Feral Horses in the Australian Alps: the Analysis of Aerial Surveys Conducted in April-May, 2014 and April-May 2019

Stuart Cairns
G.E. & S.C. Cairns Consulting Pty. Ltd.
PO Box U21
University of New England
Armidale
NSW 2351

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Contact

Postal address:	PO Box U21 University of New England Armidale NSW 2351
Telephone:	0427 454 344
email:	scairns@une.edu.au

Abstract

1. Previously, aerial surveys of the feral horse populations in the Australian Alps national parks and adjacent state forests have been conducted in 2001, 2003, 2004 and 2009.
2. More recently, further aerial surveys of these horse populations have been conducted in 2014 and 2019 in three survey blocks, identified as North Kosciuszko, Bago-Maragle and Byadbo-Victoria, within this region using survey designs developed using the automated survey design engine in DISTANCE 6.0 (Cairns 2014).
3. The survey conducted in 2019 was essentially a repeat of the one conducted in 2014. The total area of the three survey blocks was 7,443 km^2. Excluding those parts of each block that were either not part of the national park or state forest public lands, and were unsuitable and unsafe (steep terrain > 20% slope) for aerial survey, the total area surveyed was 5,450 km^2.
4. In 2014, a total of 2,755 km of transect was surveyed using helicopters flown at a ground speed of 93 km^{-1} (50 kts) 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. In 2019, a total of 2,690 km of transect was surveyed using the same methodology.
5. During the 2014 survey, a total of 301 clusters of horses were recorded in the five distance classes on of the survey strip. During the 2019 survey, a total of 455 clusters of horses were recorded.
6. Survey results were analysed as line transect data using the latest version of the distance sampling program, DISTANCE 7.3. The results for North Kosciuszko and Byado-Victoria were analysed separately for each year, 2014 and 2019. For the Bago-Maragle block, in order to ensure adequate detections, the results of the two surveys were combined for analysis.
7. The number of horses in the North Kosciusko block increased significantly ($P < 0.001$) from 3,255 in 2014 to 15,687 in 2019. Equated with this increase over the intervening five years was an annual finite rate of population increase (λ) of 1.370, or 37%.
8. The number of horses in the Bago-Maragle decreased from 1,616 in 2014 to 1,113 in 2019. Equated with this increase over the intervening five years was an annual finite rate of population increase (λ) of 0.928, which alternative represents an annual decline in numbers of 7%.
9. The number of horses in the Byadbo-Victoria block increased from 4,316 in 2014 to 8,518 in 2019. Equated with this increase over the intervening five years was an annual finite rate of population increase (λ) of 1.146, or 15%.
10. In combining the population estimates for the three survey blocks, the total number of feral horses was estimated as being 9,187 in 2014 and 25,318 in 2019. The overall annual finite rate of population increase (λ) equated to these estimates was 1.225, or 23%. This rate of increase is broadly equivalent to a maximum for feral horses proposed by Walter (2002).
11. The surveys were designed with a target level of precision of 20%. However, this level of precision was not always achieved. In 2014, it was only attained in relation to survey of the Byadbo-Victoria block. Precision in relation to the other two blocks was relatively poor, particularly in the North Kosciuszko block. In 2019, this target level of precision was attained in both the North Kosciuszko and Byadbo-Victoria blocks, but, again, not in the Bago-Maragle block.
12. Other large, introduced herbivores, namely deer, cattle, goats and pigs were observed during the surveys. There were enough sightings of deer in the Byadbo-Victoria block to estimate the number of deer in this block. In 2014, the estimated size of the population was 2,280 deer and in 2019 it was 7,630 deer. Equated with this increase over the intervening five years was an annual finite rate of population increase (λ) of 1.274, or 27%; a rate of increase much higher than that of the horse population in this block.

1. Introduction

Aerial surveys for feral horses (*Equus caballus*) were undertaken in the Australian Alps in April-May 2014 and April-May 2019. Reported on here is the design and conduct of the surveys undertaken in the North Kosciuszko, the Bago-Maragle and the large Byadbo-Victoria survey blocks during the 2014 and 2019 survey sessions, along with the analysis of the results of these surveys. The surveys were conducted as helicopter line transect surveys. The data were analysed as distance sampling data.

This report covers survey design selection, the survey method and data analysis procedures, and the results obtained from the conduct of the survey. The general survey designs are outlined in Section 2. The survey methodology and the data analysis are described in Section 3. The results of the survey, along with some discussion of these results and the methods used to obtain them are given in Section 4.

Each of the three survey blocks was stratified as part of the design process (see Section 2). With regard to the selection of the most appropriate survey designs, this was undertaken in relation to a realistic target level of precision of 20%. Any higher level of precision, while desirable from the point of view of providing good estimates for sound decision-making, always comes at an increased cost. Some further comment is made in the report with regard to this matter. The automated survey design capabilities of the program DISTANCE 6.0 (Thomas *et al.* 2010) were used in developing the survey designs. The results of these surveys were analysed by using the analysis options available in DISTANCE 7.3. Once reported on, the changes in feral horse numbers within these survey blocks and the Australian Alps in general were discussed.

1.1 Background: Previous Surveys of Feral Horses in the Australian Alps

The feral horse populations of the Australian Alps National Parks (AANP) have been surveyed using helicopter line transect sampling in 2001, 2003 and 2009 (Walter 2002, 2003; Walter & Hone 2003; Dawson 2009) and in an adjacent area of State forest 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. 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). A follow-up to this 2014 survey was undertaken five years later in April-May 2019. Apart from some almost indiscernible changes to the original survey design, the 2019 survey is a repeat of the 2014 survey, therefore allowing direct comparison of results and inferences with regard to population changes.

The 2014 survey was originally planned and carried out in four survey blocks within the Australian Alps national parks and adjacent State forests in New South Wales (NSW) and Victoria. These blocks were identified as the North Kosciusko, the Snowy Plain and the Bago-Maragle blocks within NSW, and the Byadbo-Victoria block straddling the NSW-Victoria border. All four of these blocks were surveyed in 2014. The Snowy Plain block was deleted from the 2019 survey and will not be considered in this report. The locations of the three large survey blocks that were resurveyed in 2019 are shown in Fig. 1. Descriptions of these blocks in relation to the design and conduct of the surveys within each of them are given in Section 2 of this report. With regard to the development and conduct of the two (2014 and 2019) surveys, it should be noted that, although the total survey area was expanded from a previous survey conducted in 2009 (Dawson 2009), one of the survey areas used in that survey which included the Bogong High Plains/Cobungra area of Victoria, was omitted from consideration in both the 2014 and 2019 surveys. The reason for omitting this area was that it was some distance away from the other survey blocks and was known to support only a small number of horses (Dawson 2009).

2. Study Area and Survey Design

The 2014 and 2019 surveys were conducted in three survey blocks that were set up in association with the Australian Alps National Parks (https://theaustralianalps.wordpress.com/), a region containing a number of discrete, but often contiguous, national parks, wilderness areas and nature reserves that extend along the Great Dividing Range in southern New South Wales (NSW), Victoria and part of the Australian Capital Territory (ACT). Six of these reserves are administered by

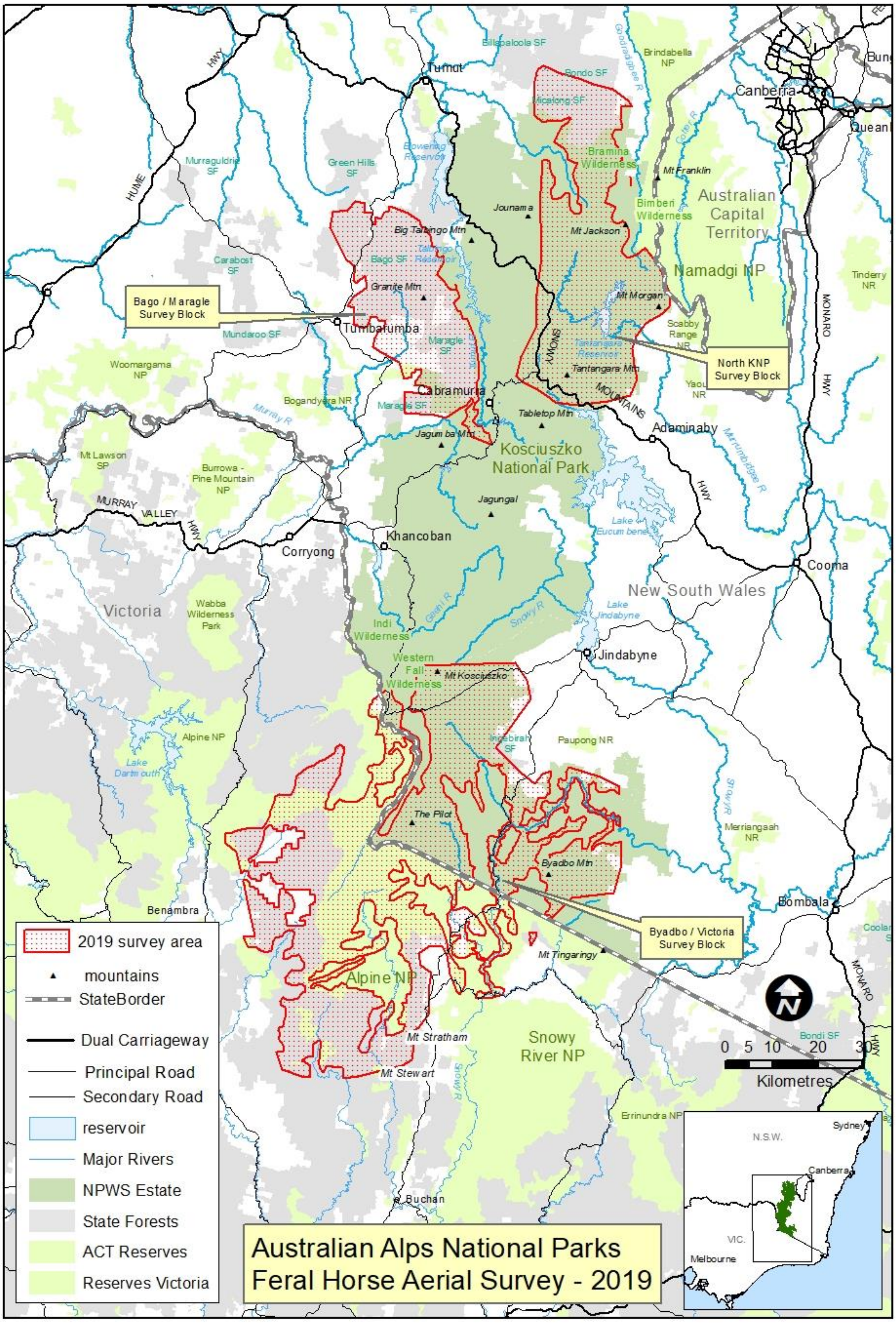

Fig. 1. The three survey blocks used in the 2019 Australian Alps Liaison Committee aerial survey of the feral horse populations in the Australian Alps.

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/). Of the three survey blocks, two, the North Kosciuszko block and the Bago-Maragle block, are in NSW. The third block, the Byadbo-Victoria block, is a large block that straddles the NSW-Victoria border, encompassing the Main Range Management unit and Pilot and Byadbo Wilderness areas within the southern part of the Kosciuszko National Park in NSW, and the northern parts of the Alpine National Park and Snowy River National Parks in Victoria where horses are known to occur (Fig. 1). For the purpose of survey design, the three blocks were divided into two or three strata based upon landscape relief and concomitant vegetation cover. Not all strata were surveyed (see below).

2.1 Survey Block Stratification

North Kosciuszko

The North Kosciuszko survey block is 1,549 km^2 in area. For the purpose of conducting the survey, this block was divided into three strata; one of which was not surveyed. Stratification was based principally on the slope of the terrain and concomitant vegetation cover. The stratum not surveyed was identified and described as the Steep terrain stratum and comprised two separate areas, one in the northeast and one in the northwest of the block, where the slope of the terrain is >20% (see Fig. 2). The Steep terrain stratum was not surveyed for reasons of logistics and safety associated with the use of a helicopter as the survey platform, and on the assumption that very few horses would frequent this very steep and usually heavily timbered terrain.

