A report to the New South Wales Department of Climate Change, Energy, the Environment and Water (DCCEEW) on the consultancy: "Design and analysis of helicopter surveys of kangaroo populations in the South East NSW kangaroo management zone, 2024".

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Summary

1. Helicopter surveys for kangaroos were conducted using line transect sampling in the seven survey blocks that make up the South East NSW kangaroo management zone. The population estimates derived from these surveys were intended to be used to set quotas for the 2025-2027 commercial harvests of eastern grey kangaroos (*Macropus giganteus*) from within this management zone.
2. The surveys were designed using an automated survey design algorithm of DISTANCE 7.5 (Strindberg, Buckland & Thomas 2004; Thomas *et al.* 2010). To facilitate survey design, each survey block was divided into two or three strata based upon land capabilities and relative kangaroo density. Those strata identified as most likely to be supporting medium to high densities of kangaroos were then surveyed. Low kangaroo density strata were not surveyed.
3. Surveys were designed with the aim of estimating eastern grey kangaroo numbers with a reasonably high level of precision. Overall, this was achieved with these surveys; with the coefficients of variation of the population estimates obtained for eastern grey kangaroos being in the range 15-25%
4. The density of eastern grey kangaroos in the management zone was estimated to be 35.5 km^{-2} which corresponded to a population estimate of 1,527,130 kangaroos. This compares to a population of 1,428,800 kangaroos estimated from a previous survey conducted in 2021.
5. Since the previous survey conducted in 2021, the eastern grey kangaroo population in this management zone has remained essentially unchanged. Prior to this, it had declined by a sharp 21% between 2018 and 2021 in response to prevailing drought during that period. Before that, the long-term trend in eastern grey kangaroo numbers in this management zone had been such that the population had been increasing at an annual rate of 11% over the period 2009-2018.
6. Three other species of macropod, the common wallaroo (*M. robustus*), the red-necked wallaby (*M. rufogriseus*) and the swamp wallaby (*Wallabia bicolor*) were recorded in this survey. There were enough sightings of each of these species for population estimates to be determined.

1. Introduction

All states and territories of the Commonwealth of Australia administer, in one form or another, macropod management plans. Commercial harvesting conducted by licensed harvesters is generally a significant component of the management of the populations of the large kangaroo species that are variously widespread and abundant throughout much of the continental Australia. The commercial harvesting of large kangaroos is undertaken in all five mainland states. Currently, it plays no part in macropod management in either the Australian Capital Territory or the Northern Territory. Further, large kangaroos are not harvested in Tasmania.

In those states where it is undertaken, the commercial harvest is limited by quotas that are set with the intention of ensuring population and harvest sustainability. It is a legislative requirement that any commercial harvesting of kangaroos be conducted on a sustainable basis (e.g., Anon. 2022). In order to set appropriate harvest quotas, it is necessary to obtain reasonably precise and accurate estimates of the sizes of the kangaroo populations proposed to be harvested. Species-specific quotas are set as proportions of these population estimates.

In New South Wales (NSW), some or all four of those species of macropod identified as large kangaroos, the red kangaroo (*Osphranter rufus*), the eastern grey kangaroo (*Macropus giganteus*), the western grey kangaroo (*Macropus fuliginosus*) and the common wallaroo or euro (*Osphranter robustus*), are currently harvested from within 15 kangaroo management zones (Anon. 2016, 2022). Nine of these management zones are located on the inland western plains. The other six are located on the tablelands and western slopes of the Great Dividing Range.

Estimates of the sizes of the kangaroo populations in the inland management zones are obtained from aerial surveys conducted annually using fixed-wing aircraft and, more recently, the method of line transect sampling (Anon. 2022). Harvest quotas for the next calendar year following the surveys are set in relation to these population estimates. Because of the general relief of the landscape in those management zones that cover the tablelands and western slopes, the kangaroo populations there cannot be surveyed using fixed-wing aircraft. Instead, they are currently surveyed on a triennial basis using helicopters and the method of line transect sampling. Annual harvest quotas for these management zones are set for the next three successive years in relation to the population estimates obtained from these surveys (Anon. 2022). The suitability and effectiveness of helicopter line transect sampling of kangaroo populations has been demonstrated by Clancy, Pople and Gibson (1997), and Clancy (1999).

