The results of a survey of the wild horse populations in the Kosciuszko National Park, October-November, 2020

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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. The most recent of these surveys was carried out in four survey blocks within the Kosciuszko NP in October-November, 2020 as an assessment of the horse population following the 2019-2020 summer bushfires.
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. A total of 1,261 km of transect was surveyed using a helicopter flown at a ground speed of 93 km^{-1} (50 kts) and at a height of 61 m (200 ft) above ground level. Two observers were seated in 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 236 clusters of horses were sighted on three of the survey blocks. No horses were detected on the fourth block (Cabramurra).
4. A single global detection function model was fitted to the data and was used to estimate horse population densities and abundances in three of the four survey blocks.
5. The population densities in the survey blocks where horses were detected were estimated to be in the range 1.25-10.18 km^{-2}
6. The estimated total number of horses in the 2,673 km^2 of the three survey blocks where horses were detected was 14,380 with the 95% confidence interval for this estimate being 8,798 – 22,555.
7. One survey block, the Northern Kosciuszko block had the highest population density and total numbers of the four survey blocks. An area encompassing this block had been surveyed in 2019. Horse density in this Northern Kosciuszko block was slightly below, but not significantly different to the 2019 estimate for this area.
8. Foal-adult ratios were determined from the survey data. The overall value of this ratio across the three survey blocks where horses were detected was 0.102. This ratio was lower than expected given horse demography for the region. The reason for this are discussed.

1. Introduction

The Kosciuszko National Park (NP) is part of the Australian Alps National Parks (AANP) that is wholly within New South Wales (NSW). Found within its boundaries are a number of populations of wild horses (*Equus caballus*). As part of the development and execution of evolving plans to manage these horse populations, a number of population surveys have been undertaken; a number of these being under the auspices of the Australian Alps Liaison Committee.

The wild horse populations of the Australian Alps National Parks (AANP), comprising reserves found in NSW, Victoria and the Australian Capital Territory (ACT), have earlier 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). A reasonably recent survey, conducted over an expanded survey area to encompass both national parks and adjacent areas of State forest, was designed and carried out in April-May 2014 (Cairns 2014, 2019a). The timing of this survey and the decision to expand the survey area was in response to recommendations with regard to future surveys made by Dawson (2009). This survey was repeated five years later in April-May 2019 (Cairns 2019a) when it was found that the horse population in the areas surveyed had increased in size by more than 175%, or 22.5% per annum over the period between surveys.

Further to the outcome of the 2019 survey (Cairns 2019a), the NSW National Parks and Wildlife Service (NPWS) decided to undertake a follow-up survey of parts of the Kosciuszko NP in 2020. The principal reason for undertaking these surveys 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. Reported on here is the outcome of this survey, conducted in four survey blocks within the Kosciuszko NP in October-November, 2020. These blocks were identified as the Northern Kosciusko, the Snowy Plains, the Cabramurra and Southern Kosciuszko blocks, all within the Kosciusko 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 current report covers the survey method and data analysis procedures, and the results obtained from the conduct of the survey, along with some discussion of these results and the methods used to obtain them.