The areas of the three strata of this survey block are given in Table 1. The Steep terrain stratum comprised 12% of the area of the block, with its exclusion giving an effective survey area of 1,366km^2. The other two strata, which were both included in the survey, were identified and described as the Open plains stratum and Medium terrain stratum. The Open plains stratum comprised 40% of the area of the block. The Medium terrain stratum, comprising timbered country where the slope was <20%, made up 48% of the area of the block. This stratum extended the full length of the survey block, enveloping the Open plains stratum (see Fig. 2).

Table 1. Partitioning into strata of the areas (km^2) of the three feral horse survey blocks in the Australian Alps. Helicopter surveys for feral horses were conducted in all strata except the high relief habitat stratum.

Area partitioning (km^2)	North Kosciuszko	Bago-Maragle	Byadbo-Victoria
Total area	1,549	948	4,946
Open plains habitat	618	–	–
Medium terrain habitat	748	847	3,098
Steep terrain habitat	183	58	1,709
River valley	–	–	139
Freehold land	–	43	–
Survey area	1,366	847	3,237

Bago-Maragle

The Bago-Maragle survey block is 948 km^2 in total area and mainly constitutes the Bago and Maragle state forests, plus some freehold lands. It is therefore not entirely part of the AANP estate. For the purpose of the survey, this block was divided into three strata, only one of which was surveyed (Table 1). As was the case with the North Kosciuszko block, the stratification was based principally on the slope of the terrain and concomitant vegetation cover. The stratum comprising Medium terrain habitat where the slope is <20%, dominated the block. It was this stratum that was surveyed. Small areas of freehold grazing land, located on the western side of the block, and small areas of Steep terrain habitat (slope >20%), located mainly on the eastern side of the block, were not surveyed. This reduced the area to be surveyed to 847 km^2 of Medium terrain habitat; 89% of the total area of the block (see Fig. 3).

Byadbo-Victoria

The Byadbo-Victoria survey block straddles the NSW-Victoria and is 4,946 km^2 in total area. For the purpose of surveying this block, it was divided into three strata; two of which were surveyed (Table 1). The initial stratification was based principally on the slope of the terrain and concomitant vegetation cover. One stratum was identified as the Steep terrain stratum and comprised a number of separate areas where the slope was >20% (see Fig. 4). This comprised 35% of the total area of the block and was excluded from the survey. The other two strata, both of which were surveyed, were identified as the Medium terrain stratum and the Snowy River Valley stratum. The Medium terrain stratum comprised 63% of the area of the block. The Snowy River Valley was a comparatively small stratum, comprising 139 km^2 of mainly riverine flats. Although it was only 3% of the block, in relation to the rationale behind the stratification, this stratum was considered likely to be possible preferred habitat for horses within this survey block, with horse numbers along the river corridor known to fluctuate substantially, depending upon and in response to environmental conditions (feed and water availability) in the surrounding landscape.

2.2 Survey Effort

In distance sampling, survey effort is described as the total length of transect surveyed in a line transect survey (Buckland *et al.* 2001); usually summed over a number of individual transect lines ($L = \sum l_i$, where l_i is the length of an individual line) laid down in accordance with a particular survey design. In planning a survey, survey effort is usually determined in relation to a target level of precision along with the precision and effort obtained from a pilot or previous survey (Buckland *et al.* 2001; p.243). For the first (2014) surveys conducted in the three survey blocks, unless otherwise stated, the target level of precision was set at 20%. Because it was intended that the second survey conducted in 2019 be, as near as possible, a repeat of the first survey, the nominal survey effort was constrained to be that determined for the first (2014) survey. The conduct of a survey will often, usually for logistical reasons, result in the realised survey effort that is near to, but not equal to the nominal survey effort (see Table 2).

The determination of the survey effort for each stratum to be surveyed within each of the three survey blocks is outlined below. A full discussion of the survey designs that were initially considered for these surveys is given in Cairns (2014).

North Kosciuszko

The survey effort for this block was determined in relation to information obtained from the re-analysis of the results of a survey conducted in parts of the AANP by Dawson (2009). For details of this re-analysis, see Cairns (2014). This re-analysis was undertaken in relation to the 386 km of a helicopter line transect survey previously flown across a smaller survey area (774 km^2) within this block which was also identified by Dawson (2009) as North Kosciuszko. The survey effort determined using the method given in Buckland *et al.* (2001) was then scaled up to the effort required for a survey of the larger North Kosciuszko block. This was done by multiplying the derived value by a factor of 1.765 (= 1,366/774) based upon the proportional difference in the areas of the 2009 survey block and proposed current survey block. Note that 1,366 km^2 was the prospective survey area with the Steep terrain habitat excluded. For a 20% level of precision, the scaled nominal survey effort for the North Kosciuszko block was calculated to be 702 km.

Because the survey was to be conducted across two strata, this nominal survey effort was divided in relation to the likelihood of each of the two strata representing suitable horse habitat. Although it comprised a smaller area, the Open habitat stratum was considered to be more suitable horse habitat than was the Medium terrain stratum. On the basis of this, 60% of survey effort was proposed to be directed to the Open plains stratum, with the remaining 40% to be directed towards the Medium terrain stratum. This resulted in the nominal survey effort for the Open habitat stratum being 421 km, with the remaining 281 km being allocated to the Medium terrain stratum.

Bago-Maragle

A previous aerial (helicopter) survey of the feral horse population in parts of the area that comprises this block was carried out by Montague-Drake (2004) using uncorrected strip transect sampling. Because of the use of strip transect sampling, the results of this survey were not used as a pilot study for determining the survey effort for the present surveys. Instead, information obtained from a re-analysis (Cairns 2014) of the results of a helicopter line transect surveys conducted in other parts of the AANP by Dawson (2009) were used as being more appropriate for this purpose. The resulting nominal survey effort determined on this basis was 440 km, which was substantially greater than the 235 km flown in 2004, *albeit* over a smaller area (Montague-Drake 2004).

Byadbo-Victoria

Survey effort for the Medium terrain stratum of this block was also determined using information derived from the re-analysis of the 2009 survey results (Cairns 2014). Initially, survey effort was determined in relation to the 914 km of transect previously flown across a smaller survey area (1,828 km^2) within the current Byadbo-Victoria survey block. This smaller block was identified by Dawson (2009) as South Kosciuszko/North Victoria. The initial survey effort determined in this analysis was scaled up for the survey area of the larger Byadbo-Victoria block by multiplying it by a factor of 1.695 (= 3,098/1,828) to give, for a 20% level of precision, a nominal survey effort of 1,590 km. Note that the 3,098 km^2 used in calculating the multiplier is the area to be surveyed after the Steep terrain stratum has been excluded and not including the Snowy River Valley stratum.

The Snowy River Valley stratum (see Fig. 4) comprises only 3% of the total area of the Byadbo-Victoria survey block, or, with the Steep terrain stratum excluded, 4% of survey area. Survey effort for this stratum was determined as 90 km for a 17.5% level of precision (Cairns 2014).

2.3 Survey Design

Separate survey designs were developed for each stratum within each of the three survey blocks that was to be listed to be surveyed. This was done using what is now recognised as a standard procedure that utilises the automated design capabilities of the DISTANCE software package (Thomas *et al.* 2010); in this case, because these surveys were being designed in 2014, version DISTANCE 6.0 (http://distancesampling.org/Distance/#download-latest-version).

A canvassing of design options was undertaken as part of the process of developing the final designs originally for the 2014 surveys and the subsequent 2019 surveys. This process is covered in some length in Cairns (2014). Two design options that were settled upon and used in these surveys. A systematic random sampling design which randomly superimposes a systematic set of parallel lines onto the survey region was used in the two survey strata of the North Kosciuszko block, the single survey stratum in the Bago-Maragle block and the large Medium terrain stratum in the Byadbo-Victoria block. An equal-spaced zigzag design, one which superimposes a continuous zigzag sampler that passes through equally spaced points on opposite sides of the survey stratum boundary was used for the Snowy River Valley stratum within the Byadbo-Victoria block.

Single realisations of the selected designs were generated for the surveys to be conducted on each block using the nominal survey efforts determined above (Section 2.2). For the systematic random sampling design, all transects run east-west. This has a logistical advantage in terms of observer performance in relation to glare and shadow on the survey strip. The distance between adjacent transects running parallel to one another was determined to some extent by the requirement that as near as possible to the nominal survey effort for a stratum was attained. In the Open plains stratum of the North Kosciuszko survey block, transects were 1.5 km apart. In the Medium terrain stratum of this block, transects were 3.0 km apart. In the Bago-Maragle block, transects were 2.0 km apart. In the Medium terrain stratum of the Byadbo-Victoria block, transects were 1.9 km apart. Visual representations of these survey designs are shown in Figs. 2-4. There are some small differences between the survey designs and actual surveys undertaken in 2014 and 2019 (Table 2).

In 2014, the aerial surveys of the three AANP survey blocks were conducted as helicopter surveys during the periods 2-8 April and 5-15 May. In 2019, the surveys were conducted during the periods 3-12 April and 6-15 May. The method of line transect sampling (Buckland *et al.* 2001; Thomas *et al.* 2002) was used. All allocated transects were flown during the surveys. All surveys were usually conducted during two or three flight sessions during the period 0900-1630 hours. The numbers of transects (samplers) flown and actual survey effort for each survey stratum are given in Table 2.

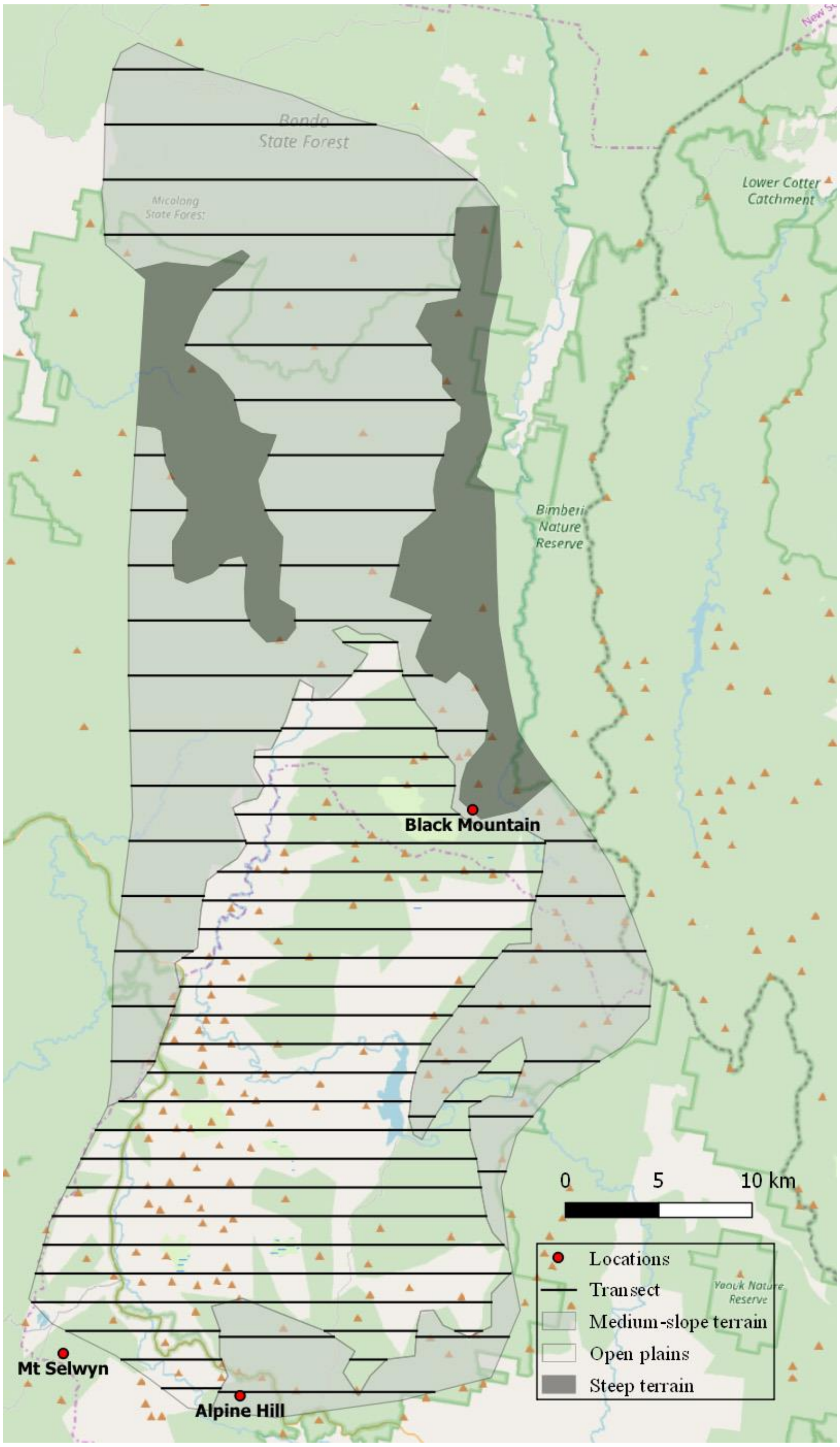

Fig. 2. The North Kosciuszko survey block. Shown are the two survey strata, some landmarks in proximity to the block and the placement of the survey transects within the Medium terrain and Open habitat strata. Note that no survey transects were placed into the Steep terrain stratum.

