A survey of the wild horse population in Kosciuszko National Park, October 2023

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Abstract

1. Aerial surveys of the feral horse populations in the Australian Alps National Parks and adjacent State forests have been conducted periodically over the past two decades. The most recent of these surveys were conducted in four survey blocks within the Kosciuszko National Park in October-November 2020, November 2022 and October 2023. The latest of these three surveys is reported on here.
2. Surveys were designed using the automated survey design engine of DISTANCE 7.5, and were conducted using helicopter line transect sampling. The data were analysed using DISTANCE 7.5.
3. A total of 1,948 km of transect was surveyed using a helicopter flown at a ground speed of 93 km^{-1} (50 kts) and a height of 61 m (200 ft). Two observers occupied the rear seats 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. A total of 416 clusters of horses were sighted in four survey blocks.
4. Key to analysing data of the form recorded here is the modelling of the detection of horses in the survey strip. To this end, a single global detection function was fitted to the data. This model was used in the estimation of horse population densities and abundances in the four survey blocks.
5. The population densities of horses in the survey blocks were estimated to be in the range 0.35-10.75 km^{-2}; the overall density for all blocks combined being 6.50 km^{-2}. This compared to an overall density of 7.03 km^{-2} estimated from a previous survey conducted in 2022.
6. The estimated total number of horses in the four survey blocks with total area of 2,675 km^2 was 17,393 (95% CI: 12,797-21,760). This compared to an overall population abundance of 18,814 (95% CI: 14,501-23,535) estimated from the survey conducted in 2022. There was no significant change in total population abundance between 2022 and 2023.
7. A foal-adult ratio of 0.178 was determined from the survey data from all four survey blocks as an indicator of population recruitment. This foal-adult ratio was not significantly different from the ratio of 0.191 determined from the results of the survey conducted in 2022.

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1. Introduction

The Australian Alps National Parks (AANP) is a broad region containing a number of discrete, but often contiguous, national parks and nature reserves that extend along the Great Dividing Range in southern New South Wales (NSW), eastern Victoria and the Australian Capital Territory (ACT) (https://theaustralianalps.wordpress.com/). Six of these reserves are administered by Parks Victoria, four are administered by the NSW National Parks and Wildlife Service (NPWS), and two are administered by the ACT Parks and Conservation Service (https://theaustralianalps.wordpress.com/the-alps-partnership/the-parks/). The Kosciuszko National Park (NP) is that part of the larger AANP estate that is wholly within NSW.

Found within the boundaries of the Kosciuszko NP is a population of wild horses (*Equus caballus*) occupying a number of distinct areas within the park. As part of the development and execution of evolving plans to manage these horse populations, a number of population surveys have been undertaken under the combined auspices of the Australian Alps National Parks Cooperative Management Program (AANPCMP) and separately by the NSW National Parks and Wildlife Service (NPWS) and Parks Victoria. To this end, there is a substantial history of monitoring the wild horse populations within the broader AANP.

In the recent past, 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 area which encompassed both national parks and adjacent areas of state forest, was designed and carried out in April-May 2014 (Cairns 2014, 2019). The timing of this survey and the decision to expand the survey area covered was in response to recommendations made by Dawson (2009). The 2014 survey was essentially replicated five years later in April-May 2019 (Cairns 2019). From this survey it was determined that the horse population in the areas surveyed had increased in size by more than 175% over the intervening five-year period, or 22.5% per annum over the period between surveys.

Further to the outcome of the 2019 survey (Cairns 2019), the NSW NPWS decided to undertake a follow-up survey in 2020 in sections of the Kosciuszko NP where horses were known to exist. 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 severely disturbed in the 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 areas that were identified as the Northern Kosciuszko, Snowy Plains, Cabramurra and Southern Kosciuszko survey 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 outcome of the survey, which was conducted in October-November, 2020, is reported in Cairns (2020b). A second survey was conducted in these survey blocks in November 2022. This survey was of the same form as the one conducted in 2020, the only difference being that, although the general survey design and survey methodology were the same, the survey effort on two of the survey blocks was increased in an attempt to improve survey precision. The design, execution and results of this survey are reported in Cairns (2022).

A further survey was undertaken in October, 2023. This survey was essentially a repeat of the two previous surveys, the difference being that there were some changes made to the survey design, again with the aim of improving survey precision. Reported on here are the survey design, the description of the sampling and data analysis methods used, along with the results obtained from the conduct of the survey. In addition to the horse survey, the population of other feral animal species was also surveyed at the same time. An analysis of the survey result for one of these animals, feral deer, is also included.

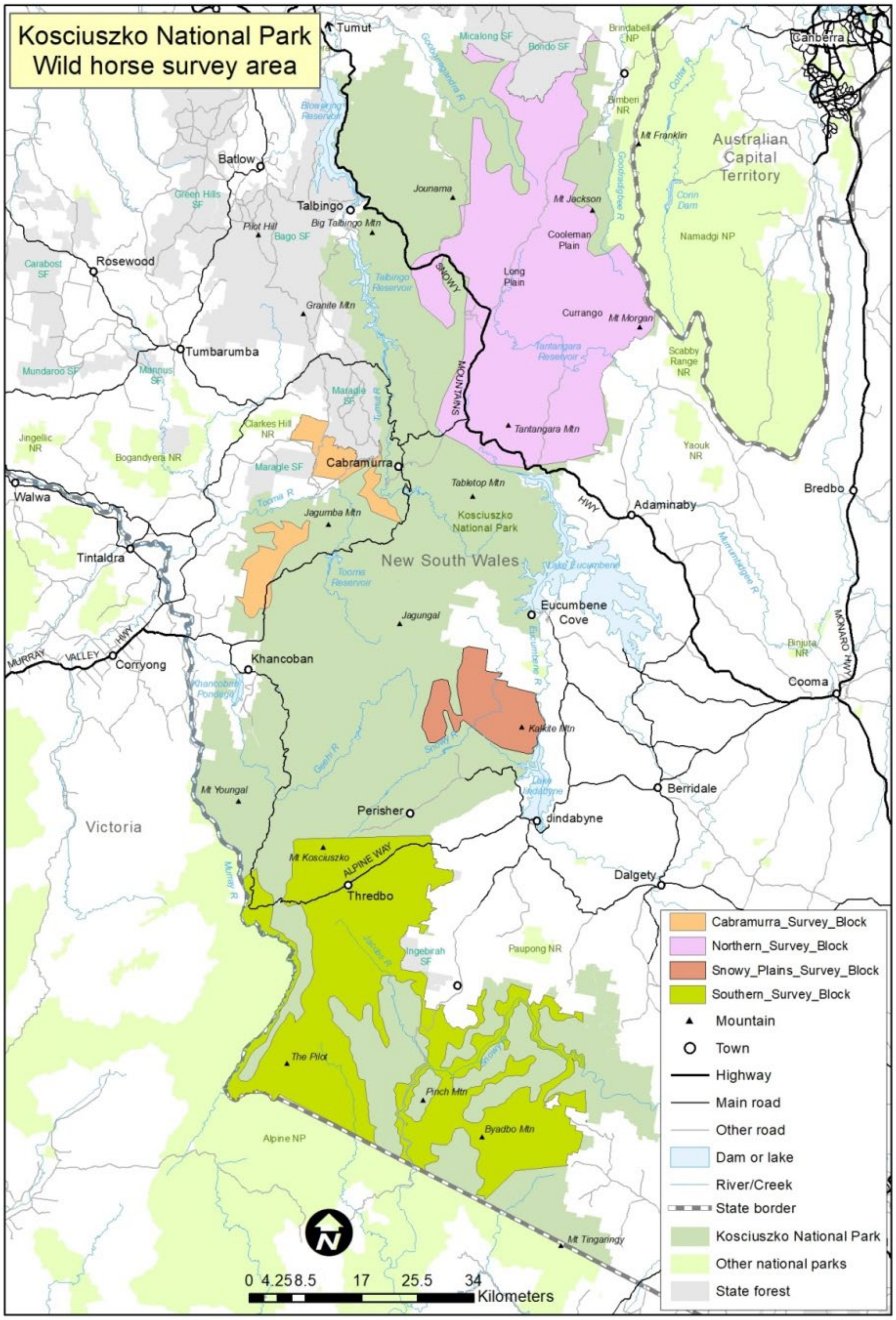

Fig. 1. The wild horse population survey blocks in the Kosciuszko NP. To identify each block, see the legend in the bottom right-hand corner of the figure.