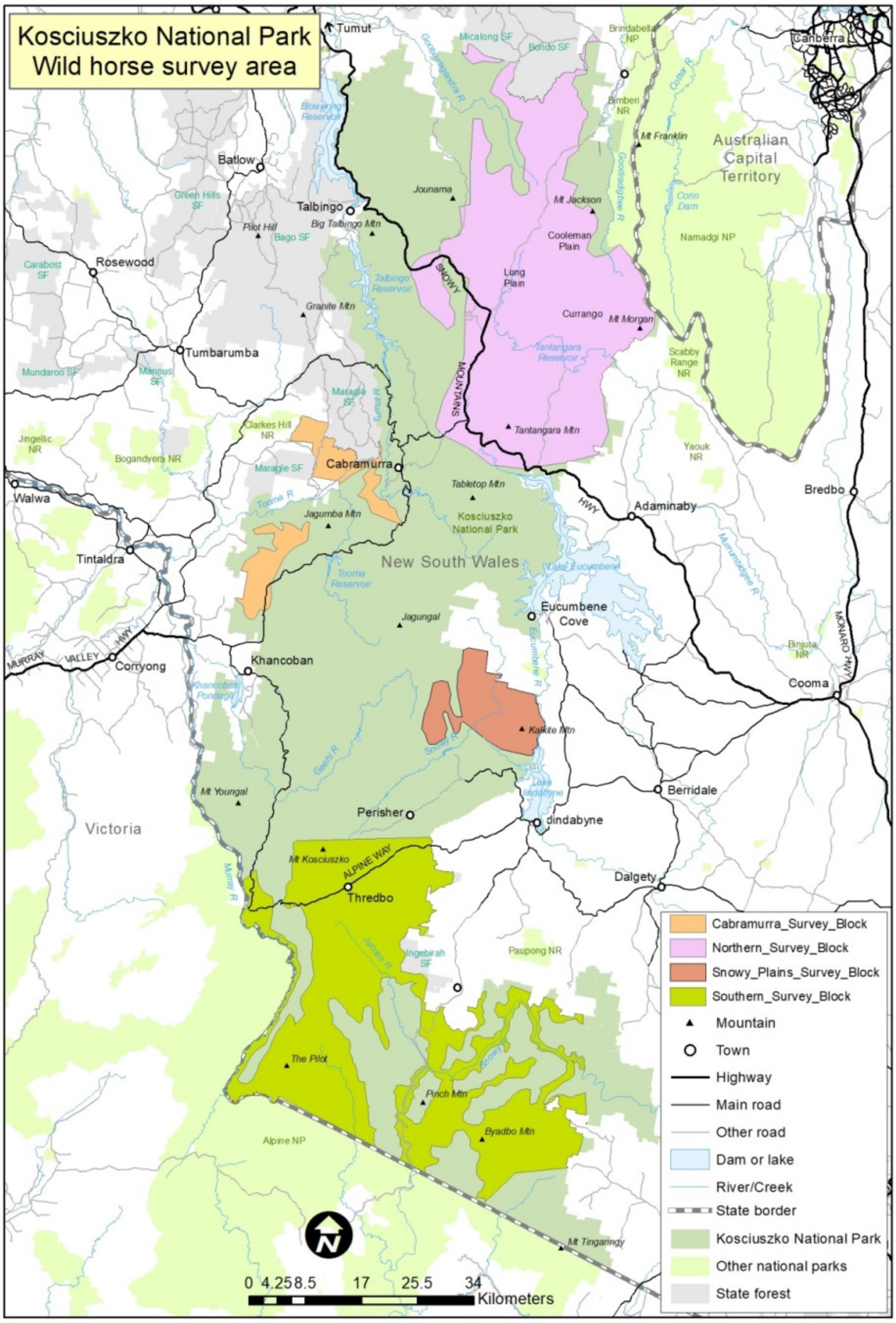

Fig. 1. The survey blocks in the Kosciuszko NP. To identify each block, see the legend in the bottom right-hand corner of the figure.

2. Study Area and Survey Design

The survey was conducted in four survey blocks that were set up in association with the Kosciuszko National Park, NSW. The survey blocks are identified as the Northern Kosciuszko, Snowy Plains, Cabramurra 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 samplers (transects) and the total survey effort for each of the realised survey designs. Given along with these values are the areas of the survey strata.

Survey block	Area (km^2)	Target precision (%)	No. of samplers	Survey effort (km)
Northern Kosciuszko	1,299	20.0	23	432.5
Snowy Plain	161	40.0	23	231.9
Cabramurra	139	25.0	34	157.0
Southern Kosciuszko	1,146	20.0	25	439.4

For each of the four blocks, a systematic random sampling survey design (a design comprising a randomly-placed grid of parallel lines) was drafted using the survey design algorithm of DISTANCE 7.3. 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. The design process which involved the testing of the selected design against alternatives is outlined in Cairns (2020a). The survey effort for each block (Table 1) was determined in relation to the prescribed level of precision using survey effort and precision information from surveys conducted in the Australian Alps in 2019 (Cairns 2019a, 2020a). The survey designs are shown on simple DISTANCE generated maps (Figs. 2-5). To visualise the relative sizes of these survey blocks, refer to Fig. 1.