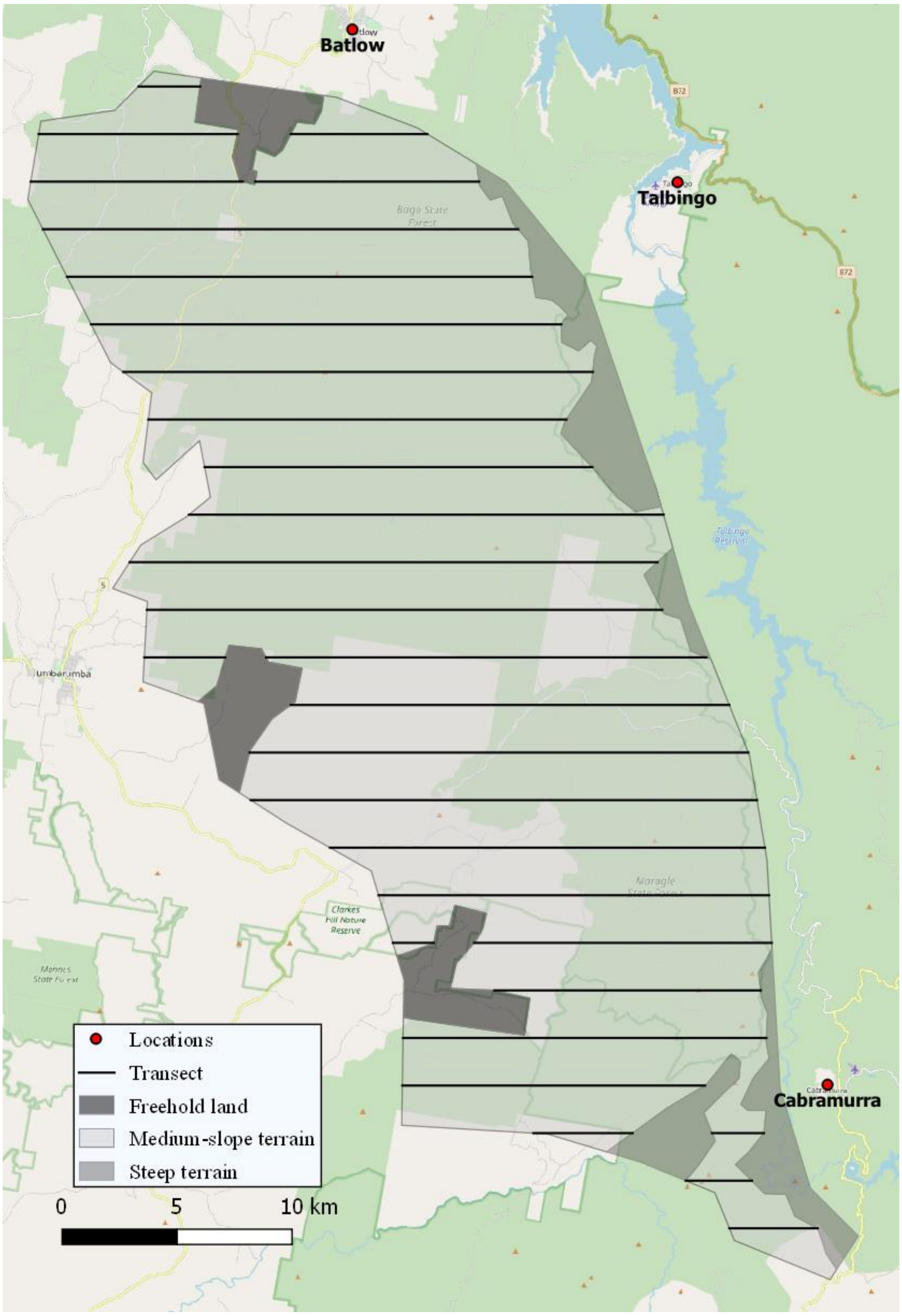

Fig. 3. The Bago-Maragle survey block. Shown are the three strata, some population centres in proximity to the block and the placement of the survey transects within the Medium terrain stratum. Note that no survey transects were placed into the Steep terrain stratum or across the Freehold land.

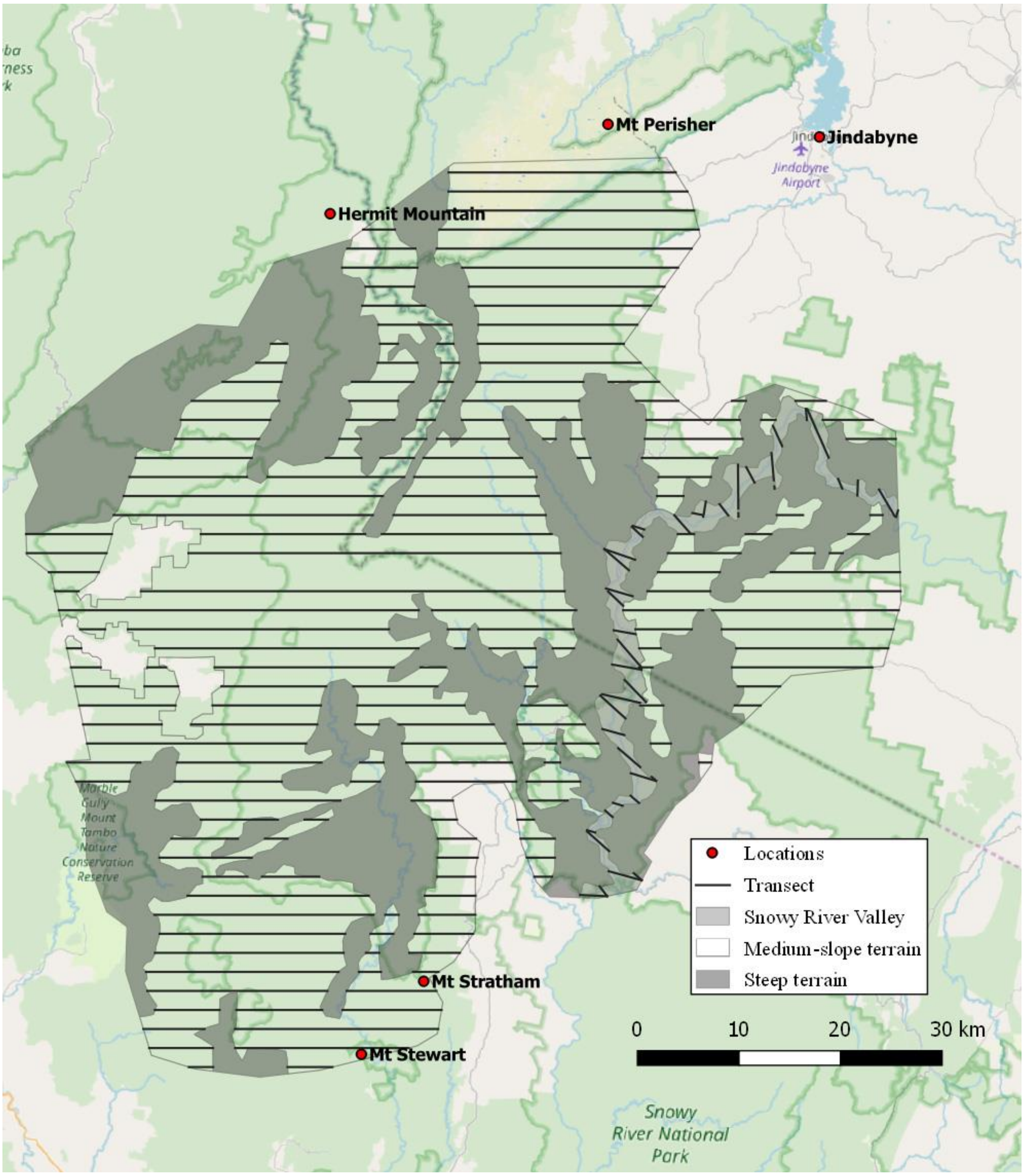

Fig. 4. The Byadbo-Victoria survey block. Shown are the two survey strata, some landmarks a population centre in proximity to the block, along with the placement of the survey transects within the Medium terrain stratum and the Snowy River Valley stratum. Note that no survey transects were placed into the Steep terrain stratum.

Table 2. The total survey effort and the number of samplers (transects) for each of the realised survey designs conducted in 2014 and repeated in 2019. Given in association with these values are the areas of the respective survey strata and the totals for all entries.

Survey block	Area (km^2)	2014 Survey effort (km)	2014 No. of samplers	2019 Survey effort (km)	2019 No. of samplers
North Kosciuszko	1,366				
Open habitat	618	403.9	27	403.6	32
Medium terrain habitat	748	267.5	26	256.2	29
Bago-Maragle	847	409.1	30	408.9	30
Byadbo-Victoria	3,237				
Medium terrain habitat	3,098	1,588.0	188	1,544.2	188
Snowy River Valley	139	86.5	42	77.1	42
Survey totals	5,420	2,755.0	313	2,690.0	321

3. Survey and Data Analysis Methods

The standard aircraft configuration for both the 2014 and 2019 surveys were maintained and repeated allowing comparison of results and therefore inference on population trends. This includes a pilot in the front right-hand seat of the aircraft responsible for flying the aircraft, maintaining a constant height and speed along the survey transect; an Air Safety Observer in the front left-hand seat of the aircraft responsible for assisting with navigation and maintaining situational awareness for the aircraft; and two Aerial Survey Specialists Observers seated in the rear of the aircraft on either side responsible for using a calibrated sighting boom and recording animal sightings (see Fig. 5).

Two helicopters were contracted for the conduct of 2014 surveys. A Bell Jet Ranger was contracted from HeliSurvey Pty. Ltd. (Jindabyne, NSW) for the surveys conducted in the three blocks in New South Wales (NSW). Colin de Pagter was the pilot and Luke McLachlin (NSW NPWS) was the Air Safety Observer. A Eurocopter AS350 BA Écureuils was contracted from Heli-Serv Pty. Ltd. (Morrabbin Airport, Victoria) for the survey conducted in the large Byadbo block straddling the NSW-Victoria border. Ian Sloane was the pilot, and John Sillins (Parks Victoria) and Mike

Irvine (Parks Victoria) were the Air Safety Observers. Two Aerial Survey specialist Observers (counters) were used on this survey. They were David Bearup (NSW NPWS) and Scott Seymour (NSW NPWS). The seating of the Aerial Survey Specialist Observers in relation to the left-hand and right-hand side of the aircraft was allocated randomly for each survey session.