2. Study Area and Survey Design

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

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 7.5 (http://distancesampling.org/Distance/#download-latest-version). These surveys were designed with the aim of broadly achieving levels of survey precision ranging from better than 20% in relation to the two large survey blocks, which are known historically to support relatively large horse populations, and 25% and 40%, respectively, in relation to the two smaller survey blocks, the Cabramurra and the Snowy Plains blocks. In relation to setting these levels of survey precision, it should be noted that there were some logistical constraints. A relatively high level of precision was considered to be logistically feasible for the two larger blocks. However, only lower levels of precision were possible for the Cabramurra and Snowy Plains blocks; survey blocks that were essentially an order of magnitude smaller in area than the two larger blocks. This restricted the number of transects that could be flown in these blocks. With regard to this, attaining a relatively high level of precision was important with regard to the two larger survey blocks which, as has been shown from previous surveys (Cairns 2020b, 2022) to support >95% of the wild horses in the Kosciuszko NP. It was expected that this would generate the best overall precision for the whole study area, the four survey blocks combined.

The original design process involved the testing of the selected design against alternatives (Cairns 2020a). For previous surveys conducted in these four blocks, survey effort was determined using the method outlined in Buckland *et al.* (2001, p. 243) using information obtained from a most recent previous survey. For example, the survey effort (total transect length) for the 2022 survey conducted in the Northern

Kosciuszko block (Cairns 2022) was determined using survey effort and precision information from a survey conducted in this block in 2020 (Cairns 2020b). The survey efforts determined for the other three blocks for the 2022 survey were determined using survey effort and precision information from surveys conducted in similar areas of the Australian Alps in 2019 (Cairns 2019, 2020a).

For the Cabramurra and Snowy Plains blocks, the survey designs used were the same designs used in the 2022 survey (Cairns 2022). For the two large survey blocks, a different approach was taken to the survey design. While maintaining a systematic random sampling design, transects were placed across these survey blocks at a “saturation” level. In other words, as many transects were laid across the block in a systematic random sampling design to the extent that each adjacent transect was far enough away from the transects on either side of it to avoid the possibility of double counting horse from these adjacent transects during a survey session. The threshold distance between transects was determined as being 1.5 km to minimise the likelihood of flushing horses onto adjacent transects during the conduct of the survey (Linklater & Cameron 2002). Given this, for each of the Northern Kosciuszko and the Southern Kosciuszko blocks, systematic random sampling designs were developed that maintained a distance of 1.5 km between adjacent transects.

The details of these surveys are given in Table 1, with diagrammatic representations of them being shown in Figs. 2-5. The target levels of precision given in Table 1 for the Cabramurra and Snowy Plains blocks were pre-determined. The corresponding values given for the Northern Kosciuszko and Southern Kosciuszko blocks have been determined *post hoc* in relation to the constrained designs used.

The survey regions within each block included those parts where the relief was <20%. 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 all orientated in a northeast-southwest direction. These design layouts produced optimal coverage of the survey regions (Cairns 2020a). To visualise the relative sizes of the survey blocks, refer to Fig. 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	1,229	13*	43	794	– *
Snowy Plain	161	40	23	233	AANPCMP (2019)**
Cabramurra	139	25	34	156	AANPCMP (2019)**
Southern Kosciuszko	1,146	20*	44	765	– *

* Transects were set at a fixed distance apart of 1.5 km
**Cairns (2019)

In the two larger Northern Kosciuszko and Southern Kosciuszko blocks, adjacent transects were 1.5 km apart which would allow the sequential traversing of adjacent transects during the surveys of these two blocks. 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.

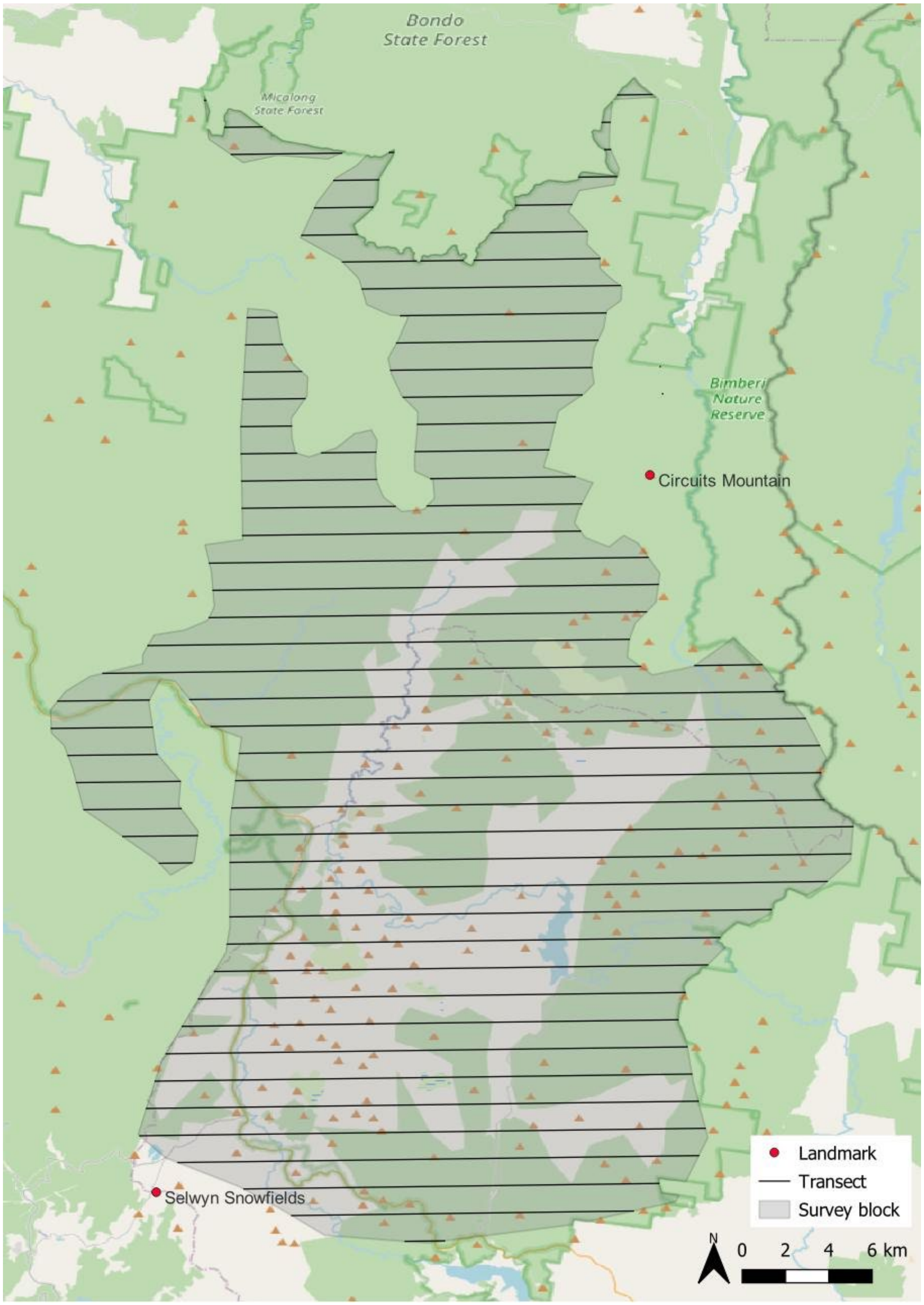

Fig. 2. The planned systematic random (parallel) survey design for the Northern Kosciusko block with an estimated survey effort of 794 km and a total trackline length of 1,015 km. High points in the landscape are indicated by the orange triangles. For the geolocation of this survey block, see Fig. 1.