In the two larger survey blocks, the Northern Kosciuszko and Southern Kosciuszko blocks, adjacent transects were 2.85 km and 2.63 km apart, respectively. In the Cabramurra block, adjacent transects were 720 m apart. In the Snowy Plains block, the adjacent transects 734 m apart. The closeness of adjacent transects in the two smaller blocks constrained the ways in which the surveys of these blocks were conducted.

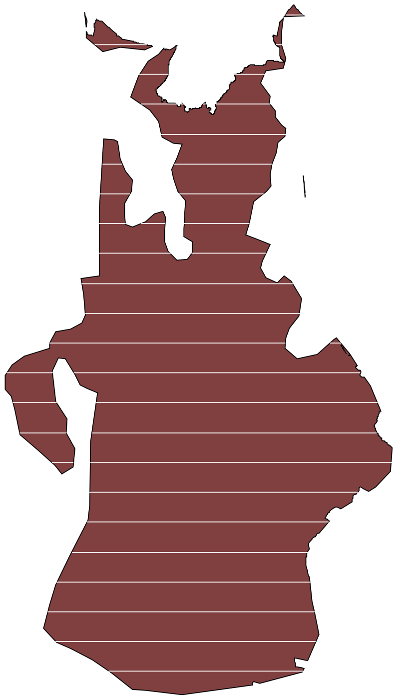

Fig. 2. A simple map showing a systematic random (parallel) design with a survey effort of 435 km and a total survey length of 585 km in the Northern survey block (Cairns 2020).

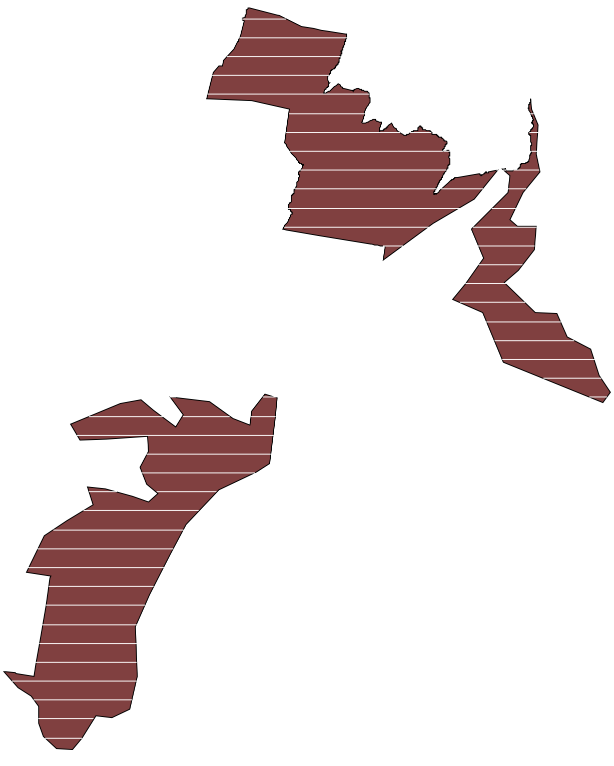

Fig. 3. A simple map showing a systematic random (parallel) design with a survey effort of 176 km and a total survey length of 309 km in the Cabramurra survey block (Cairns 2020).