Conducting these surveys on a triennial basis is considered to be a safe option for monitoring kangaroo populations in mesic environments such as the tablelands and western slopes of NSW, as opposed to semi-arid rangeland environments (Pople 2003, 2008). According to Pople (2008), the risk of quasi-extinctions occurring in relation the setting of harvest quotas using triennial population estimates is relatively low in mesic environments.

One of the six kangaroo management zone along the Great Dividing Range is the South East Tablelands kangaroo management zone (see Fig. 1). When established and first surveyed in 2003, this zone comprised five Rural Land Protection Board (RLPB) districts (Cairns 2004, 2007). It was later expanded in size with the addition of a two more RLPB districts (Cairns, Lollback & Bearup 2010; Cairns, Bearup & Lollback 2016). The RLPB districts now no longer exist as administrative/management units, but they remain as defined blocks within this kangaroo management zone for the purpose of survey design. Across NSW, clusters of RLPB districts have now been combined to form Local Land Service regions (see http://www.lls.nsw.gov.au/).

The original five RLPB districts (hereafter referred to as survey blocks owing to the redundancy of the RLPB) comprising the management zone were first surveyed in the early spring of 2003 in accordance with the survey plan developed as part of a feasibility study conducted the previous year (Pople, Cairns & Menke 2003). The outcome of this survey was reported in Cairns (2004) and harvest quotas for eastern grey kangaroos were set for a three-year trial period (2004-2006). The harvest offtake for each of the survey blocks comprising the South East Tablelands kangaroo management zone were monitored during this period and a second helicopter survey undertaken three years after the first, in early spring 2006 (Cairns 2007). This second survey was redesigned in relation to the density distributions of eastern grey kangaroos reported as a result of the first survey (Cairns 2004). A third survey was conducted in early spring 2009, with the incorporation of the Young survey block (former RLPB district) into the management zone and further adjustment being made to stratum boundaries based on the density distributions of eastern grey kangaroos reported in the first and second surveys (Cairns, Lollback & Bearup 2010). With this kangaroo management zone now established operationally, a fourth survey was conducted in early spring 2012 (Cairns, Lollback & Bearup 2013). As well as the survey of the six survey blocks comprising the management zone, a survey was also undertaken in an area to the southeast of the management zone that was based upon the former Bombala RLPB district. In 2015, a fifth survey was undertaken of the six survey blocks comprising the management zone (Cairns, Bearup & Lollback 2019). The Bombala block was not surveyed. A sixth survey was undertaken in early spring 2018 (Cairns, Bearup & Lollback 2019). This survey was of an expanded management zone, one that included the Bombala survey block. The Bombala survey block is now an integral part of the South East NSW kangaroo management zone. Three years later, a seventh survey was undertaken in early spring 2021 (Cairns, Bearup & Lollback 2022).

Following on from the seven surveys conducted to date, an eighth survey was undertaken in early spring 2024. Reported on here, in relation to the survey design and the survey and data analysis methods used, are the results of this eighth triennial survey. The population estimates obtained from this survey will be used to set the 2025-2027 harvest quotas for eastern grey kangaroos in the South East Tablelands kangaroo management zone.

2. Study Area: South East Tablelands Kangaroo Management Zone

The South East Tablelands kangaroo management zone (Fig. 1) is a large management zone which surrounds the Australian Capital Territory. It is subdivided into seven survey blocks which were formerly identified as Rural Lands Protection Board (RLPB) districts: Bombala, Braidwood, Cooma, Goulburn, Gundagai, Yass, and Young. The Bombala, Braidwood, Cooma, Goulburn and Yass survey blocks now comprise part of the South East Local Land Services region. The Gundagai and Young survey blocks are now part of the Riverina Local Land Services region.

Biogeographically, this management zone comprises parts of the South Eastern Highlands Biogeographic Region (IBRA) and the South Western Slopes Biogeographic Region (IBRA) (Sahukar *et al.* 2003). The Bombala, Braidwood, Cooma and Goulburn survey blocks are all within the South Eastern Highlands Biogeographic Region. The Gundagai and Yass survey blocks lie substantially within the South Eastern Highlands Biogeographic Region, with their western edges extending into the South Western Slopes Biogeographic Region. The Young survey block lies entirely within the South Western Slopes Biogeographic Region.