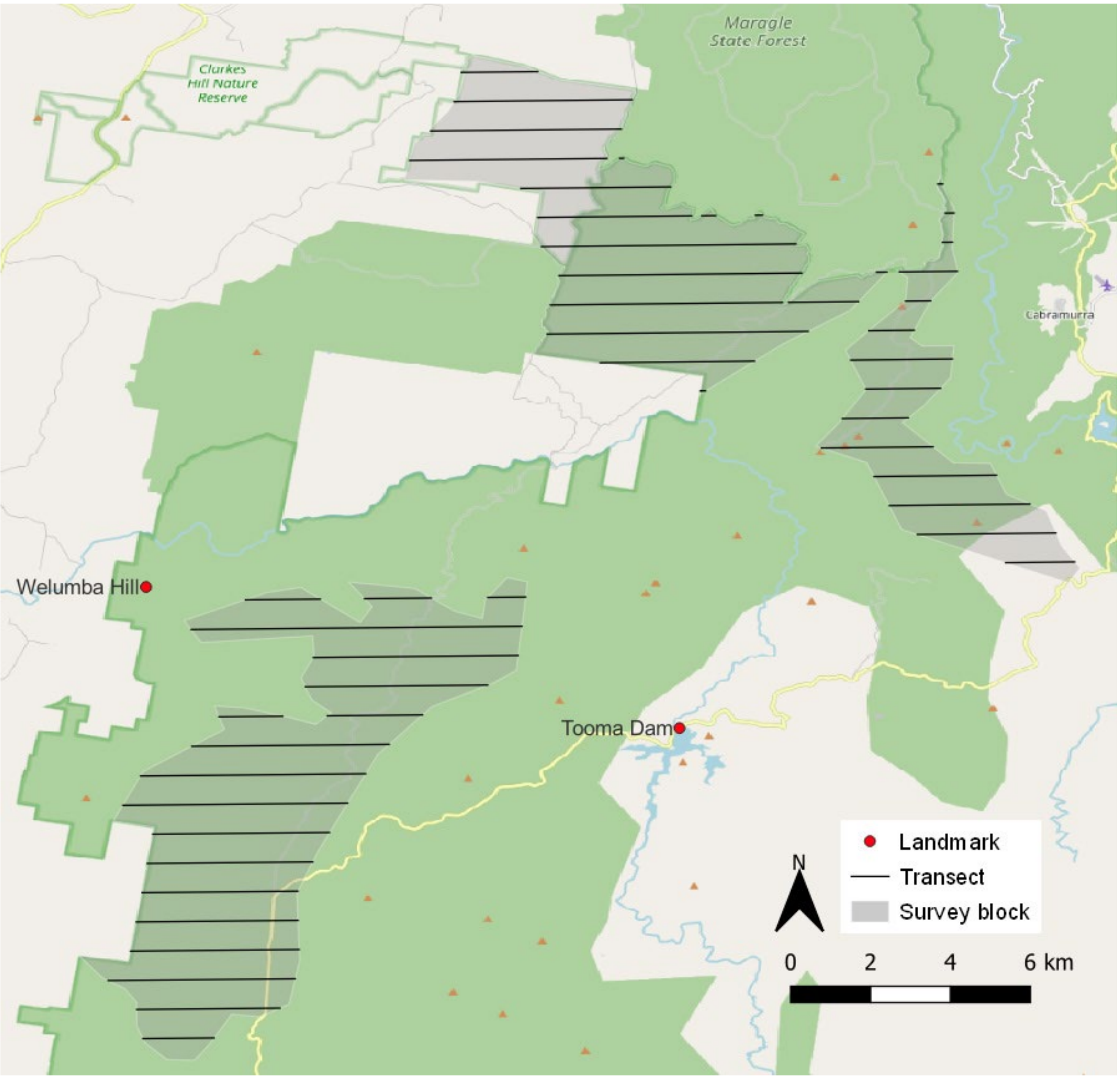

Fig. 3. The planned systematic random (parallel) survey design for the Cabramurra survey block with an estimated survey effort of 156 km and a total trackline length of 309 km. High points in the landscape are indicated by the orange triangles. For the geolocation of this survey block, see Fig. 1.

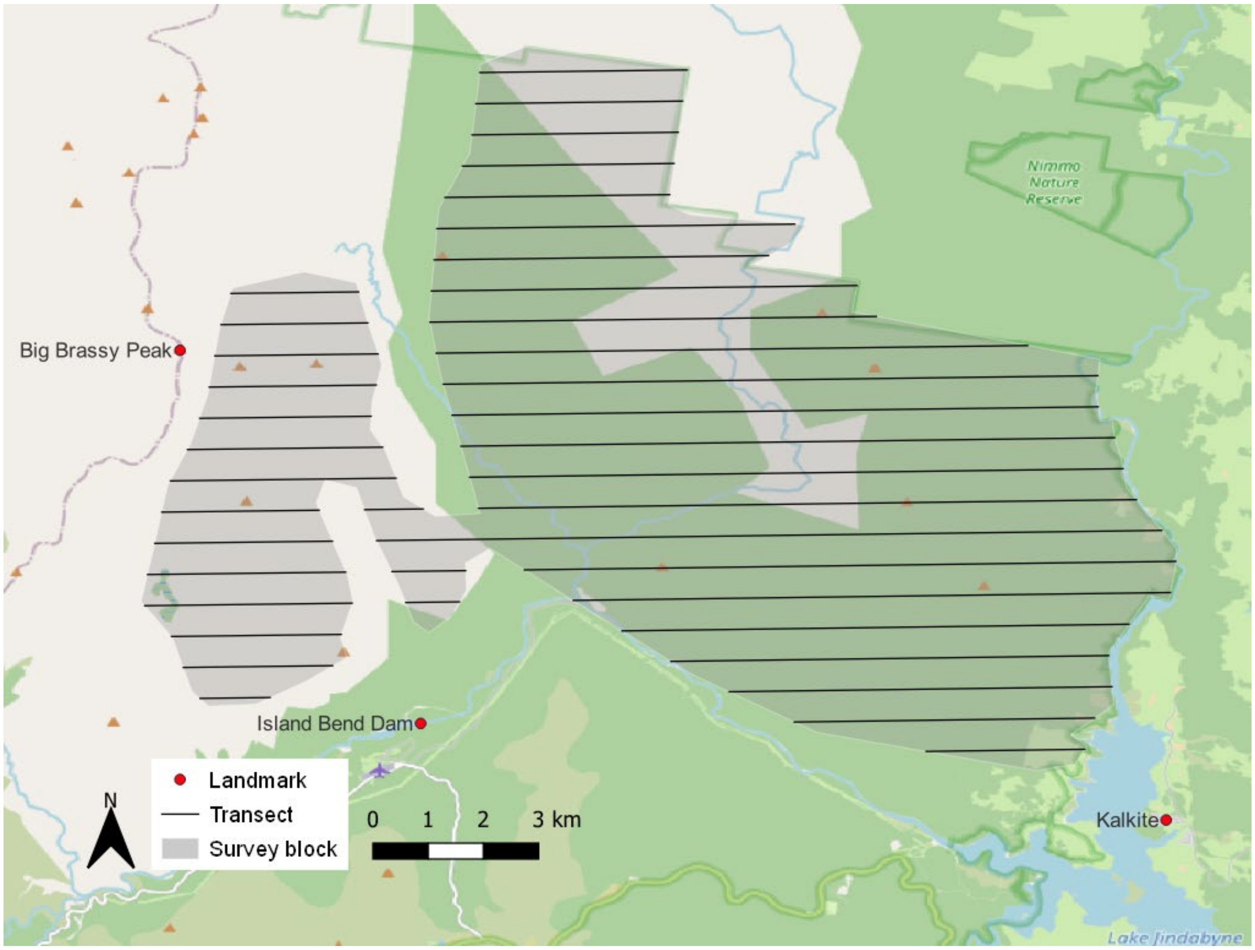

Fig. 4. The planned systematic random (parallel) survey design for the Snowy Plains survey block with an estimated survey effort of 233 km and a total trackline length of 291 km. High points in the landscape are indicated by the orange triangles. For the geolocation of this survey block, see Fig. 1.