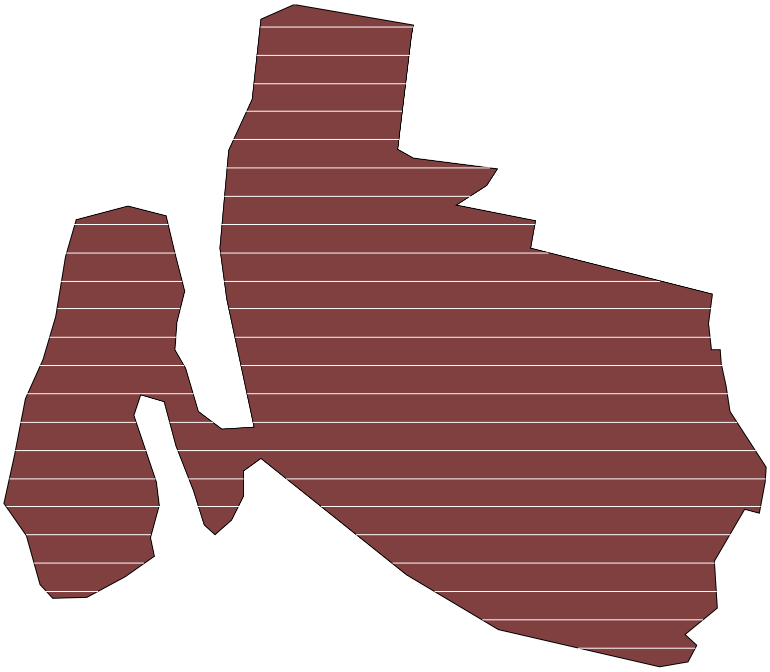

Fig. 4. A simple map showing a systematic random (parallel) design with a survey effort of 232 km and a total survey length of 291 km in the Snowy Plains survey block (Cairns 2020).

Fig. 5. A simple map showing a systematic random (parallel) design with a survey effort of 429 km and a total survey length of 738 km in the Southern survey block (Cairns 2020).

3. Survey and Data Analysis Methods

Two previous aerial surveys have been conducted on the wild horse populations either within the Kosciuszko NP or its vicinity, including other parts of the Australian Alps national park estate. These surveys were conducted in 2014 and 2019 as helicopter line transect surveys (Cairns 2019a). For the conduct of both these surveys, a standard aircraft configuration was used. It includes a pilot seated in the front right-hand seat of the aircraft and who is 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 is 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 are responsible for using a calibrated sighting boom and recording animal sightings during a survey (see Fig. 5). This configuration has also been used for the present survey.

The aircraft used was the NSW NPWS ParkAir Eurocopter AS350 Écureuil (*Squirrel*) single-engine light helicopter. Four different pilots were deployed during this survey. Three observers were used, operating two at a time in rotation. The observer not being used during a particular survey session acted as the Air Safety Observer. 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

The surveys were carried out during daylight hours. The conduct of the surveys was such that with the two larger survey blocks, the designated northern and southern blocks (Fig. 1), transects were flown sequentially within single sessions. The parallel transect lines being 2.9 km apart in the northern block and 2.6 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, Cabramurra and Snowy Plain, where transects were only some 700 m apart, 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, guarding against 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 2 km up to 44 km. A number of transects were broken into segments in relation to the landscape (Figs. 2-4), with the data collected in these segments being combined for analysis.

In conducting the surveys of the four blocks, the helicopter, with the two rear doors open, was flown 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 occupying the rear seats of the helicopter counted horses seen on either side of the aircraft, recording the sizes of the clusters observed within specified perpendicular distance classes from the transect line. Sightings of clusters of horses were recorded into the 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. 5).

Data in the form of the numbers of clusters (groups of one or more) of horses sighted within the different delineated distance classes from the centreline of a transect were voice-recorded, along with sightings of any other large mammal species (kangaroos, wild dogs and wombats excluded). As well as recording the sizes of the clusters of horses detected, because foals were present in the population, the numbers of foals in these clusters were also recorded. Ancillary information relevant to the analysis of the survey results was also recorded. Along with observer identification, this information took the form of the habitat occupied by horses at the point-of-detection and the proportion of cloud cover during a survey session to be used as an index of general visibility. The seating positions of the observers and the direction flown on each transect were also recorded to determine survey aspect. Voice-recorded information was transcribed at the end of each survey session.