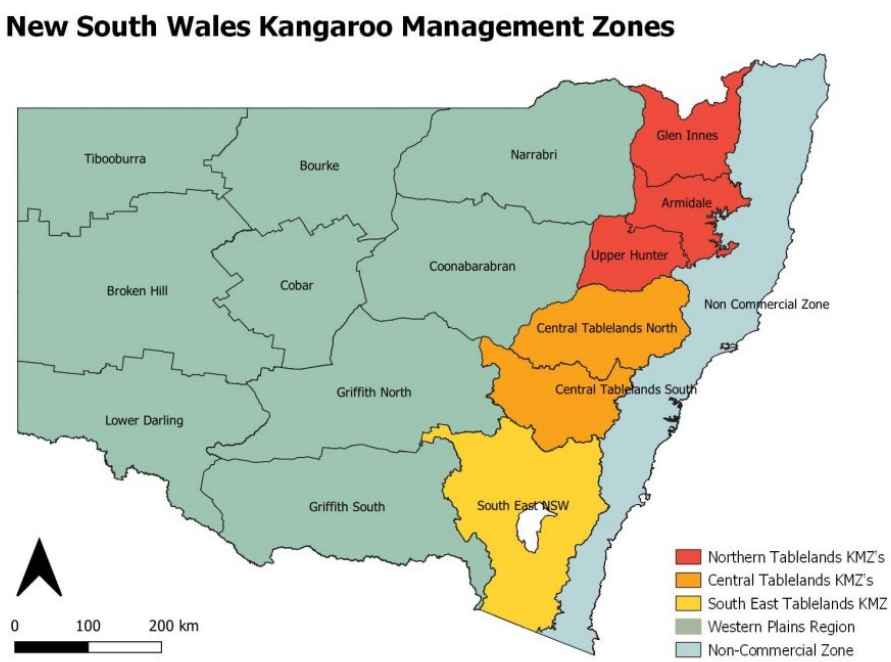

Fig. 1. The 15 kangaroo management zones administered by NSW DCCEEW.

The characteristic landforms of the South Eastern Highlands Biogeographic Region comprise the dissected ranges and plateau of the Great Dividing Range that are topographically lower than the Australian Alps, which lie towards the southwest of this bioregion (Sahukar *et al.* 2003). In the east, this bioregion extends to the Great Escarpment, while its western slopes comprise part of the inland drainage of the Murray-Darling basin. The topography of this bioregion comprises relatively steep, hilly and undulating terrain, giving way in the west to hilly ranges and peaks set in wide valleys. The characteristic landforms of the South Western Slopes Biogeographic Region are represented by a large area of foothills and ranges that extend from the western fall of the Great Dividing Range to the edge of the Riverina bioregion (Sahukar *et al.* 2003). The topography of the South Western Slopes Biogeographic Region also comprises some relatively steep, hilly and undulating terrain, giving way towards the west to hilly ranges and peaks set in wide valleys.

For the purpose of surveying this management zone, areas of national park, state forest urban consolidation and high relief were excised from the area to be surveyed (see Table 1). Following this, each survey block was subdivided into either two or three strata based upon the suitability of the terrain for the conduct of aerial surveys, agricultural land use, and kangaroo occupancy and relative density (see Section 3.1). This subdivision was initially undertaken using information on landscape relief, vegetation cover and land use, and anecdotal information on kangaroo densities obtained from National Parks and Wildlife Service (NPWS) and Local Land Services offices (Pople, Cairns & Menke 2003). Stratification of the survey blocks has been periodically updated in relation to the results of subsequent helicopter surveys (Cairns 2004, 2007; Cairns, Lollback & Bearup 2010, 2013). Areas of high relief were excluded from the surveys. An update of these stratifications in relation to national estate lands and urban consolidation was undertaken for the 2021 survey (Cairns, Bearup & Lollback 2022). In relation to this update, the estimated total area of the management zone remained unchanged at 58,043 km^2. The estimated total area of survey strata was adjusted to 40,707 km^2 and the total area of strata to be actually surveyed adjusted to 33,400 km^2 (see Table 1). The extent of the changes made can be referenced in relation to Table1 in Cairns, Bearup & Lollback (2019).

3. Survey Design

The South East Tablelands kangaroo management zone comprises seven survey blocks, each of which was stratified for the purpose of survey design. Survey design was undertaken using what is now recognised as a comparatively standard procedure that utilises the automated design capabilities of the most recent version of the

DISTANCE software package (Thomas *et al.* 2010); in this case, DISTANCE 7.5 (http://distancesampling.org/Distance/#download-latest-version).