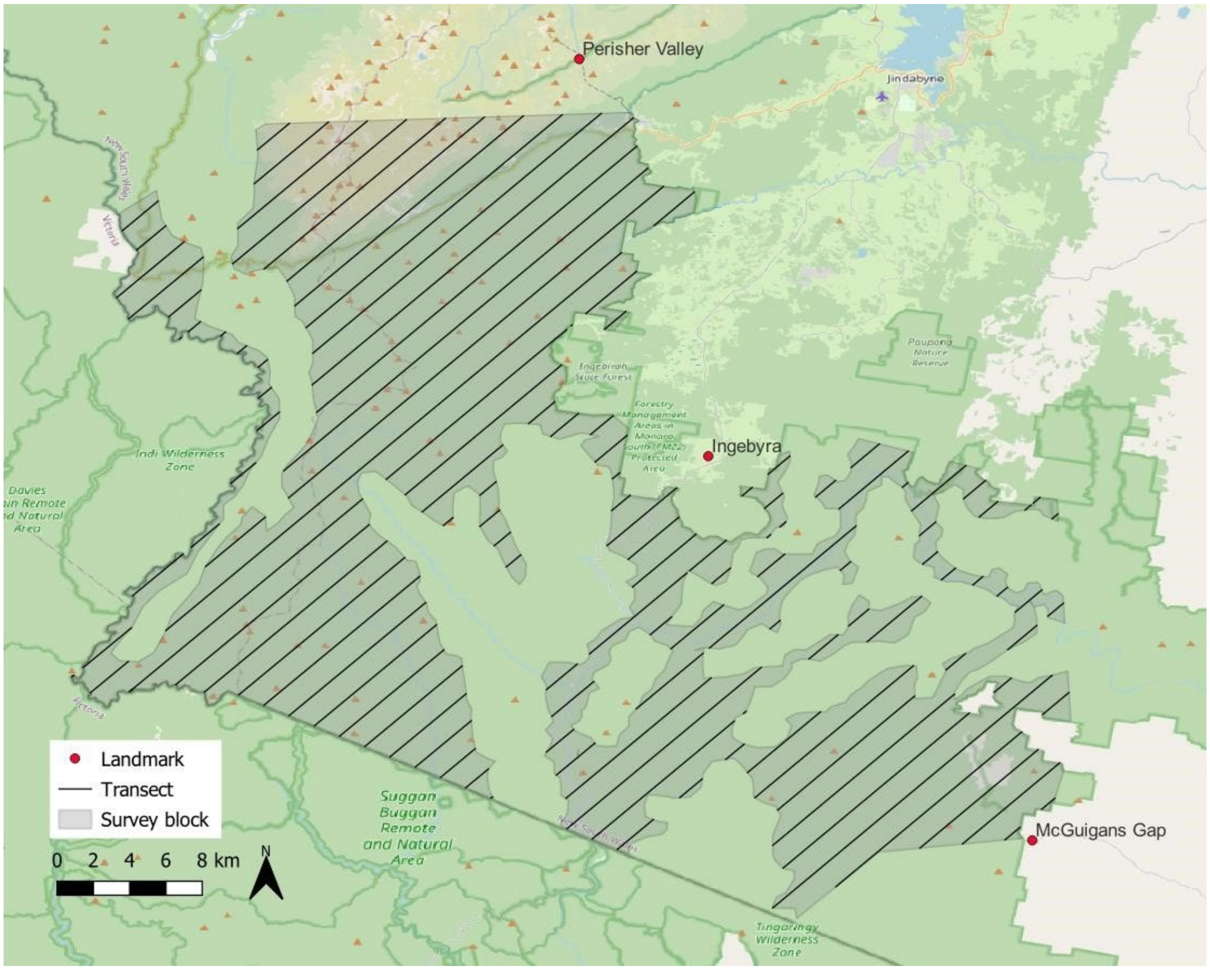

Fig. 5. The planned systematic random (parallel) survey design for the Southern Kosciuszko survey block with an estimated survey effort of 765 km and a total trackline length of 1,212 km. High points in the landscape are indicated by the orange triangles. For the geolocation of this survey block, see Fig. 1.

3. Survey and Data Analysis Methods

For the conduct of the survey, the aircraft crewing configuration 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 transects; an air safety observer seated in the front left-hand seat of the helicopter 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).

The aircraft used was a ParkAir Eurocopter AS350B3 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 via a coin-toss for each survey session.

3.1 Helicopter Line Transect Surveys

Surveys were carried out during daylight hours, with two or three sessions being flown each day. 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 in each of these blocks were 1.5 km apart which allowed this to be undertaken with reasonable degree of confidence that there would be no double counting of horses on adjacent transects during any given 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).

The survey transects (samplers) varied widely in nominal length, ranging from 1.5 km up to 43 km. A number of transects were broken into segments in relation to landscape features, namely through the exclusion of terrain with relief of >20% (Figs. 2-

5), with the data collected in these segments being combined on the basis of the nominal transect 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 counts of the number of individuals in 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 feral or introduced herbivorous mammal species (kangaroos and wombats excluded). The numbers of adult horses and foals in each cluster were recorded separately. In addition, ancillary information that could influence detection probability was also recorded for a survey session. This information included vegetation cover at the point-of-detection of a cluster of horses, observer identification, the proportion of cloud cover, wind speed and temperature during a survey session. The seating positions of the observers and the direction flown on each transect were also recorded to identify the survey aspect (north-facing or south-facing) associated with the recording of sighting of a cluster of horses.

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 a Eurocopter AS350B3 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 probability of the detection of animals within the covered area (the 150 m wide survey strip). Following this, the density of animals within the covered area can be estimated given this probability of detection, after which the number of animals in the entire 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, $0 \leq x \leq w$ 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 individual animals (horses) within clusters detected in each of the five distance bins used in these surveys, were analysed using DISTANCE 7.5 (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 at least 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 at least 60-80 for reliable modelling of the detection function. The numbers of transects flown across each survey block are given in Table 1.

The analysis program DISTANCE 7.5 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 in the modelling process other than the perpendicular distance of a detected cluster of horses from the transect centreline. Hence, an assumption of pooling robustness is made, i.e. it is assumed that the models used yield unbiased (or nearly unbiased) estimates when distance data collected under variable survey 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 accurate. The model with the lowest value for a penalised log-likelihood in the form of Akaike's Information Criterion ($AIC = -2 \times \text{log-likelihood} + 2[p + 1]$; 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 these overall 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 detections were recorded as clusters of horses within associated distance categories, estimation of expected cluster size for use in the determination of population density (see eqn. 1) can be problematic. This is to do with the fact that the obvious estimator of expected cluster size, the mean size of detected clusters, may be subject to group size-bias. If larger clusters are more detectable at greater distances from the transect centreline than are small clusters, then the mean size of detected clusters will be 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 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 does exist.