For the 2019 survey, a Eurocopter AS350 BA Écureuil helicopter was contracted from Helisurveys Pty Ltd (Jindabyne, NSW). Three pilots were used, namely Ken Jakobi, Tom Lowry and Colin de Pagter (all from Helisurveys), The Air Safety Observers used were Michelle Barton, Luke McLachlan, Magnolia Sutcliffe, Mika Saunders and Tim Greville (all from NSW NPWS). Three Aerial Survey Specialists Observers (counters) were used on this survey. They were David Bearup (NSW NPWS), Mika Saunders (NSW NPWS) and Scott Seymour (now of the ACT Emergency Services Agency). The three Aerial Survey Specialist Observers (counters) were deployed two at a time and rotated on this survey. 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

In conducting the surveys, the helicopter, with the two rear doors either removed or open, depending upon the aircraft configuration, 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 trained flight specialists observers (counters) occupied the rear seats of the helicopter and 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 line. The distance classes were delineated on metal booms extending from either side of the helicopter (Fig. 5).

Fig. 5 Distance boom mounted on the left-hand side of the Eurocopter AS350 Écureuil helicopter used in the 2019 surveys. 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.

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). 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. Voice-recorded information was transcribed at the end of each survey session.

The survey transects (samplers) varied widely in nominal length, ranging from 1 km up to 41 km. 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, of clusters of horses in this instance, should be 60-80 for reliable modelling of the detection function. The numbers of replicate transects flown across the survey strata of the three blocks during the 2014 and 2019 surveys are given in Table 2. The replicate numbers of clusters of horses observed within the strata of the three survey blocks are given in Table 3.

Because there were enough observations of clusters of horses made during the 2014 and 2019 surveys of the North Kosciuszko and the Byadbo-Victoria blocks, the results for each of the two surveys in each of these two blocks were able to be analysed separately. However, because there were not enough observations of clusters made during each of the two surveys conducted in the Bago-Maragle block for separate analyses to be undertaken, the results from the 2014 and 2019 surveys were combined to ensure an adequate number of replicate observations for modelling the detection function. In this analysis, the two surveys were treated as separate strata.

Table 3. The numbers of clusters of horses and the total numbers of individual horses observed within these clusters in the 2014 and 2019 surveys of the strata within of the three feral horse survey blocks. Given in association with these values are the areas of the respective survey strata actually surveyed (therefore excluding Steep terrain and freehold land).

Survey block	Area (km^2)	2014 No. of clusters	2014 No. of horses	2019 No. of clusters	2019 No. of horses
North Kosciuszko	1,366				
Open habitat	618	84	305	226	1,125
Medium terrain habitat	748	20	64	43	173
Bago-Maragle	847	38	97	29	76
Byadbo-Victoria	3,237				
Medium terrain habitat	3,098	149	366	152	362
Snowy River Valley	139	10	15	5	12

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, 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 ($AIC = -2 \times \text{log-likelihood} + 2[p+1]$; where p is the number of parameters in the model) was, as is generally the case, selected as the most likely detection function. 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 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 optional 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 (g(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(c) and g(x) is increased and the likelihood of Type II error is decreased. Here, increasing the likelihood of accepting an association between ln(c) and g(x) may represent a "false positive" in outcome (Type I error), but it has a precautionary advantage in case this association really exists.

If required, this method is able to correct for size-biased detection and the underestimation of the size of detected clusters, provided that neither of these effects occur at the transect centreline (Buckland *et al.* 2001). If the observed sizes of detected clusters are independent of distance from the transect centreline (i.e. if *g(x)* does not depend upon c), then the sample mean cluster size ($\bar{c}$) is taken as an unbiased estimator of the mean size of the *n* clusters in the covered area. If, however, the observed sizes of detected clusters are found to be dependent upon the perpendicular distance from the t, 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. 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, cloud cover score and habitat cover at point-of-detection. All these covariates were categorical. There were three observers (DS, MS and SS), three grades of cloud cover (1 = clear to light, 2 = medium, 3 = overcast to dull) and two categories of habitat cover at point-of-detection (1 = open, 2 = timbered), indicating that horses were either sighted in the open or in timbered habitat. The three covariates were included in the analysis either singly or in pairs. 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. 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.

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.

4. Results and Discussion: Feral Horses

4.1 Survey Results Summaries

The total area of the three survey blocks was 7,443 km^2 (Table 1). The total area of the constituent survey strata of these three blocks was 5,450 km^2. The survey design being the same for both surveys, this amounted to 73% of the total area being available to be surveyed in both 2014 and 2019.

During the 2014 survey, a total of 2,755 km of survey effort was flown across the three survey blocks. The relative distribution of this survey effort and the constituent number of samplers (transects) for each block are given in Table 2. During this survey, a total of 301 clusters of horses were sighted on these transects. A breakdown of these sightings across survey blocks is given in Table 3. In the North Kosciuszko block, more horses were observed to be in the Open plains habitat (81%) than in the Medium terrain habitat. The survey strata of the other two blocks mainly comprised Medium terrain habitat.

During the 2019 survey, a total of 2,690 km of survey effort was flown across the three survey blocks. The relative distribution of this survey effort and the constituent number of samplers (transects) for each block are given in Table 2. A total of 455 clusters of horses were sighted on these transects. A breakdown of these sightings across survey blocks is given in Table 3. In the North Kosciuszko block, as was the case in 2014, the majority of horses were observed to be in the Open plains habitat (89%) than in the Medium terrain habitat. The survey strata of the other two blocks mainly comprised Medium terrain habitat.

4.2 Line Transect Analysis and Probability of Detection

The analyses used to determine the densities and abundances of feral horses in the three survey blocks conformed to a generally well understood framework for analysing distance sampling data, as outlined in Buckland *et al.* (2001). Both the CDS and the MCDS analysis engines of DISTANCE 7.3 (Thomas *et al.* 2010) were used to analyse the survey results. The distance classes used in these analyses were those set on the survey booms: 0-20 m, 20-40 m, 40-70 m, 70-100 m and 100-150 m. Feral horse density and abundance estimates resulting from 2014 and 2019 surveys were determined separately for each stratum within each survey block.

In the North Kosciuszko block, there were two survey strata based upon different types of landscape. In the analyses, the survey results from each of these strata were combined for the purpose of modelling the detection function. This was done in order to ensure an adequate number of detections in relation to the Medium terrain stratum. The density and abundance estimates were determined separately for each stratum in relation to a single probability of detection. This was done with the results from both the 2014 survey and the 2019 survey. There were also two survey strata in the Byadbo-Victoria block. The same protocol used to analyse the results from the North Kosciuszko block was used in the analysis the results of the Byadbo-Victoria block, but in this instance, this was done to ensure an adequate sample size in relation to the Snowy River Valley stratum. The Bago-Maragle block contained only one survey stratum. However, the number of sighting of clusters of horses in each survey (2014 and 2019) was below the recommended threshold of 60-80 replicate observations (Buckland *et al.* 2001) required for a separate analysis of the results of each survey. In order to ensure an adequate sample size for modelling the detection function for horses in the Bago-Maragle block, the results from two surveys were combined, with densities and abundances being estimated separately for each year in relation to a single probability of detection.

In each analysis involving the modelling of the detection function, a suite of 16 models were compared: four fitted using the CDS analysis engine and 12 using the MCDS analysis engine, with the factor covariates of observer (OBSERVER), cloud cover (CLOUD) and habitat cover at point-of-detection (COVER) being included in a model either singly or in pairs (see Section 3.2). For each analysis, the most parsimonious (likely) of the 16 detection function models was selected essentially on the basis of it being the one that yielded the smallest value of the AIC statistic (see Section 3.2). Some consideration was be given shape criterion, which in all cases proved to be satisfactory. However, goodness-of-fit could not be considered in relation to models produced using the MCDS analysis engine because of a lack of degrees of freedom.

The most parsimonious detection function models fitted to the results of the surveys of feral horses in the three survey blocks are given in Table 4. Except for the 2014 survey in the North Kosciuszko block, the detection function models were all MCDS-derived models, each with two covariates with one of these being, in all four instances, habitat cover at point-of-detection.

Table 4. The number of sightings of clusters of horses (n), DISTANCE analysis engine used to derive the detection function models (including covariates) for feral horses in the three survey blocks for surveys conducted in April-May 2014 and April-May 2019. CDS is the conventional distance sampling engine and MCDS is the multiple-covariate distance sampling engine.

Survey block	Year	n	Analysis engine	Model	Covariates
North Kosciuszko	2014	104	CDS	Hazard-rate	–
	2019	269	MCDS	Half-normal	COVER + CLOUD
Bago-Maragle	combined	67	MCDS	Half-normal	COVER + OBSERVER
Byadbo-Victoria	2014	159	MCDS	Hazard-rate	COVER + CLOUD
	2019	157	MCDS	Half-normal	COVER + OBSERVER

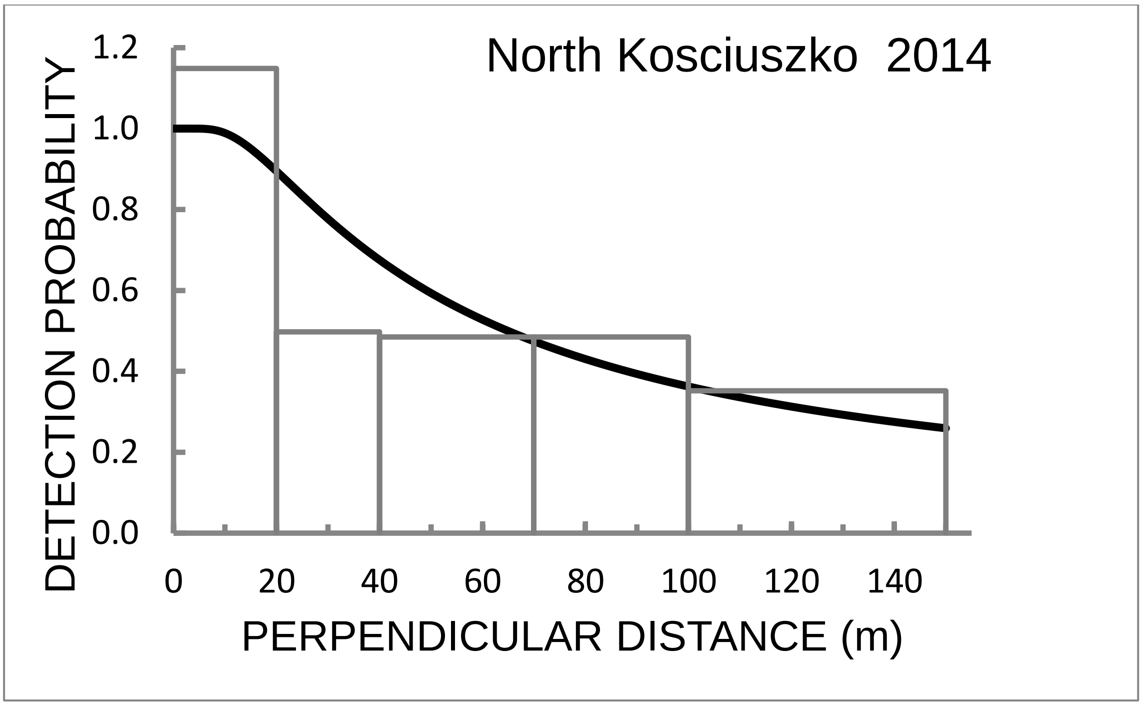

Fig. 6. The Hazard-rate detection function for feral horses in the North Kosciuszko survey block, 2014. This detection function was derived using the CDS analysis engine of DISTANCE 7.3 (for further details, see Table 4).