Fig. 5 Distance boom mounted on the left-hand side of the Eurocopter AS350 Écureuil helicopter. The distance bins 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.

No rest breaks were taken by the observers on any transect during the survey sessions. Hence, for the purpose of data analysis, the exact sampler lengths were equal to the allocated lengths in the survey designs.

3.2 Data Analysis

The analysis of distance sampling data such as those collected here first involves the estimation of the detection probability of animals within the covered area (usually a designated survey strip), then the estimation of the density of animals within the covered area given this detection probability and, finally, the estimation of the number of animals in the survey region 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 $x = 0$ (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 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 exceed 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). If the MCDS analysis engine is used, then additional covariates can be included in the analysis. This can help to relax to some extent (but not entirely) reliance on the assumption of pooling robustness (Burnham *et. al.* 2004).

The analysis protocol followed was such that 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 which was the most parsimonious model and, hence, which were the most likely and accurate estimates of population density and abundance. 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, as is generally the case, 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. Although available as an option to improve goodness-of-fit, no manipulation of the grouping intervals was undertaken.

Four 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 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 the sighting of horses was recorded as clusters, estimation of expected cluster size for use in the determination of density and abundance 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). There are a number of remedial measures that can be used to address this possible problem (Buckland *et al.* 2001). The one used here was a regression method, 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 ($\mathrm{g}(\mathrm{x})$) at the distance (x) from the transect centreline. Significance of this relationship is determined in relation to α = 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 $\ln(\mathrm{c})$ and $\mathrm{g}(\mathrm{x})$ is increased, and the likelihood of Type II error decreased. Here, increasing the likelihood of accepting an association between $\ln(\mathrm{c})$ and $\mathrm{g}(\mathrm{x})$ 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 the perpendicular distance from the transect line, 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, they 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 three observers (DS, MS and SS), two survey aspects (northerly and southerly) and three grades of cloud cover (1 = clear to light, 2 = medium, 3 = overcast to dull). 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 outcomes of analyses using either of 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 quite often, it is not. If it is not, then 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, in order to determine the bootstrap confidence intervals, 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. Confidence intervals determined using this method have some advantages. One of these is that, 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.

Further analyses of the form outlined above were undertaken to determine as an indication of extent of recruitment, the foal-adult ratios for the populations surveyed. This involved first determining separately the adult and foal densities, and then calculating foal-adult ratios from these.

4. Results and Discussion

The aerial survey of the four survey blocks were completed over four days: 20-21 October, 2 November and 6 November. Two survey sessions were flown on each of these days. A total of 1,261 km of transects were flown across the four survey blocks which had a total area of 2,675 km^2. The number of transects flown across each survey block ranged from 23-34 (Table 1). A total of 236 clusters of horses were sighted during the survey. Most sightings occurred in the large Northern Kosciuszko block (see Table 5). No horses were sighted in the Cabramurra block (Fig. 1). Because of this, all analyses and discussion were based upon the two large blocks, the Northern Kosciuszko and Southern Kosciuszko blocks, and the much smaller Snowy Plains block.

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. Because there were not enough (60-80) replicate clusters sighted separately in each of the survey blocks, a global detection function model was fitted to the data for the three blocks in which horses were sighted. 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 this analysis, the most parsimonious (specific) detection function was selected principally on the basis of it being the one that yielded 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 $\Delta \text{AIC} > 2$, 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 $\Delta \text{AIC} < 2$, then it can be thought that there is 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 AICs in model selection, see Burnham & Anderson (2002).