If required to be used, this method is able to correct for both size-biased detection and for 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 accepted 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 relationship between $\bar{c}$ and $g(x)$ (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. 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, vegetation cover at point-of-detection, survey aspect and cloud cover score. All these covariates were categorical. There were three observers, two classes of vegetation cover at point-of-detection (nominally open habitat and habitat with tree canopy cover), 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 four 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, lower and upper confidence limits (LCL and UCL, respectively) and coefficients of variation (cv %) 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 often it is not. If it is not, then the calculation of confidence intervals using the conventional method of estimation can fail 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 particularly advantageous because with bootstrap resampling of the data, the variance and associated interval estimates will include a component derived from 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 generally known as being distribution-free because their determination is based only on quantiles derived from the data in the sample and do not include reference to a formal statistical distribution.

Similar analyses were also undertaken to determine separately the respective densities and 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

4.1 Survey Data Summaries

The aerial survey of the four survey blocks was conducted over the period 10-19 October, 2023. Three survey sessions were flown on three of these days, two sessions were flown on another four days and, because of poor survey conditions due to weather, no surveys were flown on the remaining three days (which occurred in the middle of this period). In total, 144 transects comprising 1,948 km were flown across the four survey blocks, which had a total area of 2,675 km^2. This resulted in a coverage of some 22% of the area of the survey blocks, which was a substantial increase on the

17% coverage of the survey undertaken in the previous year (Cairns 2022). The numbers of transects flown across each block are listed in Table 1.

A total of 416 clusters of horses were sighted during the survey. This compared to 419 clusters sighted during the survey conducted in the previous year (Cairns 2022). As was the case in 2022, and also during the 2020 survey (Cairns 2020b), most sightings in the present survey (65%) occurred in the large Northern Kosciuszko block (see Table 5).

4.2 Line Transect Analysis

The results of this survey were used to estimate the population densities and abundances of the wild horses in each of the survey blocks. The method of analysis used to do this 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 a cluster is from the transect centreline when sighted. The principal outcome of this modelling process is to estimate the probability of the detection of a cluster of horses on the nominal survey strip. This probability is critical to the estimation of the density of horses in the covered area (see eqn. 1). In relation to this, a number of global detection function models were 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 7.5 (Thomas *et al.* 2010), with the different fitted models being compared to select the most likely, preferred model (see Section 3.2). Model selection is based upon the Principle of Parsimony whereby a proper model should be supported by the data and thus have enough parameters to avoid large bias but not so many parameters that precision is lost (Buckland *et al.* 2001).The process of model selection is based principally on the use of the AIC statistic, with some other considerations being taken into account (see Section 3.2).

The result of the comparative model selection process is given in Table 2. There was clearly a best global detection function model; 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 vegetation cover at point-of-detection. For all the other models tested it was found that comparison with this model resulted in ΔAIC>>2.00 (Table 2), pointing to the strength of the influence of vegetation cover in the detection process. The general form of the preferred detection function is shown in Fig. 7. Note that the effect of an added covariate in a model is to alter the scale of the detection function, but not its general shape (Marques & Buckland 2004).

Table 2. Comparison of the top six detection function models generated using the conventional distance sampling (CDS) and multiple-covariates distance sampling (MCDS) analysis engines in DISTANCE 7.5. Model selection was based upon comparison of the AIC statistics. For details of the models and the selection process, see text.

Analysis engine	Model	Covariates	AIC	ΔAIC
CDS	Half-normal/Cosine	–	1312.98	37.75
	Hazard-rate	–	1312.87	37.63
MCDS	Half-normal	cover	1275.23	**0.00**
	Half-normal	observer	1297.23	22.00
	Hazard-rate	cover	1295.95	20.71
	Hazard-rate	observer	1299.72	24.49

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), the total number of detections divided by the total survey effort, and the probability (P_a) that a randomly selected cluster of horses in the surveyed area will be detected. Both these parameters are integral to the process of estimating the density and abundance of the horses in the survey blocks (see eqn. 1). Both are also useful statistic from a comparative point-of-view.

According to Buckland *et al*. (2001), the encounter rate is a more informative statistic than is n itself, the number of clusters detected. High precision associated with the encounter rate points to low variability between the counts of clusters of horses on individual transects which is usually taken as an indicator of how well a survey has been designed. In this survey, the precision of the encounter rates for both of the larger survey blocks was relatively high, with a coefficient of variation (cv) of 11.4% for the Northern Kosciuszko block and a cv of 14.4% for the Southern Kosciuszko block. Encounter rate precision was low for the two small survey blocks. In distance sampling, encounter rate variance is usually the dominant component of the overall variance of object (horse) density. Low variance in the encounter rate can be taken as an indicator of low bias in a density estimate, thus making it closer to the true density. If the variance in n/L is low, then the variances in the density and abundance estimates will be correspondingly low (Buckland *et al.* 2001). By way of comparison, the variances associated with the estimates of n/L from the 2022 survey (Cairns 2022) were the same in relative terms for the Northern Kosciuszko block (cv = 11.6%) as in the present survey, but somewhat higher for the Southern Kosciuszko block (cv = 22.7%) than in the present survey.

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 2023 in the four survey blocks.

Survey block	n/L	P_a
Northern Kosciuszko	0.34 ± 0.04	0.56 ± 0.02
Snowy Plains	0.09 ± 0.04	0.52 ± 0.09
Cabramurra	0.02 ± 0.01	0.49 ± 0.22
Southern Kosciuszko	0.16 ± 0.02	0.42 ± 0.03