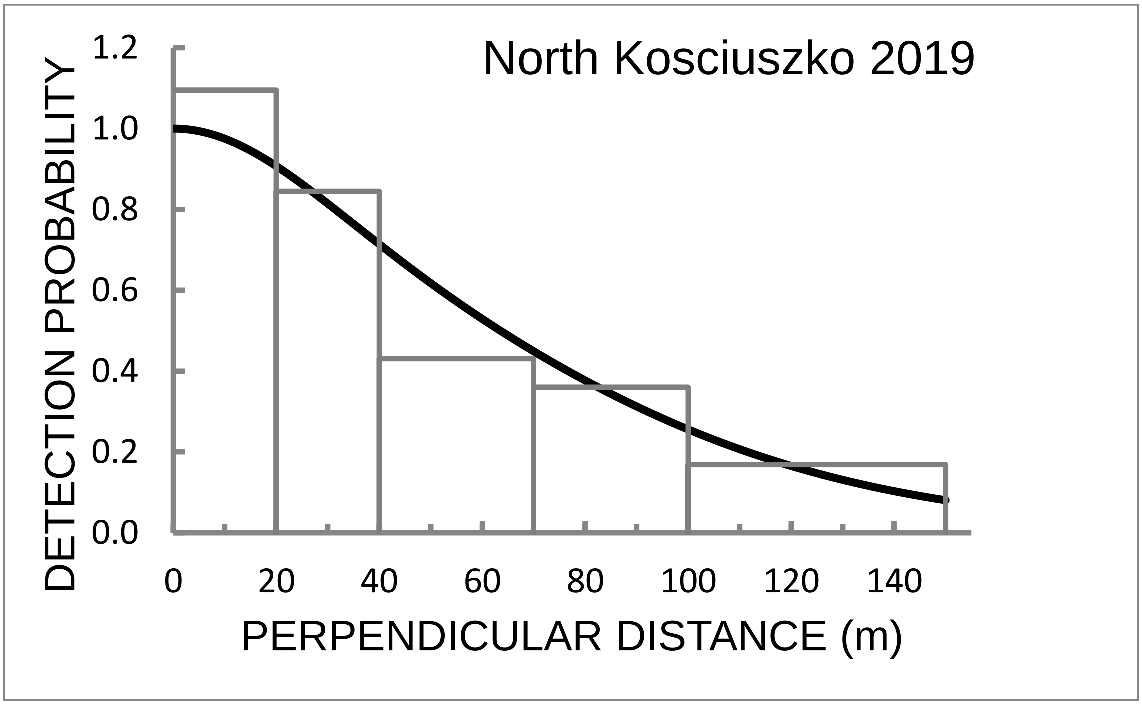

Fig. 7. The Half-normal detection function for feral horses in the North Kosciuszko survey block, 2019. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details regarding covariates, see Table 4).

For the 2014 survey in the North Kosciuszko block, a robust CDS-derived model proved to be the most parsimonious model of those tested. This model consisted of a Hazard-rate key function without any series adjustments (Table 4, Fig. 6). The goodness-of-fit this model was borderline acceptable ($P < 0.09$). The nearest alternative models to this one was a Half-normal function with a single covariate of habitat cover at point-of-detection (ΔAIC = 1.70) and then a Half-normal function with a single covariate of observer (ΔAIC = 2.64). There was a marked difference in the effective strip widths associated with these models (see later).

The most parsimonious model fitted to the survey data from the 2019 North Kosciuszko survey was the Half-normal function with two covariates (Table 4, Fig. 7). The only alternative model near to this one was a Half-normal function with a single covariate of habitat cover at point-of-detection (ΔAIC = 5.64). Unlike the comparison of the models nearest to one another in relation to the 2014 survey, the effective strip widths associated with these two models were similar; this presumably being associated with the inclusion of the covariate for the cover at point-of-detection in both models.

For the analysis of the combined results of surveys conducted in the Bago-Maragle block, the most parsimonious model was the Half-normal function with two covariates (Table 4, Fig. 8). The nearest alternative models to this one was a Half-normal function with a single covariate of habitat cover at point-of-detection (ΔAIC = 1.91) and then a Half-normal function with a single covariate of cloud cover (ΔAIC = 5.51). The effective strip widths associated with these three models were similar.

For the 2014 survey in the Byadbo-Victoria block, the most parsimonious model was the Half-normal function with two covariates (Table 4, Fig. 9). The nearest alternative models to this were a Half-normal function with the two covariates of habitat cover at point-of-detection and observer (ΔAIC = 1.61) and then a Half-normal function with the single covariate of habitat cover at point-of-detection (ΔAIC = 4.12). The effective strip widths associated with these three models were similar.

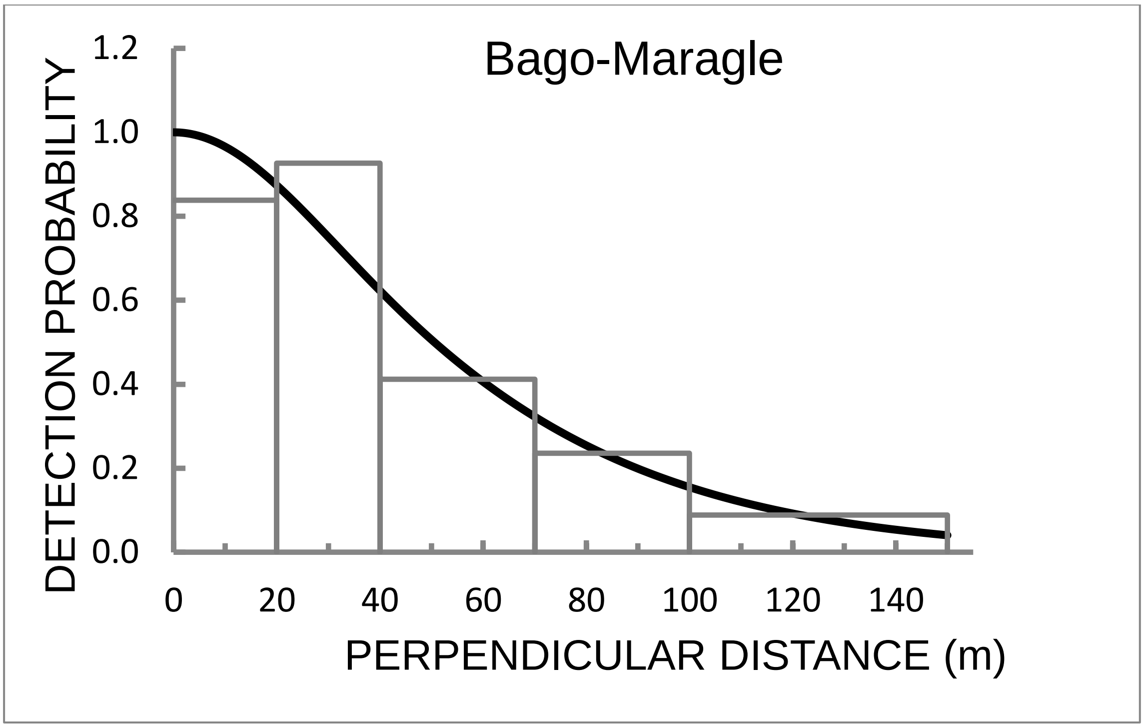

Fig. 8. The Half-normal detection function for feral horses in the Bago-Maragle survey block, 2014-2019. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details regarding covariates, see Table 4).

The most parsimonious model fitted to the survey data from the 2019 Byadbo-Victoria survey was the Half-normal function with two covariates (Table 4, Fig. 10). The nearest alternative models to this one was a Hazard-rate function with the same two covariates of habitat cover at point-of-detection and observer (ΔAIC = 1.21) and then a Half-normal function with the single covariate of habitat cover at point-of-detection (ΔAIC = 1.29). There was some difference in the effective strip widths associated with these models. In relation to the graphical representations of the detection function models shown in Figs. 6-10, although not shown it should be noted that where covariates were included in the models (Table 4), their inclusion has the effect of altering the scale of the detection function, but not its general form (Marques & Buckland 2004).

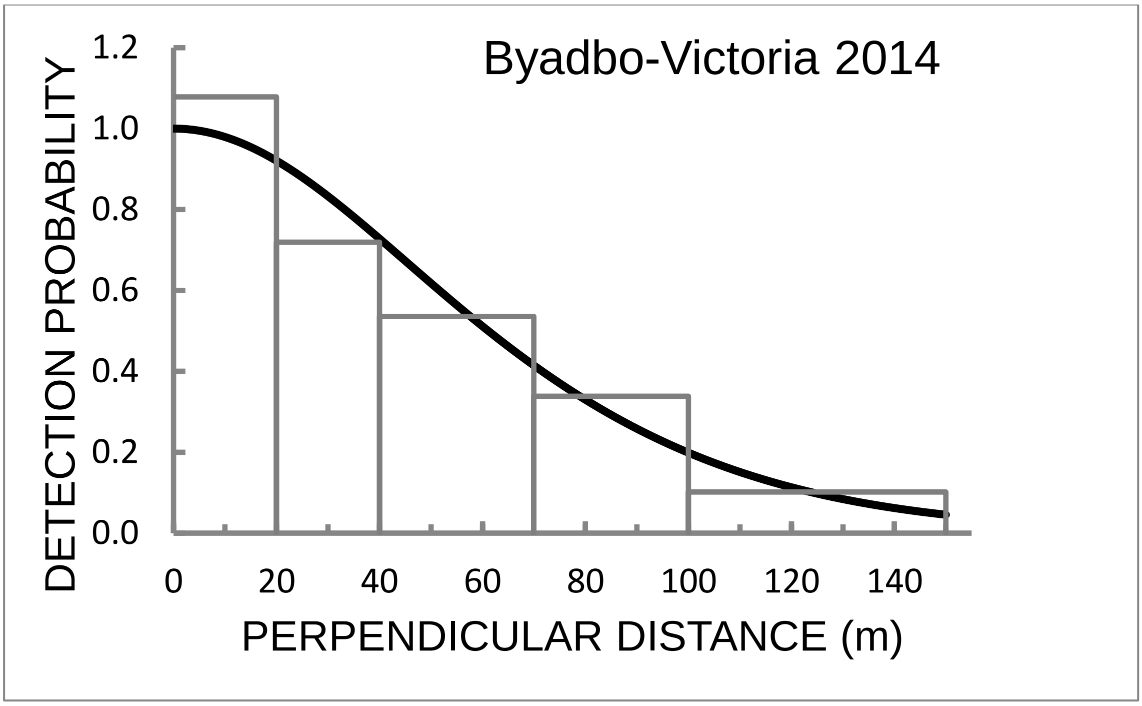

Fig. 9. The Half-normal detection function for feral horses in the Byadbo-Victoria survey block, 2014. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details regarding covariates, see Table 4).

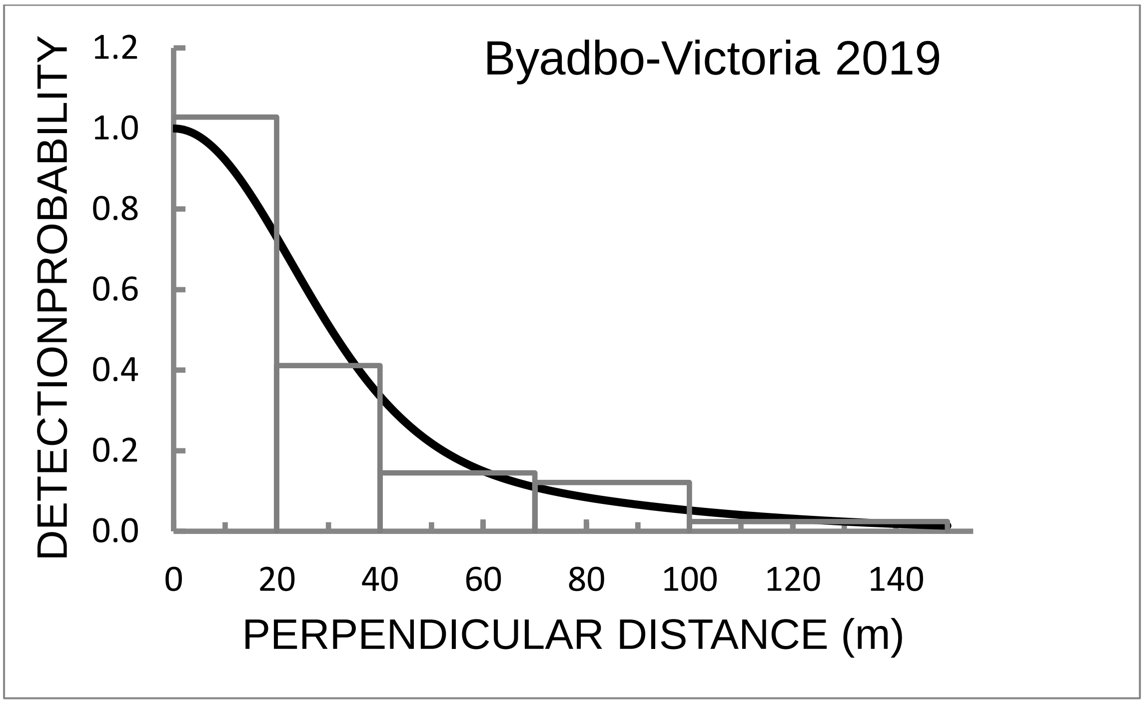

Fig. 10. The Half-normal detection function for feral horses in the Byadbo-Victoria survey block, 2019. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details regarding covariates, see Table 4).