The outcome 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 with no series adjustment, but included, along with the perpendicular distance of a cluster from the transect centreline, the added covariate of observer (DB, MS and SS). The risk of over-parameterisation precluded the use of more than one covariate in modelling the detection function. On the basis of the test criterion, there is strong support for this model. The general form of the detection function is shown in Fig. 6. Although not shown in this figure, it should be noted that the inclusion of a covariate such as observer in a 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 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	Half-normal/Cosine	–	759.75	18.82
	Hazard-rate/Polynomial	–	760.07	19.13
MCDS	Half-normal	Observer	740.93	**0.00**
	Half-normal	Aspect	766.26	25.32
	Half-normal	Cloud	740.93	18.12

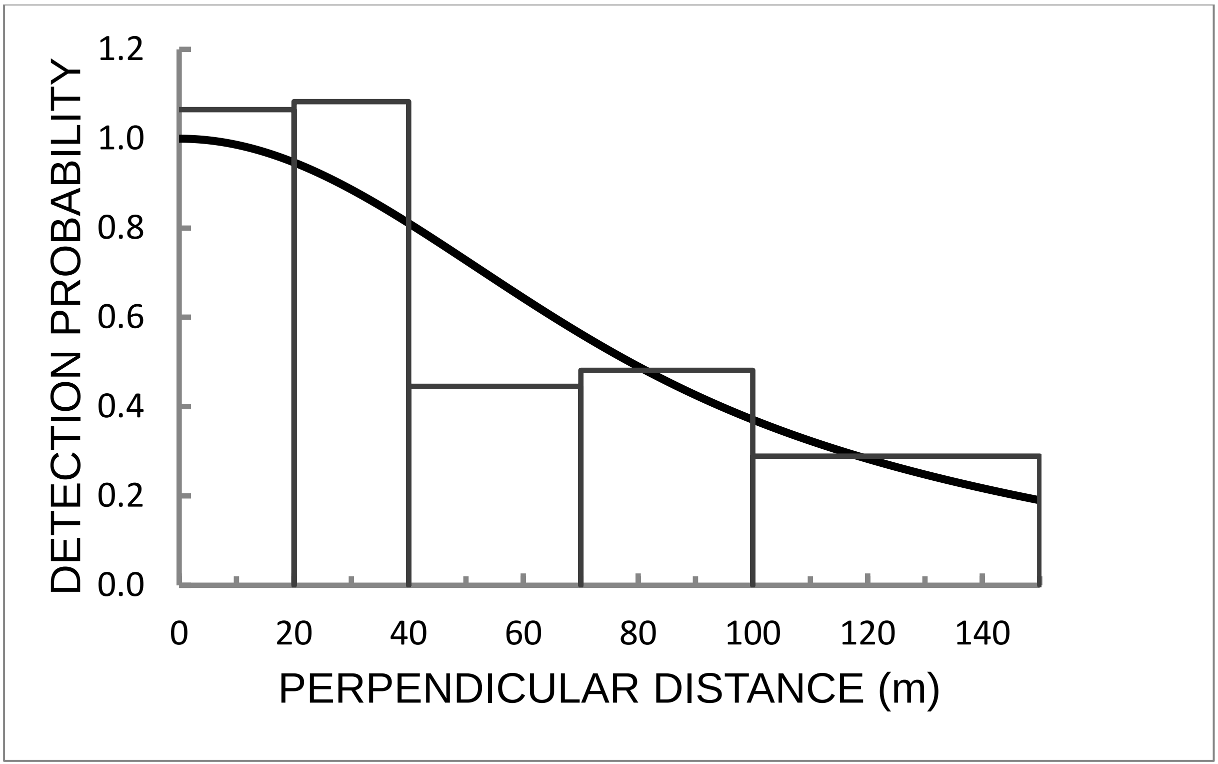

Fig. 6. The Half-normal detection function for wild horses in the Kosciuszko NP survey blocks. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details regarding covariates, see Table 2).

Associated with the survey outcome and detection function modelling are a small number of informative, ancillary statistics. These are listed in Table 3 in relation to each survey block as the encounter rate (n/L), the probability (P_a) that a randomly selected cluster of horses in the nominal survey strip (150 m) will be detected. The encounter rate is a useful statistic from a comparative point-of-view. It is perhaps 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. Compared to the other two survey blocks in which horses were detected, the encounter rate in the Northern Kosciuszko block was almost 4x as high and reasonably precise (CV = 17.3%).

