko National Park.* A report to New South Wales National Parks and Wildlife Service, October 2020. 20 pp.

Cairns, S. C. (2020b). *The Results of a Survey of the Feral Horse Populations in the Kosciuszko National Park, October-November, 2020*. A report to New South Wales National Parks and Wildlife Service, November 2020. 29 pp.

Dawson, M. J. (2009). *2009 aerial survey of feral horses in the Australian Alps.* A report to the Australian Alps Liaison Committee. 20 pp.

Laake, J., Dawson (nee Walter) M. and Hone, J. (2008). Visibility bias in aerial survey: mark–recapture, line-transect or both? *Wildlife Research* **35**: 299-309.

Linklater, W., and Cameron, E., (2002). Escape behaviour of feral horses during a helicopter count. *Wildlife Research* **29**: 221-224.

Marques, F. F. C. and Buckland, S. T. (2004). Covariate models for detection function. In: *Advanced Distance Sampling* (eds. S. T. Buckland, D. A. Anderson, K. P. Burnham, J. L. Laake and L. Thomas). OUP, Oxford. Pp. 31-47.

Montague-Drake, R. (2004). *A Pilot Study Examining the Accuracy and Precision of Different Aerial Survey Techniques to Monitor Wild Horse Densities and Abundance in Bago and Maragle State Forests*. A Report to NSW State Forests. 68 pp.

Pierce, R. A. II, Summers, J. & Finn, E. (2012). *Estimating Deer Populations on Your Property: Population Dynamics.* University of Missouri Extension. Retrieved in December 2022 from https://extension.missouri.edu/publications/g9488

Southwell, C. J. and Weaver, K. E. (1993). Evaluation of analytical procedures for density estimation from line-transect sampling data: data grouping, data truncation and the unit of analysis. *Wildlife Research* **20**: 433-444.

Thomas, L., Buckland, S., Burnham, K., Anderson, D., Laake, J., Borchers, D. and Stringberg, S. (2002). Distance sampling. In: Encyclopedia of Environmentrics (eds. A. H. El-Shaarawi and W. W. Piegorsch). Volume 1, pp. 544-552.

Thomas, L., Buckland, S. T., Rexstad, E. A., Laake, J. L., Strinberg, S., Hedley, S. L., Bishop, J. R. B., Marques, T. A. and Burnham, K. P. (2010). Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* **47**: 5-14.

Walter, M. (2002). *The population ecology of wild horses in the Australian Alps*. Ph.D. thesis, University of Canberra. 179 pp.

Walter, M. (2003). The effect of fire on wild horses in the Australian Alps. A report to the Australian Alps Liaison Committee.