Key to estimating the density of animals in the covered region is P_a, the probability of detecting a cluster of the animals within w, the half-width of the designated survey strip (see eqn. 1). The values of this statistic derived from the detection function models given in Table 4 are given in Table 5, along with their coefficients of variation and the associated effective strip widths (μ) referred to previously. While P_a is required as part of the estimation process, both these statistics can be viewed as indicators of the interaction between the subjects of the survey, the landscape they occupy, the conditions of the survey and the observers on the survey platform. They have some comparative value.

The probability that a randomly selected cluster of horses in the survey strip will be detected (P_a) showed some variation across survey strata and the two years; ranging from 0.25 to 0.53, with a median value of 0.43. It was higher in relation to the survey block containing more open country, i.e. the North Kosciuszko block. In contrast, the value of this statistic was particularly low for the Byadbo-Victoria block in 2019. Given that in all instances P_a <1.00, this points to the fact that it was essential that distance sampling methods were used with these surveys. If they had been undertaken as strip transect surveys, which are generally constrained by the assumption that P_a = 1.00, then the numbers of feral horses in these survey blocks would have been clearly underestimated for a strip 150 m wide. The extent of this underestimation would have been in the range of 35-70%; the highest value being in relation to the 2019 survey of the Byadbo-Victoria block.

Associated with the probability of detection is the effective strip width (μ), the perpendicular distance from the transect centreline for which as many animals (horses) are detected beyond that distance (μ) as remain undetected within that distance (Buckland *et al.* 2001). Given this, a line transect survey could be thought of as effectively covering a survey strip of a total area of 2Lμ, for some value of μ ≤ w and length L (Borchers & Burnham 2004). By virtue of the way μ is determined (μ = w x P_a; where, w is the nominal strip (half-) width of the survey transect), the higher the value of P_a, the wider will be the effective strip width. The effective strip widths determined in relation to the results of these surveys ranged from 38 m to 80 m (Table 5).

Table 5. The probabilities of detecting a cluster of horses within the nominal (150 m) survey strip (P_a), the coefficients of variation (CV%) for these estimates and the associated effective strip widths (μ) for the surveys conducted in 2014 and 2019 in the survey strata of the three blocks.

Survey block/stratum	2014			2019		
	P_a	CV(%)	μ(m)	P_a	CV(%)	μ(m)
North Kosciuszko						
Open plains	0.53	23.5	79.6	0.47	5.6	71.0
Medium terrain	0.53	23.5	79.6	0.47	14.0	71.2
Bago-Maragle	0.41	14.7	62.2	0.37	17.0	55.5
Byadbo-Victoria						
Medium terrain	0.45	6.3	66.9	0.25	7.8	37.7
Snowy River Valley	0.48	23.1	72.4	0.34	43.3	50.8

4.3 Population Estimates

Population estimates are based upon the detection of clusters of horses, the expected (average) sizes of which are estimated from the survey results. Expected cluster size was determined separately for each survey stratum. As stated in Section 3.2, estimating expected cluster size can be subject to bias, with larger clusters of horses likely to be more readily detected at greater distances from the transect centreline than are small clusters. The likelihood of this size bias occurring was tested and, if required, accounted for in the analyses. Size bias in the detection of clusters of horses was found in relation to the survey results from the Open habitat stratum of the North Kosciuszko block in 2014, from the Bago-Maragle block in 2019 and from the Medium terrain stratum in the Byadbo-Victoria block in both 2014 ans 2019. No size bias was found in any of the other survey strata; in either 2014 or 2019. The expected cluster size used to estimate numbers in relation to the surveys where size bias in detection was found was that estimated from the regression method described in Section 3.2. Where no size bias was detected, the mean observed cluster size was used.

Within the context of these surveys, clusters of horses can be defined as observational groups; each group being defined by the bounds of the distance bins in the survey strip and not by any presumed (social) relationship between individuals within the group. Two of these distance classes were 20-m wide, two were 30-m wide and one was 50-m wide. As counted, these clusters were not social groups, as might be counted in ground-based surveys, but would be variously, but immaterially, whole or parts of social groups. The size range of the clusters counted within the distance bins defined on the survey strip was 1-28, with the larger clusters being mostly encountered wider out on the survey strip, in distance classes >70 m. The expected cluster sizes used in the analyses were in the range 1.50-3.20 horses for the 2014 surveys and 2.05-4.98 horses for the 2019 surveys. Almost all of these estimates have associated with them reasonably high degrees of precision (Table 6).

Helicopter surveys for feral horses using line transect sampling have previously been conducted in a number of survey blocks within the Australian Alps (Walter 2002, 2003; Walter & Hone 2003; Dawson 2009). In analysing the results of these surveys, Walter (2002, 2003) and Walter & Horne (2003) used cluster sizes derived from survey data to estimate population sizes. However, in translating survey results to population estimates, Dawson (2009), on the pretext that cluster sizes had somehow been underestimated from survey results, replaced observed cluster sizes with a (social) group size estimated from ground observations that had been conducted in 2001. Smaller estimated observational group sizes were replaced by a larger social group size estimated from a ground survey conducted a number of years earlier. This would appear to have been a rather unorthodox step to take, particularly given the difference between the time of the aerial survey and the conduct of the ground observation study.

A re-analysis of Dawson's (2009) survey results suggested that the expected cluster sizes estimated in relation to 50-m wide distance bins on a 150-m wide survey strip were plausible and, in the case of the block surveyed in North Kosciuszko, quite near to the replacement ground-observation value of 5.65 (± 0.51 se) horses (Cairns 2014). However, the expected cluster size estimated for the more heavily timbered South Kosciuszko/North Victoria block (part of the Byadbo-Victoria block of the present surveys) was about half that estimated for the block surveyed in North Kosciuszko. It is possible that, in this instance, replacing the cluster size estimated from the aerial survey with the ground-observation value could have resulted in an overestimation of horse numbers in that area. A broadly similar comparative difference between survey blocks to that found from Dawson's survey results has been observed in relation to the 2014 and 2019 surveys reported on here (Table 6).

Table 6. The estimated sizes ($\hat{E}(c)$) of cluster of horses detected within the five distance bins in the 150 m survey strip for the surveys conducted in 2014 and 2019 in the survey strata of the three blocks. Given along with these estimates are the coefficients of variation (CV%) and the size ranges of the clusters detected. The values given in bold are regression-adjusted values (see text for further details).

Survey block/stratum	2014			2019		
	$\hat{E}(c)$	CV(%)	Range	$\hat{E}(c)$	CV(%)	Range
North Kosciuszko						
Open plains	**2.64**	9.4	1-13	4.98	5.7	1-28
Medium terrain	3.20	7.0	1-5	4.02	11.1	1-15
Bago-Maragle	2.55	9.0	1-6	**2.06**	14.6	1-7
Byadbo-Victoria						
Medium terrain	**1.91**	6.0	1-10	**2.05**	5.4	1-12
Snowy River Valley	1.50	14.9	1-3	2.40	38.6	1-6

The observational cluster sizes estimated from the surveys reported on here that were conducted in 2014 and 2019 are not implausible, having been estimated from counts made mostly in relation to distance bins within the survey strip that were narrower than 50 m wide. If the distance bins are narrower and the observational cluster sizes accordingly smaller, then there is more than likely to be a compensatory increase in the numbers of clusters counted, assuming similar horse densities. Defining clusters by the bounds of the distance bins on the survey strip should take some of the arbitrariness out of the counting and distance placement process.

In relation to the issue of accuracy (and precision) of estimation, it is contended that the surveys undertaken here, both in 2014 and in 2019, have addressed this potential problem through the use of experienced observers capable of accurately counting under survey conditions the observational groups (clusters) of horses within delineated distance bins on the survey strip. This was enhanced by the increased survey effort and stratification of the survey areas within the blocks which allowed the variable cluster sizes in different habitat types within the Alps be accounted for in the analysis. Some random error is, of course, an unavoidable part of data collection. It can, however, be controlled in the analysis/modelling process using DISTANCE 7.3.

The densities of clusters of horses and the corresponding population densities in each survey block in the 2014 survey are given in Table 7. There was a marked difference in both cluster and individual horse density between the two survey strata in the North Kosciuszko block. Both these densities were much higher in the Open plains stratum than in the Medium terrain stratum. This presumably shows a marked preference on the part of the horses for the Open plains habitat. Densities of clusters across the three survey blocks were reasonably similar, but individual densities were higher in the North Kosciuszko block than in the Bago-Margle block, than in the Byadbo-Victoria block. Dawson (2009) had also recorded densities higher in the North Kosciuszko block than within a second, South Kosciuszko/North Victoria block.

The densities of clusters of horses and the corresponding population densities in each survey block in the 2019 survey are given in Table 8. Both these densities were much higher in the Open plains stratum than in the Medium terrain stratum of the North Kosciuszko block; the extent of the difference in population density being somewhat larger than it was in 2014. Densities of clusters across the three survey blocks were no longer similar, as was found to be the case in 2014 (Table 7). Individual densities were substantially higher in the North Kosciuszko block than in the either of the other two survey blocks, with the density in the Bago-Maragle block showing an apparent decline from its 2014 level.

Table 7. Results of the helicopter line transect surveys of feral horses conducted in the three Australian Alps survey blocks in April-May, 2014. Given for each block is the area of the strata surveyed, the density of clusters of horses sighted (D_s) and the horse population density (D). Given in association with the two density estimates are the empirically-estimated and bootstrap-estimated coefficients of variation (CV %), and the bootstrap confidence intervals.

Survey block/stratum	Area (km^2)	Cluster density (km^{-2})				Population density (km^{-2})			
		D_s	CV (%)	95% bootstrap confidence interval	CV_{boot} (%)	D	CV (%)	95% bootstrap confidence interval	CV_{boot} (%)
<u>North Kosciuszko</u>									
NK Open	618	1.31	29.1	0.55-3.65	55.2	3.45	30.6	1.73-6.44	46.0
NK Medium	748	0.47	37.7	0.17-1.67	64.8	1.50	38.3	0.67-2.97	63.7
NK Combined	1,366	0.85	27.9	0.43-1.86	55.7	2.38	28.7	1.35-4.32	43.7
<u>Bago-Maragle</u>	847	0.74	29.3	0.45-1.30	27.1	1.91	30.7	1.09-3.31	28.3
<u>Byadbo-Victoria</u>									
Byadbo	3,098	0.70	12.7	0.52-1.04	21.9	1.34	14.2	0.98-2.30	27.0
Snowy River Valley	139	0.80	45.5	0.25-1.50	39.6	1.29	47.9	0.33-2.29	43.2
BV Combined	3,237	0.71	-	0.52-1.03	21.0	1.33	-	1.00-2.26	26.2

Table 8. Results of the helicopter line transect surveys of feral horses conducted in the three Australian Alps survey blocks in April-May, 2019. Given for each block is the area of the strata surveyed, the density of clusters of horses sighted (D_s) and the horse population density (D). Given in association with the two density estimates are the empirically-estimated and bootstrap-estimated coefficients of variation (CV %), and the bootstrap confidence intervals.