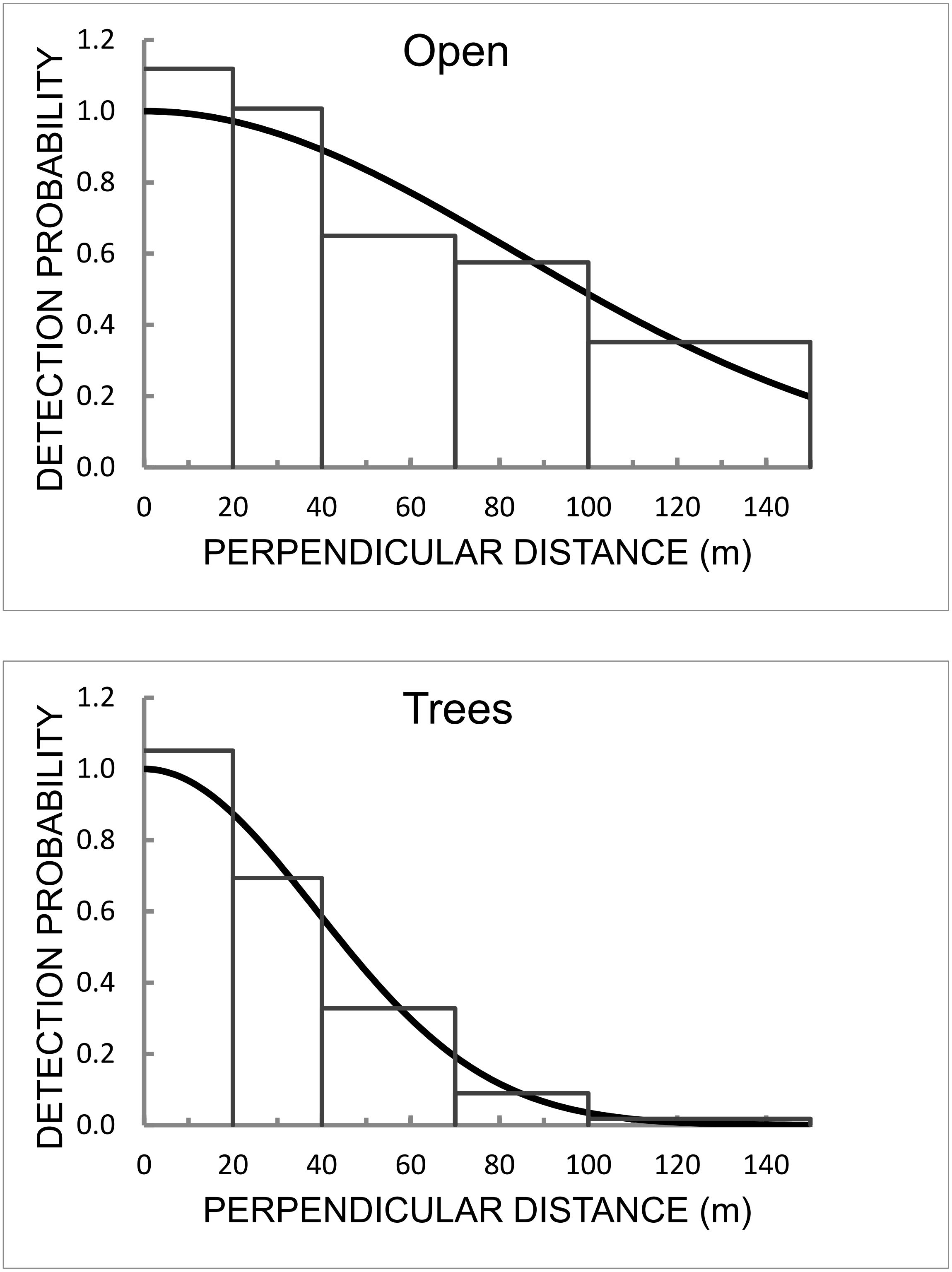

Fig. 7. The Half-normal detection function for wild horses in the survey blocks. This detection function was derived using the MCDS analysis engine of DISTANCE 7.5 with vegetation cover at point-of-detection as a covariate (for further details regarding covariates in detection models, see Table 2).

While P_a is required as part of the estimation process, it can also be viewed as an indicator 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 higher for the Northern Kosciusko block than it was for the Southern Kosciuszko block (Table 3). In relation to this, it should be noted that a relatively high proportion (55%) of sightings were made in timbered country in the Southern Kosciuszko block. The opposite was the case with the Northern Kosciuszko block, where the great majority of sightings (85%) were made in open country. The estimates of P_a were approximately twice as precise for the more open survey blocks, Northern Kosciuszko and Snowy Plains, than they were for the other two, more timbered, blocks. This difference in precision could be a consequence of only using only a two-level factor covariate in the analysis for vegetation cover at point-of-detection. Perhaps using a narrower classification system could have increased the precision of the estimates of this statistic for the two, more timbered survey blocks, Southern Kosciuszko and Cabramurra.

As well as n/L and P_a, another statistic determined from the survey data that is required for density estimation is an estimate of the expected 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 1-26, 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 the Southern Kosciuszko block (P <0.15). For this survey block, 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 Northern Kosciuszko, Snowy Plains and Cabramurra blocks (P >0.15), where the mean cluster size was used as the expected cluster size in the analyses (Table 4). Although some large clusters of horses were observed, the estimated expected cluster sizes across all survey blocks were in the range 2.67-5.29 horses. 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. Defining observed clusters this way was done in an attempt to standardise the survey methodology and reduce any arbitrariness in observer decision-making.

Table 4. The expected sizes ($E(c) \pm SE$) of the clusters of horses counted on the survey transects in 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	5.29 ± 0.30	1 – 26	-0.068	0.151
Snowy Plain	3.90 ± 0.03	1 – 6	0.425	0.973
Cabramurra	2.67 ± 0.33	0 – 3	-0.857	0.172
Southern Kosciuszko	2.67 ± 0.17	1 – 13	-0.245	0.004

4.3 Wild Horse Population Estimates

The densities of clusters of horses and the corresponding population densities in each survey block are given in Table 5. The estimates of population abundance are given in Table 6. Given with the densities in Table 5 are the 95% bootstrap confidence intervals. Given with the abundance estimates in Table 6 are the 90%, 95% and 99% bootstrap confidence intervals.

There are two points that can be noted with regards to the densities given in Table 5. The first of these is that, not unexpectedly, there was a strong correlation between cluster density and population density across the survey blocks ($r_2 = 0.95$). This points to the fact that, like almost all animal species, as density increases, so does the extent of aggregation (Taylor 1961), a not unexpected phenomenon associated with a highly social species. The second point is also to do with this association is the general decrease in precision between the estimation of cluster density and population density, particularly in the two larger blocks with larger, more aggregated populations. There is considerable variability among cluster sizes (see the size ranges listed in Table 4). In the Northern Kosciuszko block, cluster size contributed 17.7% to the variance in density estimation. In the Southern Kosciuszko block, cluster size contributed 12.8% to the variance in density estimation. This compared, in both these instances, with the approximately 70% contribution that could be attributed to encounter rate.

Table 5. Results of the helicopter line transect surveys of wild horses conducted in the four Kosciuszko NP survey blocks in October, 2023. 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%).

Survey block	*n*	Cluster density (km^{-2})			Population density (km^{-2})		
		D_c	95% confidence interval	*cv* (%)	*D*	95% confidence interval	*cv* (%)
Northern Kosciuszko	272	2.03	1.59 – 2.53	11.7	10.75	7.24 – 13.70	16.3
Snowy Plains	21	0.58	0.21 – 1.15	39.3	2.25	0.74 – 4.62	41.2
Cabramurra	3	0.13	0.00 – 0.30	59.3	0.35	0.00 – 0.76	58.9
Southern Kosciuszko	120	1.23	0.87 – 1.72	17.5	3.29	2.04 – 4.99	23.7
Kosciuszko NP	416	1.50	1.24 – 1.89	10.7	6.50	4.78 – 8.13	13.8

Regarding the abundance estimates given in Table 6, reference can be made to the lower limits of the three sets of confidence intervals in relation to the management of the horse population. For example, with the 90% confidence interval it can be deduced that there is 95% confidence (because the operational context is one-sided) that the number of horses in the population is greater than the value of the lower limit. With the 95% confidence interval this one-sided confidence is 97.5%, while the 99% confidence interval it 99.5%.These lower confidence limits can be used as reference points for making management decisions.

Table 6. The population estimates (N) for each of the four Kosciuszko NP survey blocks. Given along with these estimates of abundance are three sets of bootstrap confidence intervals and coefficients of variation (cv%). For each block, the confidence intervals are, in descending order, 90%, 95% and 99%. Given also with these estimates are the areas surveyed, including the total area of the four survey blocks.

Survey block	Area (km^2)	N	Bootstrap confidence intervals	cv %
Northern Kosciuszko	1,229	13,212	9,471 – 15,995 8,895 – 16,842 7,912 – 17,858	16.3
Snowy Plain	161	363	149 – 675 119 – 743 59 – 908	41.2
Cabramurra	139	49	8 – 94 0 – 106 0 – 136	58.9
Southern Kosciuszko	1,146	3,769	2,603 – 5,204 2,337 – 5,720 2,062 – 6,137	23.7
Kosciuszko NP	2,675	17,393	13,638 – 20,365 12,797 – 21,760 11,949 – 22,464	13.8

There have now been three successive surveys conducted of the wild horse population in the Kosciuszko NP. The results of these surveys can be compared on both an overall basis and for each of the four survey blocks. This was done using the two-sample z-statistic test given in Buckland *et al.* (2001, pp 84-86). For comparison, the population estimates obtained from the three successive surveys and the results of the comparisons are given in Table 7.

Across the four survey blocks, there was estimated to be a total population of 17,393 (95% CI: 12,797-21,760) horses which was equivalent to an average density of 6.50 km^{-2}. In 2022, the total population of horses in the four blocks surveyed was estimated to be 18,814 (95% CI: 14,501-23,535) individuals, which was equivalent to an average density for the total survey area of 7.03 km^{-2} (Cairns 2022). Although there appeared to be a decrease in the size of the total population over the period between the 2022 and 2023 surveys, this decrease was far from being statistically significant (Table 7: z = 0.42; P = 0.674). This has followed on from a similar recording of no significant change in total horse numbers over the period between the 2022 survey and one conducted prior to it in 2020 (Table 7: z = 1.06; P = 0.289).