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 2020 in the four survey blocks.

Survey block	n/L	P_a
Northern Kosciuszko	0.38 ± 0.07	0.55 ± 0.03
Snowy Plains	0.12 ± 0.04	0.51 ± 0.08
Cabramurra	–	–
Southern Kosciuszko	0.10 ±0.02	0.72 ± 0.06

While P_a is required as part of the estimation process (see eqn. 1), both it and the associated effective strip width 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 similar for the Northern Kosciusko and Snowy Plains blocks where all three observers were used. However, it was much higher in the Southern Kosciuszko block where only two of the three observers were used.

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 ($\hat{E}(c)$). Details regarding the determination of this parameter are given in Table 4. The overall size range of the clusters counted was 1-20, with, in most instances, larger groups being encountered wider out on the survey strip, in distance classes >70 m. Size bias was detected in the estimation of cluster size across the transect width in both the Northern Kosciuszko and Snowy Plains (P <0.15), so for these two survey blocks an expected value of cluster size based on the relationship between cluster size and the estimated probability of detection was used 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). The expected cluster sizes were in the range 1.25-4.41 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. They do not represent social groupings.

Table 4. The expected sizes ($\mathrm{E(c)} \pm \mathrm{SE}$) of the clusters of horses counted on the survey transects with each of the four survey blocks. Given along with the estimates of $\mathrm{E(c)}$ 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 $\ln(\mathrm{c})$ and estimated $\mathrm{g(x)}$. For further details, see text.

Survey block	E(s)	Range	r	P-value
North Kosciuszko	4.41 ± 0.31	1 – 20	-0.264	0.130
Snowy Plain	3.54 ± 0.43	1 – 9	-0.374	0.027
Cabramurra	–	–	–	–
South Kosciuszko	1.25 ± 0.34	1 – 8	-0.063	0.340

The densities of clusters of horses and the corresponding population densities in each survey block are given in Table 5, and the horse population abundance estimates are given in Table 6. The highest density of horses was in the North Kosciuszko block, where it was some 4-8x the estimates for the other two survey blocks. This is similar to the findings of the previous surveys conducted by Dawson (2009) and Cairns (2019), where the density of horses in the north of Kosciusko NP has been found to be greater than in other parts of the Alps estate that have been surveyed for wild horses. The population in the Northern Kosciuszko block comprised in excess of 85% of the total number of horses estimated in all blocks combined (Table 6).

Table 5. Results of the helicopter line transect surveys of wild horses conducted in the four Kosciuszko survey blocks in October-November, 2020. 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 no horses were detected during 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 (%)
North Kosciuszko	164	2.31	1.54 – 3.21	18.5	10.18	5.79 – 16.89	27.2
Snowy Plain	27	0.76	0.34 – 1.46	37.1	2.71	1.09 – 5.29	38.4
Cabramurra	–	–	–	–	–	–	–
South Kosciuszko	45	0.48	0.27 – 0.72	24.0	1.25	0.83 – 1.70	19.2
Kosciuszko NP	236	1.38	0.97 – 1.85	15.6	5.67	3.47 – 8.89	24.1

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

Survey block	Area (km^2)	N	95% confidence interval	CV %
Northern Kosciuszko	1,229	12,511	7,111 – 20,761	27.2
Snowy Plain	161	436	176 – 851	38.4
Cabramurra	–	–	–	–
Southern Kosciuszko	1,146	1,433	949 – 2,028	19.2
Kosciuszko NP	2,673	14,380	8,798 – 22,555	24.1

Conducting surveys in the northern parts of the 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 sightings of groups of horses were made 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 sighting were made in the block surveyed; this number increasing to 269 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 this block had increased significantly from 2.38 km^{-2} to 11.48 km^{-2} ($z = 4.12$; $P < 0.001$; Cairns 2019).