		Cluster density (km^{-2})				Population density (km^{-2})			
Survey block/stratum	Area (km^2)	D_s	CV (%)	95% bootstrap confidence interval	CV_{boot} (%)	D	CV (%)	95% bootstrap confidence interval	CV_{boot} (%)
North Kosciuszko									
NK Open	618	3.95	14.1	2.87-5.27	15.7	19.64	15.2	13.18-25.76	17.4
NK Medium	748	1.18	40.9	0.54-2.08	34.7	4.75	42.4	2.17-8.63	37.8
NK Combined	1,366	2.43	-	1.78-3.38	16.7	11.48	-	7.75-15.06	17.0
Bago-Maragle	847	0.64	32.5	0.31-1.061	31.3	1.31	35.7	0.65-3.14	40.8
Byadbo-Victoria									
Byadbo	3,098	1.31	13.0	1.01-1.78	14.1	2.68	14.1	2.00-3.97	18.0
Snowy River Valley	139	0.64	61.7	0.13-1.43	50.7	1.53	72.8	0.10-2.61	61.7
BV-SRV	3237	1.28	-	0.98-1.70	14.0	2.63	-	1.95-3.85	17.8

For the 2014 estimates, the precision for both cluster density and population density, determined either empirically or by bootstrapping the data, was somewhat variable across the survey blocks, with this variability being accentuated at the stratum level. It was high in the Byadbo-Victoria block, but relatively low in the Bago-Maragle block and particularly low in the North Kosciuszko block (Table 7). For the 2019 estimates, precision of the estimates for the Byadbo-Victoria block was reasonably high, as it was for the density estimates determined for the North Kosciuszko block. The precision of the estimates for the Bago-Maragle block in 2019 was, however, lower than that determined for the 2014 density estimates for this block (Table 8).

If required, the overall levels of precision of future surveys could be improved by increasing the survey effort. This could be done either by increasing the number of transect lines across the survey area, something that would be possible in the Bago-Maragle block but perhaps not possible in the North Kosciusko block because of the already closeness of the transects of the current survey, or by repeat sampling of existing transect lines. As previously suggested (Cairns 2014), if budgetary constraints were an issue, increasing survey effort in the North Kosciuszko and Bago-Maragle blocks could be done by reducing the survey effort expended on the Byadbo-Victoria block, for which the precision of the present survey was particularly high. In fact, by taking an adaptive management approach to designing any future surveys on these blocks, survey effort could be determined in relation to a prescribed level of precision, which would almost certainly mean reducing the effort in some survey areas and correspondingly increasing it in others. An approach similar to this is taken in relation to kangaroo surveys conducted in the NSW tablelands kangaroo management zones (e.g., Cairns, Bearup & Lollback 2019).

Bootstrap coefficients of variation and confidence intervals were calculated for all estimates, with the bootstrap confidence intervals being given in preference to standard normal-theory confidence intervals (Tables 7 and 8). This approach is becoming more common and is recommended because it relaxes the constraint of assuming that data are normally distributed and confidence intervals are therefore symmetrical (Crawley 2005). The confidence intervals for both the estimates of cluster density and population density were slightly positively skewed, indicating that the data were not normally distributed. This was accentuated when the densities were translated to population abundances (see Tables 9 and 10). The bootstrap coefficients of variation proved useful when this statistic could not be estimated empirically, as was the case for the combined estimates for the North Kosciuszko block in 2019 and Byadbo-Victoria block in both 2014 and 2019 (Table 8).

The estimated population densities given in Tables 7 and 8 were translated to population abundances by multiplying them by the area of the proportion of each block that was surveyed. There were parts of each block that were not surveyed either because of the steepness of the terrain or because the land was under private ownership and were therefore not included in the calculations of population abundance (see Section 2.1). In 2014, the largest population of horses was in the large Byadbo-Victoria block, with the second largest population being in the North Kosciuszko block and the smallest population being in the Bago-Maragle block (Table 9). In 2019, the largest population of horses was recorded in the North Kosciuszko block, with the second largest population being in the Byadbo-Victoria block and the smallest again being in the Bago-Maragle block (Table 10).

Given along with the population abundances in Tables 9 and 10 are a second set of population densities. These are densities derived in relation to the total areas of the survey blocks. Implicit in their estimation are the assumptions that the horse population in a block would be aggregated in its distribution and that the density of horses in the very steep country within the survey blocks would be at trace levels; i.e. near to zero. This assumption could be open to challenge, but could only be refuted with comparable survey results. The proportions of the North Kosciuszko and the Bago-Maragle blocks not surveyed was relatively low at around 12%. However, in the Byadbo-Victoria block, some 35% of the area was not surveyed because it comprised steep and heavily timbered terrain. Because they were determined in relation to the total area of each survey block and not just the area surveyed, the densities given in Tables 9 and 10 are lower than those given in Tables 6 and 7, respectively.

Table 9. The population estimates (N) and density estimates (D), adjusted for the area of the whole survey block, of feral horses in each of the three survey blocks in the Australian Alps in April-May 2014. Given with these estimates are the 95% bootstrap confidence intervals and the bootstrap coefficients of variation (CV_{boot}).

Survey block	Area (km^2)	N	95% bootstrap confidence interval	D (km^{-2})	95% bootstrap confidence interval	CV_{boot} (%)
North Kosciuszko						
NK Open		2,131	1,071-3,984			
NK Medium		1,124	413-2,728			
NK Combined	1,549	3,255	1,846-5,900	2.10	1.19-3.81	43.7
Bago-Maragle	948	1,616	782-2,574	1.70	0.82-2.72	28.3
Byadbo-Victoria						
Byadbo		4,150	3,043-7,111			
Snowy River Valley		166	46-318			
BV-SRV	4,946	4,316	3,316-6,577	0.87	0.67-1.33	26.2
Australian Alps	7,443	9,187		1.23		19.0

Table 10. The population estimates (N) and density estimates (D), adjusted for the area of the whole survey block, of feral horses in each of the three survey blocks in the Australian Alps in April-May 2019. Given with these estimates are the 95% bootstrap confidence intervals and the bootstrap coefficients of variation (CV_{boot}).

Survey block/stratum	Area (km^2)	N	95% bootstrap confidence interval	D	95% bootstrap confidence interval	CV_{boot} (%)
North Kosciuszko						
NK Open		12,139	8,416-15,918			
NK Medium		3,547	1,320-6,657			
NK Combined	1,549	15,687	10,598-20,569	10.13	6.84-13.38	17.0
Bago-Maragle	948	1,113	463-2,364	1.17	0.49-2.49	40.8
Byadbo-Victoria						
Byadbo		8,305	6,196-12,288			
Snowy River Valley		213	14-362			
BV-SRV	4,946	8,518	6,321-12,464	1.72	1.28-2.52	17.8
Australian Alps	7,443	25,318		3.40		12.3

With surveys of the feral horse populations in these three blocks having now been undertaken on two occasions, five years apart, and using essentially the same survey methods on the same survey strata, an assessment can be made of the changes in the numbers of horses in these blocks over this period. Population estimates were compared using the methods given in Buckland *et al.* (2001, pp 84-86). Also, to help further understand the broader dynamics of the changes in feral horse numbers that have occurred within the three survey blocks over the five years between successive surveys, the annual finite rate of population increase (λ) were determined. This statistic is a compound multiplier representing the rate at which a population would increase over unit time (Krebs 1994). The annual finite rates of population increase for the horse populations in each of the three survey blocks are given in Table 11. Using a method proposed by Rexstad (2016), uncertainty in these rates of population change was determined from 1,000 realisations of the respective population estimates for each survey block drawn from a log-normal distribution. This enabled 95% confidence limits on the estimated values of λ to be determined as the lower and upper 2.5% quantiles of the 1,000 realisations (Table 11).

In the North Kosciuszko block, the feral horse population was estimated to have increased from 3,255 individuals in 2014 to 15,687 individuals in 2019. This represented a significant increase in numbers over the five years between surveys ($z = 4.12$; $P<0.001$). This increase in numbers translated into a particularly high annual finite rate of increase (λ) of 1.370 (i.e. 37%) per individual per year for the horse population in this survey block. This annual rate of increase exceeds the maximum rate ($\lambda = 1.220$) that has been proposed by Walter (2002). Examination of the results of the simulations of λ for this population show that the probability that the annual rate of increase exceeds that for replacement ($\lambda = 1$) for the period between surveys was essentially certain, and that the probability that it exceeds the maximum rate of increase predicted by Walter (2002) is $P = 0.94$. Although, in most instances, the annual population growth rates for wild horse populations are often reported to be in the range 10-22%, growth rates as high as 37%, whilst not commonly reported, are not unheard of (Grange *et al.* 2009; Scorolli & Lopez Cazorla 2010).

Table 11. The numbers of feral horses (N) and bootstrap standard errors (se) in the three survey blocks estimated from the results of the aerial surveys conducted in 2014 and 2019. Given in association with these estimates are the annual finite rates of population increase (λ) for the intervening period between the surveys and the confidence intervals for these estimates of population increase.

Survey block	2014		2019			
	N	se	N	se	λ	CI
North Kosciuszko	3,255	1,423	15,687	2,667	1.370	1.176 – 1.658
Bago-Maragle	1,616	457	1,113	454	0.928	0.754 – 1.124
Byadbo-Victoria	4,316	1,131	8,518	1,518	1.146	1.017 – 1.301
Australian Alps	9,187	1,741	25,318	3,102	1.225	1.123 – 1.339

There are factors that could account for the estimated high rate of increase in this population. These include the fact that the North Kosciuszko is not an enclosed area and, apart from recruitment into the population through births (countered to some extent by expected deaths), this area could well have seen a substantial movement of horses into it from outside the survey area over the period between the two surveys. It is relatively close to the Bago-Maragle block and the Australian Capital Territory (Fig. 1), two areas known to support feral horse populations (J. McCrae, *pers. comm*.). Also, it is distinctly possible that the Open plains habitat, where horse density was highest (Table 8), could well be thought of as being preferred habitat for large grazing animals such as horses. Further, affecting this could be that there has been little or no management of the feral horse population in North Kosciuszko in the intervening period between surveys, with records showing that only 881 horses were trapped and removed from the area in that five-year period (R. Gibbs, *pers. comm*.). With this estimated rate of increase, the feral horse population in the North Kosciuszko block would have a doubling time of 2.20 years. From aerial surveys conducted by Dawson (2009) of the feral horse population in the general region of the current North Kosciuszko survey block, the density of horses in this region was estimated to be 2.33 km^{-2} (Rexstad 2016). In comparison to the estimate of the density of horses in the survey area determined from the 2014 survey results (2.38 km^{-2}: Table 7), the annual finite rate of population increase for the period 2009-2014 was 1.004 (0.839-1.212); a rate substantially lower than that determined for the period 2014-2019, and essentially near to that for replacement ($\lambda = 1$).

In the Bago-Maragle block, the population was estimated to have declined from 1,616 individuals in 2014 to 1,113 individuals in 2019. This amounted to there being effectively no change in the size of the horse population in this block over the five years between surveys ($z = 0.30$; $P = 0.382$). The fact that a common detection function was used in determining the two population estimates was taken into account when testing for any difference between them (Buckland *et al.* 2001). This essentially static situation is associated with an estimated annual finite rate of increase for the feral horse population in the Bago-Maragle block of 0.928 per individual per year, which is equivalent to an annual rate of decline of 7%. In association with this, examination of the simulations of λ for this population show that the probability that the annual rate of increase is less that for replacement (λ = 1) for the period between surveys is P = 0.80. Associated with the perceived decline in numbers might be the fact that since the 2014 survey, some areas of preferred open habitat within this survey block had been enclosed by fencing in order to exclude horses and hence protect identified and formally listed Endangered Ecological Communities of alpine and montane peatland bogs (G. Robertson, *pers. comm*.). This exclusion could be expected to have some impact on the distribution and abundance of feral horses in this survey block. If the population in the Bago-Maragle block was declining at an annual rate of 7%, it would be expected to halve in 9.28 years.