Table 7. The population estimates obtained from the last three surveys conducted on the four survey blocks in the Kosciuszko NP. Given with each of these estimates are the 95% bootstrap confidence intervals and the results of the tests of the sequential differences between these estimates. See text for details of this test.

Survey block	2020 survey (Cairns 2020)	2022 survey (Cairns 2022)	2023 survey (this study)
Northern Kosciuszko	12, 511 (7,111 – 20,761)	12,774 (9,379 – 16,862) z = 0.07; P = 0.944	13,212 (8,895 – 16,842) z = 0.16; P = 0.872
Snowy Plains	436 (170 – 851)	705 (343 – 1,222) z = 0.95; P = 0.342	363 (119 – 743) z = 1.26; P = 0.207
Cabramurra	–	–	49 (0 – 106) –
Southern Kosciuszko	1,433 (949 – 2,038)	5,335 (2,979 – 8,384) z = 2.60; P = 0.009	3,769 (2,337 – 5,720) z = 91; P = 0.363
Kosciuszko NP	14,381 (8,798 – 22,555)	18,814 (14,501 – 23,535) z = 1.06; P = 0.289	17,393 (12,797 – 21,760) z = 0.42; P = 0.674

Further comparisons of these population estimates can be made at the level of 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 in excess of 3-4X the density estimates for the other survey blocks (Table 5). This was in broad terms similar to the findings of the previous surveys which were conducted within these four survey blocks (Cairns 2020b, 2022), 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 76% of the total number of horses estimated in all four blocks combined (Table 6). In 2022, this proportion was 68%, while in 2020 it was at 85% (Cairns 2020b). At 13,212 (95% CI: 8,895-16,842), the population in the Northern Kosciuszko block appears to have been unchanged over the period 2022-2023 (Table 7: z = 0.16; P = 0.872), as was also the case between 2020 and 2022 (Table 7: z = 0.07; P = 0.944). So for the last three years, the population in this block has remained consistently high, as of course has the total population for all four survey blocks, i.e. across Kosciuszko NP, which is dominated by the population in this northern block.

There was also no significant change in the size of the horse population in the Southern Kosciuszko block even though there appeared to be some decline in numbers (Table 7: z = 0.91; P = 0.363). Prior to this though, the population in this southern block had increased substantially in size between 2020 and 2022 (Table 7: z = 2.60; P = 0.009). In relation to this, it should be noted that although there had been a significant change in the number of horses in the Southern Kosciuszko block, there had been no significant change in the total population between 2020 and 2022. 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.

Numbers in the Snowy Plains block also remained essentially unchanged between the 2022 and 2023 surveys (Table 7: z = 1.26; P = 0.207), as they were between 2020 and 2022 (Table 7: z = 0.95; P = 0.342). Previously in the Cabramurra block, there had been no horses sighted during the 2020 and 2022 surveys. In 2023, however, a small number of horses were detected. This resulted in the estimation of a very small population in this block (Table 6).

To draw some inferences with regards to changes in horse numbers in the park estate, some discussion can be directed towards what has happened in the north of Kosciuszko NP. Conducting surveys in the northern parts of Kosciuszko NP (Fig. 1) has been a common practice for some time (Dawson 2009; Cairns 2019). In terms of encounters, Dawson (2009) reported that in a survey conducted in this region in 2009, 26 clusters of horses were sighted on 387 km of survey transect (n/L = 0.07), although it needs to be noted these sightings were made by two observers counting on only one side of the aircraft. In 2014, 104 clusters were sighted on 671 km of survey transect in the north Kosciuszko block that was surveyed (n/L = 0.16; Cairns 2019). In 2019, the number of clusters encountered in this same block had increased to 269 on 660 km of survey transect (n/L = 0.41; 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 current Northern Kosciusko block which has been surveyed in 2020, 2022 and 2023, 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 since 2019. In relation to this, it should be recalled the density of horses in this region increased from 2.38 km^{-2} in 2014 to 11.48 km^{-2} in 2019 (Cairns 2019). Subsequent to this, the density in this region, within the Northern Kosciuszko block, remained fairly constant, and was estimated to be 10.18 km^{-2} in 2020, 10.39 km^{-2} in 2022 and then 10.75 km^{-2} in 2023.

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 numbers translated into two substantially and significantly different densities of horses: 1.33 km^{-2} in 2014 and 2.63 km^{-2} in 2019 ($z = 2.41$; $P = 0.008$), which represented an implausible increase in the size of the population from recruitment and survival alone.

In relation to the current series of surveys conducted within Kosciusko NP, the density of horses in the Southern Kosciuszko block, which overlaps with the northern (NSW) portion of the Byadbo-Victoria block, was found to have initially increased substantially from 1.25 km^{-2} in 2020 to 4.66 km^{-2} in 2022 ($z = 2.60$; $P = 0.009$). In 2023, the density of horses in this block was found to be 3.29 km^{-2}, which was not significantly different from the 2022 density estimate ($z = 0.88$; $P = 0.39$).

Although direct comparisons cannot be made here between changes in numbers in the population surveyed in the Southern Kosciuszko block over the past three years, and in the broader population surveyed in the Byadbo-Victoria block in 2014 and 2019, a possible explanation for the two successive increases in numbers between 2014 and 2019, and the again between 2020 and 2022, could be associated with the 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 previous two surveys, 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 vegetation cover at point-of-detection. The probability of detection (P_a) of foals on the survey strip was in the range 0.34-0.50, which was somewhat lower than it was found to be for the 2020 and 2022 surveys. For adult horses, P_a was also lower than it was in 2020 and 2022, being in the range 0.42-56, which was essentially the same as it was for adults and foals combined (Table 3). In both instances, the higher detection probabilities were from the more open Northern Kosciuszko and Snowy Plains blocks, while the lower values were for the other two, more timbered blocks.

The results of these analyses are given in Table 8. The estimated densities of adult horses in the four 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.

For the overall population, the foal-adult ratio was 0.178, ranging from 0.091 in the Snowy Plains block to 0.186 in the Northern Kosciuszko block (Table 8). In relation to this, it is noteworthy that there was only one foal observed within the small number of horses detected in the Cabramurra block. This overall foal-adult ratio for 2023 was not significantly different from the ratio of 0.191 determined from the 2022 survey ($z = 0.06$; $P = 0.955$), which, in turn, was not significantly different from the ratio of 0.102 determined from the results of the 2020 survey ($z = 0.42$; $P = 0.675$). This was also the case when the ratios for the three survey blocks other than Cabramurra (excluded) were compared ($P > 0.50$). Overall, these figures suggest that the level of recruitment for each of the three years was broadly similar.

These aerial surveys were designed with the intention of providing realistic and reasonably precise population estimates of wild horses in four survey blocks. Except for the Cabramurra block, where very few horses were detected for the first time, the precision of the estimates as indicated by the coefficients of variation were generally near to the target level of precision (Table 1). This was important in relation to the two larger survey blocks where the majority of horses are found because it resulted in a high overall level of precision for the survey as a whole (Table 5).

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. Some of these were static data associated with the survey platform and some were 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, although observer was always going to be a strong influencing factor, it was vegetation cover at point-of-detection that proved to be the dominant covariate (Table 2). In the 2022 and 2020 surveys, observer was also used as a detection function model covariate (Cairns 2020b, 2022). For both these surveys there were unfortunately too many missing records to use vegetation cover at point-of-detection in the model selection process. However, in relation to earlier Australian Alps National Parks Cooperative Management Program surveys (Cairns 2014, 2019), it was found that both observer and vegetation cover at point-of-detection, were strong competing covariates in the model selection process. With regard to using vegetation cover at point-of-detection as a covariate in the analysis of future surveys, consideration could be given to broadening the vegetation cover classification beyond the binary one currently being used. It is possible that this could improve the modelling of detection.