The block surveyed on the two previous occasions (2014 and 2019) in north Kosciuszko was 1,366 km^2 in area and overlapped with the current Northern Kosciusko block which is 1,229 km^2 in area. Given this, a cautious, but useful exercise is to compare the current estimated density of horses in the Northern Kosciuszko block with the density estimate obtained for north Kosciuszko in 2019. The density of wild horses estimated for this region in 2020, which was 10.18 km^{-2} (Table 5), 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 the Kosciuszko NP in the last year.

During the conduct of the present 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 and index of recruitment, 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 adult horses 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. A similar model was derived for the foals, but instead of an additional covariate of observer, into incorporated one defining cloud cover. The probability of detection of foals on the survey strip was 0.52-0.57, while for adult horses it was similar in the Northern Kosciuszko and Snowy Plains blocks, but higher (0.72) in the Southern Kosciuszko block.

The results of these analyses are given in Table 7. The estimated densities of adult horses in the three survey blocks were broadly similar to those determined for all horses (Table 5). The densities of foals were, of course lower and less precise, with relatively high coefficients of variations. This is lower precision is presumably related to the relatively low counts of this age class. Overall, the foal-adult ratio was 0.102, ranging from 0.075 in the Southern Kosciuszko block to 0.132 in the Snowy Plains block (Table 7).

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 say 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, would give an estimate of the density of foals in that population of twice the density given in Table 7. Although horses have a birth pulse in spring to early summer (Dawson 2002), it is possible that if the calculated rather than the observed density of foals in the population is nearer to the true density, then perhaps at the time of the survey the recruitment of foals into the population had not yet finished. Alternatively, recruitment could have been affected by poor fecundity or perinatal survival, or a combination of these factors. It is hard to say how useful a foal-adult ratio could be. It may prove to be a useful index if it were part of an annual survey program conducted at the same time each year in relation to the monitoring of management areas.

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 near to the target level of precision. The only one that was slightly marginal was that for the Northern Kosciuszko block. However, it was still acceptable, as was the overall level of precision for the combined survey result.

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 data took the form of 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. Unfortunately, the recording of habitat cover at point-of-detection was incomplete and was therefore precluded from being used in the analyses. This was somewhat unfortunate because in the analysis of the results of a previous survey (Cairns 2014), this covariate proved to be dominant, even in comparison with observer; a covariate of strong influence.

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 of unmodelled heterogeneity in the data and the fact that the principle detection probability (P_0), the probability of detection on the transect centreline is, in fact, <1.00. A key assumption of CDS and MCDS analyses is that $P_0 = 1.00$ (Buckland *et al.* 2001). With the use of covariates in the MCDS analyses (Table 2), some of the unmodelled heterogeneity is, in fact, modelled. However, the assumption of $P_0 = 1.00$ *remains.* In relation to their analyses, 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 demonstrated that the values of P_0 were equal to, or near to 1.00 (Cairns, 2019b, 2020b). In relation to this, that the population estimates obtained from the present surveys may be underestimates cannot be ignored. However, the extent of underestimation could well be marginal.

In conducted aerial surveys of wild horse populations, 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.

5. Acknowledgements

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Table 7. The foal-adult ratios for the four Kosciuszko survey blocks in October-November, 2020. Given for each block is the numbers of clusters of adult horses and detected (n), 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 (%)	
North Kosciuszko	161	9.77	1.49 – 3.09	24.8	50	0.99	0.52 – 1.93	37.9	0.101
Snowy Plain	27	2.51	0.30 – 1.39	36.5	6	0.33	0.05 – 0.71	61.4	0.132
Cabramurra	–	–	–	–		–	–	–	–
South Kosciuszko	45	1.20	0.26 – 0.72	19.0	10	0.09	0.03 – 0.15	39.8	0.075
Total	233	5.28	3.32 – 6.77	22.0	66	0.54	0.31 – 0.97	34.0	0.102