In the Byadbo-Victoria block, the population increased from 4,316 individuals in 2014 to 8,518 in 2019. This represented a significant increase in numbers over the five years between surveys (z = 2.41; P = 0.008). This increase in numbers translated into an annual finite rate of increase (λ) of 1.146 (i.e. 15%) per individual per year for the horse population in this survey block. Examination of the results of the simulations of λ for this population show that the probability that the annual rate of increase exceeds that for replacement (λ = 1) for the period between surveys is essentially certain, and that the probability that it exceeds the maximum rate of increase predicted by Walter (2002) is P = 0.13. With this estimated rate of increase, the feral horse population in the Byadbo-Victoria block would have a doubling time of 5.09 years. From aerial surveys conducted by Dawson (2009) of the feral horse population in in the general region of the current Byadbo-Victoria survey block, the density of horses was estimated to be 1.13 km^{-2} (Rexstad 2016). In comparison to the estimate of the density of horses in the survey area determined from the 2014 survey results (1.33 km^{-2}: Table 7), the annual finite rate of population increase for the period 2009-2014 was 1.033 (0.928 – 1.155), i.e. increasing annually at a modest 3%

If the three populations are combined and assumed to represent the total feral horse population in the Australian Alps, then a total population of 9,187 in 2014 increased to one of 25,318 in 2019, with a finite rate of increase of 1.225 (i.e. 23%) per individual per year. This is broadly equivalent to a maximum of 1.220 (i.e. 22%) for horse populations in the Australian Alps that had been proposed by Walter

(2002). By way of comparison, Dawson (2009) estimated a finite rate of increase for the horse population in the AANP over the period 2003-2009 of 1.217 per individual per year (i.e. 22%). Compared to this, it would appear that the horse population in Alps showed little or no increase in size between 2009 and 2014, but has, of course, increased in size since 2014. Although the probability that the finite rate of increase of the horse populations in North Kosciuszko for the period 2009-2014 exceeds that of replacement (λ = 1) was P = 0.063, for the horse population in Byadbo-Victoria, this probability was considerably lower at P = 0.123 (Rexstad 2016).

4.4 Other Species

Apart from horses, and apart from macropods, some other species of large herbivore were counted during the surveys. These included introduced deer, domestic cattle, feral goats and feral pigs. The numbers of these species sighted during the 2014 and 2019 surveys are given in Table A1. The most numerous of these species sighted during these surveys were introduced deer. Most of these were recorded in the Byadbo-Victoria block; there being enough sightings for determining population estimates in this large survey block (Table A1). Although these deer were not identified to species, it is thought, based on some local knowledge (S. Seymour and G. Robertson, pers. com.), that they were mostly sambar deer (*Rusa unicolor*), with some fallow deer (*Dama dama*) also being sighted.

The counts of deer in the Byadbo-Victoria block were analysed using the CDS and MCDS analysis engines of DISTANCE 7.3. 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 two surveyed strata within the block, the Medium terrain stratum and the Snowy River Valley stratum, with a single detection function being fitted to data from both strata.

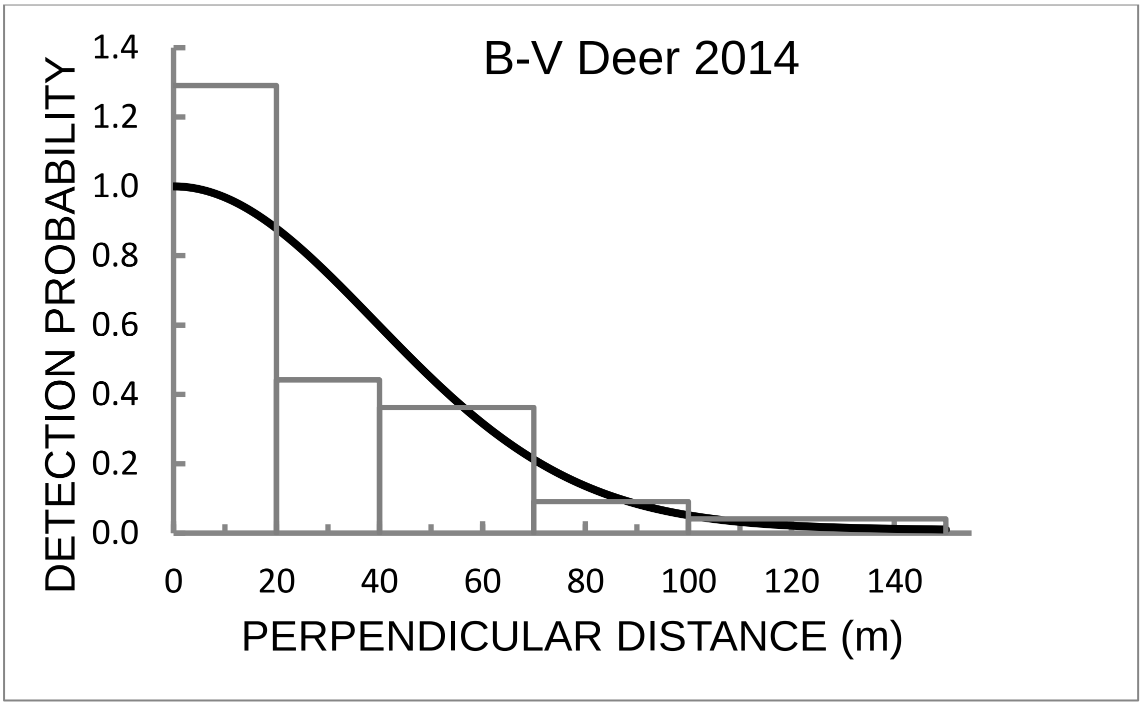

Fig. 11. The Half-normal detection function for deer in the Byadbo-Victoria survey block, 2014. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details regarding covariates, see text).

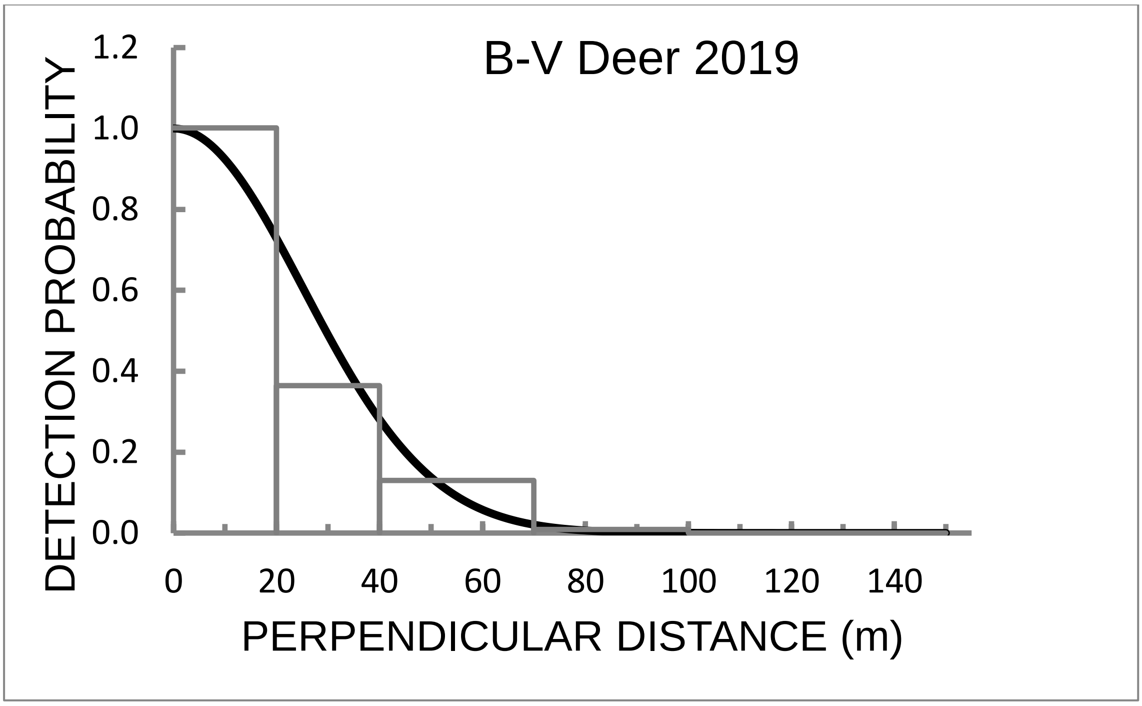

Fig. 12. The Half-normal/Hermite polynomial detection function for deer in the Byadbo-Victoria survey block, 2019. This detection function was derived using the CDS analysis engine of DISTANCE 7.3 (for further details, see text).

For the analysis of the 2014 survey results, the most parsimonious global detection function model was a Half-normal model with a single covariate of habitat cover at point-of-detection (Fig. 11). The values for the probability of detection (P_a) and the effective strip width (μ) were 0.34 and 50.9 m, respectively. For the analysis of the 2019 survey results, the most parsimonious detection function model was a Half-normal/Hermite polynomial model (Fig. 12); a robust model without any covariates. The values for the probability of detection (P_a) and the effective strip width (μ) were 0.21 and 31.4 m, respectively. In both instances, these values are somewhat lower than those for horses in this block (Table 5); this probably being in line with deer being smaller and somewhat more cryptic in the landscape than are horses.

The population densities and abundances of deer in the two strata of the Byadbo-Victoria survey block are given in Table 12. The densities given are for the two strata surveyed. Thirty-five percent of the Byadbo-Victoria block was not surveyed because it comprised steep terrain. As was the case with horses, it has been assumed that deer numbers in this steep terrain stratum were at trace, negligible levels, and that the estimates given for the sizes of the deer population are plausible estimates for the whole of the Byadbo-Victoria block. This is an assumption that could be open to challenge. However, if it can be assumed to be true, then the densities of deer for the whole block (4,946 km^2) were 0.46 km^{-2} in 2014 and 1.54 km^{-2} in 2019. With estimated densities as high as this, particularly with regard to the 2019 survey, deer must come a strong second to horses as having an impact as herbivores in the Byadbo-Victoria block. The density of feral horses in this block in 2019 was estimated to be 1.72 km^{-2}. With an annual finite rate of population increase (λ) of 1.274 (1.161-1.397) per individual per year, the deer population in this large block is more than comparable to the horse population in terms of demographic performance. The estimated annual finite rate of increase for the horse population over the period 2014-2019 was 1.146 (Table 11).

Table 12. Results of the helicopter line transect surveys of introduced deer conducted in the Byadbo-Victoria survey block in April-May, 2014 and April-May 2019. Given separately and combined for each of the two strata 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/stratum	Deer population density (km^{-2})				Deer population abundance	
	D	CV (%)	95% bootstrap confidence interval	CV_{boot} (%)	N	95% bootstrap confidence interval
2014						
Medium terrain	0.54	22.4	0.34-0.83	21.7	1,666	1,062-2,566
Snowy River Valley	4.39	34.1	2.07-7.25	31.8	610	331-1,143
Byadbo-Victoria	0.70	–	0.54-1.21	20.6	2,277	1,608-3,257
2019						
Medium terrain	2.23	15.9	1.55-3.37	20.4	6,916	4,817-10,454
Snowy River Valley	5.15	28.6	2.15-8.72	58.3	716	299-1,213
Byadbo-Victoria	2.36	15.0	1.65-3.52	19.7	7,632	5,354-11,369

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Table A1. The numbers of introduced deer, cattle, feral goats and feral pigs recorded in the 2014 and 2019 surveys of the strata within of the three feral horse survey blocks.

Survey block/Stratum	Area (km^2)	2014				2019			
		Deer	Cattle	Goats	Pigs	Deer	Cattle	Goats	Pigs
North Kosciuszko	1,366								
Open plains	618	–	–	–	–	6	–	–	11
Medium terrain	748	–	5	–	–	11	1	–	2
Bago-Maragle	847	6	–	–	–	28	1	–	1
Byadbo-Victoria	3,237								
Medium terrain	3,098	87	140	5	37	217	42	5	12
Snowy River Valley	139	37	–	1	5	25	–	–	–