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 and 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 and 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).

Table 8. The foal-adult ratios for the four survey blocks in October, 2023. Given for each block is the numbers of clusters of adult horses and foals detected (n), respectively, and the estimated densities of adult 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	272	8.32	5.80 – 11.04	16.2	116	1.55	1.03 – 2.00	17.0	0.186
Snowy Plains	21	2.09	0.69 – 4.02	41.7	6	0.19	0.05 – 0.38	45.6	0.091
Cabramurra	3	0.31	0.00 – 0.62	53.9	1	0.06	0.00 – 0.22	101.7	–
Southern Kosciuszko	120	2.93	1.90 – 4.13	19.5	35	0.45	0.23 – 0.77	32.2	0.157
Total	416	5.22	3.99 – 6.54	12.7	158	0.93	0.64 – 1.17	15.2	0.178

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 in Distance. 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.

4.4. Other Species

Apart from horses, and apart from macropods, some other species of large herbivore were counted during the surveys. These included feral goats, pigs and deer. There were only two clusters of pigs sighted in the Southern Kosciuszko block, which amounted to a raw count of nine animals. There was one cluster of goats sighted in the Northern Kosciuszko block and two sighted in the Southern Kosciuszko block, which amounted to a raw count of 18 animals. Because of the low number of sightings, no useful analysis could be undertaken using these data. One hundred and twenty clusters of deer which amounted to a raw count of 280 individuals were sighted across the four survey blocks. Most of these detections were made in the two more timbered survey blocks, with 70 being made in the Southern Kosciuszko block and 31 in the Cabramurra block.

The counts of deer were analysed using the CDS and MCDS analysis engines of DISTANCE 7.5, 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.

For the analysis of the survey results, the most parsimonious global detection function was a Half-normal model with a covariate of vegetation at point-of-detection (Fig. 8). The probability of detection (P_a) was in the range 0.22-0.24, 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, with a propensity to frequent the more timbered parts of the landscape.

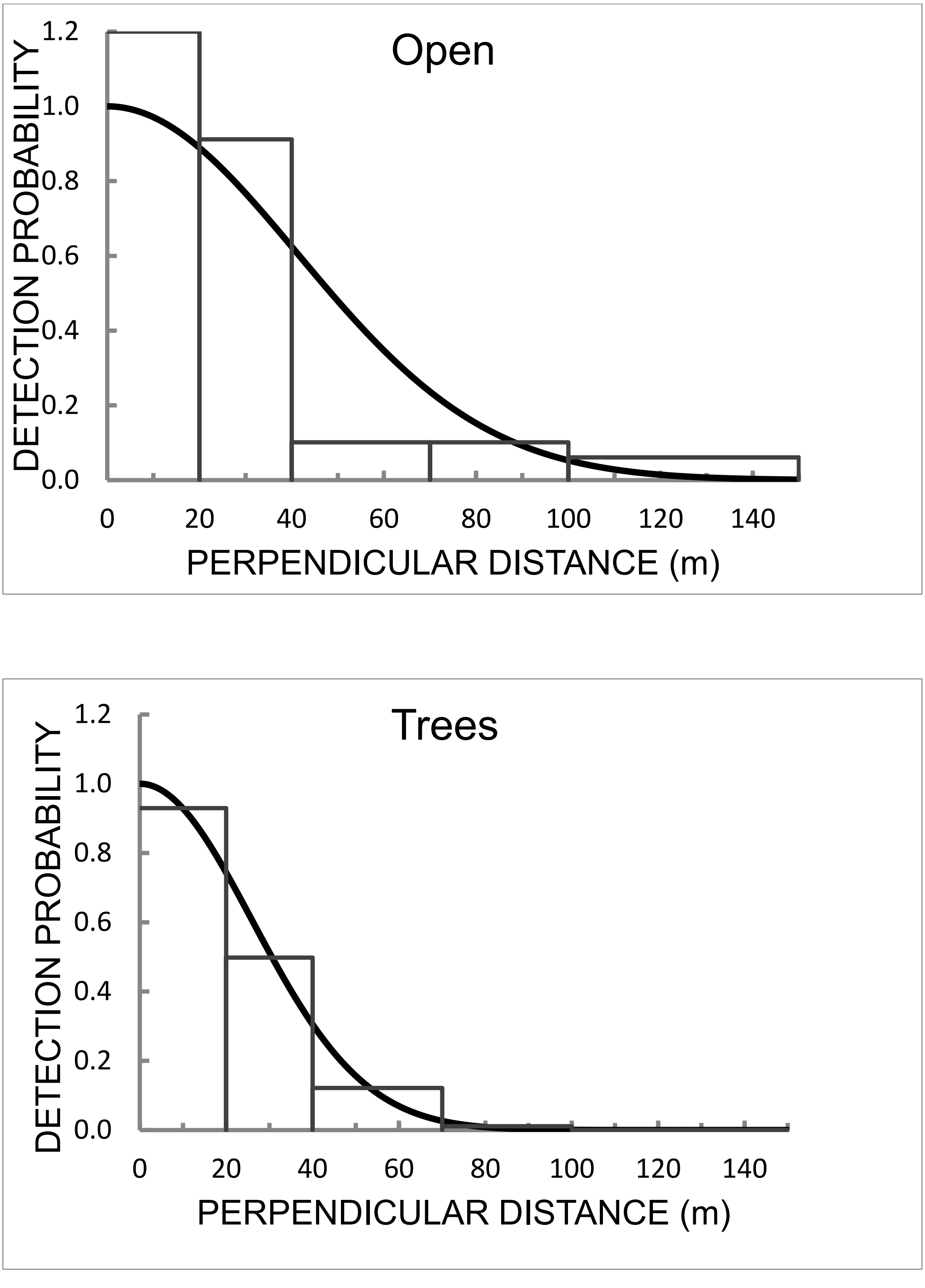

Fig. 8. The Half-normal detection function for deer in the survey blocks. This detection function was derived using the MCDS analysis engine of DISTANCE 7.5 with vegetation cover at point-of-detection as a covariate (for further details regarding covariates, see text).

The population densities and abundances of deer in the four survey blocks are given in Table 9. In terms of numbers, there was a strong north to south increasing trend in density across the park. At the level of the individual survey block, precision of estimation was generally rather poor. However, the overall level of precision, at 28.4%, could be considered fairly reasonable for a survey not designed specifically for deer.

Compared with the results of a survey conducted in late spring 2022 (Cairns 2022), when the deer population in the park was estimated to be 6,323 (95% CI: 3,624-9,454), the current population of 5,237 (95% CI: 3,584 – 6,830), despite being apparently some 17% smaller in size, represents no significant change in deer numbers over the period between these two surveys ($z = 0.49$; $P = 0.624$). This compares with an increase in numbers of 2.5X between the time of the survey conducted in 2020 and the one conducted in 2022 ($z = 2.50$; $P = 0.012$). The deer population in 2020 was estimated to be 2,565 (95% CI: 1,717-3842) (Cairns 2022).

Table 9. Results of the helicopter line transect surveys for deer conducted in the four survey blocks in October, 2023. Given for each survey block are the population density (D) and abundance (N). Given in association with the two these 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 (%)	N	95% bootstrap confidence interval
Northern Kosciuszko	0.58	0.24 – 1.05	35.8	716	297 – 1,292
Snowy Plains	0.61	0.12 – 1.27	48.2	97	20 – 204
Cabramurra	7.90	3.51 – 13.81	35.1	1,098	488 – 1,919
Southern Kosciuszko	2.90	1.73 – 3.86	42.1	3,326	1,983 – 4,424
Kosciuszko NP	1.96	1.34 – 2.55	28.4	5,237	3,584 – 6,830

6. References

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