To design a survey using DISTANCE, GIS shape files of the survey areas are required, along with estimates of the nominal survey effort. The shape files used here were stratified and nominal survey efforts determined in relation to the precision of surveys conducted previously in the management zone (see below). For each new survey conducted in each survey block, the boundaries of the strata may be redefined in relation to kangaroo density and survey count information. This option of redefining of stratum boundaries before proceeding to design a survey was considered to be consistent with the adoption of an adaptive management approach to the conduct of aerial surveys in the tablelands management zones.

3.1 Zone Stratification

To increase both the efficiency and the precision of the surveys, six of the seven survey blocks were divided into two or three strata. This is done using GIS shape files obtained originally from the NSW DCCEEW. These files contained the attributes of eight categories of land capability which extend from cultivation, through to mixed farming and grazing, through to grazing only (with decreasing levels of grazing intensity), through to steep, timbered country, through to rocky outcrops. They also contained information on the location of state forests, gazetted reserves and national parks, all of which were excluded from the survey areas of each block. The eight categories of land capability were merged into a smaller number of broad categories to form the initial basis of the two or three strata to be used in the survey design process for each survey block.

Within each survey block, based upon these attribute categories, areas identified as being dominated by cultivation practices were merged with areas identified as being dominated by rocky outcrops along with some areas identified as comprising steep, timbered country to form the basis of a likely low kangaroo density stratum. Areas of low intensity cropping and grazing lands were merged with the remaining areas of steep, timbered country to form the basis of likely medium to high density kangaroo strata.

Five of the seven survey blocks were divided into a low and a medium kangaroo density stratum. One block comprised only a single medium to high density stratum, and one other was divided into three strata: a low, a medium, and a high density stratum. The low density in this block comprised cultivated land. The medium density stratum comprised low intensity cropping and grazing lands. The high density stratum comprised land used for grazing only that was known to support relatively high numbers of kangaroos.

In setting up the stratifications, the boundaries of the strata were adjusted in relation to coincidental knowledge of kangaroo densities. The kangaroo density information used for the first surveys of these blocks conducted in 2003 (Cairns 2004) was anecdotal (Pople *et al.* 2006). For the second survey conducted in 2006 (Cairns 2007), the stratum boundaries were adjusted using kangaroo densities and transect line counts taken from the results of the 2003 survey (Cairns 2004). This applied to all of the survey blocks, except the Young block, which was not incorporated into the management zone until 2009, and the Bombala block which was not added to the management zone until 2015. A preliminary survey, conducted in the Young block in 2008 (Cairns & Lollback 2009), provided the kangaroo density information needed complete the stratification of this block. For the Bombala block, stratification was based upon land capabilities and information on kangaroo density obtained from a preliminary survey conducted in 2012 (Cairns, Bearup & Lollback 2013). Using density estimates and transect counts of eastern grey kangaroos obtained from the surveys conducted in 2009 (Cairns, Lollback & Bearup 2010) and 2012 (Cairns, Bearup & Lollback 2013), the boundaries of the strata within the survey blocks were further redrafted with the aim of improving the design stratification. Recently, the stratification of all seven survey blocks has been further reviewed and updated for the 2021 survey going forward (see Section 2). The breakdown of the area of the management zone into the constituent survey blocks and stratification is given in Table 1.

Table 1. Areas (km^2) of the seven survey blocks (former RLPB districts) that constitute the current South East Tablelands kangaroo management zone (KMZ). The survey areas do not include reserved lands such as National Parks (NPs) or State Forests (SFs), nor those areas of high relief outside reserve lands that are unsuitable for the conduct of aerial surveys. The remaining areas are subdivided into three strata representing habitat associated with, in relative terms, high, medium and low kangaroo densities (adapted from Pople, Cairns & Menke 2003). The area surveyed comprises the high density and medium density strata.

Survey block	Bombala	Braidwood	Cooma	Goulburn	Gundagai	Yass	Young	KMZ
RLPB district	6,722	8,824	11,375	6,426	9,507	6,305	8,884	58,043
NP, SF and high relief areas	3,683	4,757	4,301	561	3,225	748	61	17,336
Survey block area	3,039	4,067	7,074	5,865	6,282	5,557	8,823	40,707
Block stratification								
High density	–	–	–	–	–	–	3,140	3,140
Medium density	2,631	3,811	7,074	4,462	5,502	4,486	2,294	30,266
Low density	408	256	–	1,403	780	1,071	3,389	7,307
Area surveyed	2,631	3,811	7,074	4,462	5,502	4,486	5,434	33,400

As has been the case in recent years, only the high and medium density strata were slated to be surveyed on this occasion. With the exclusion of population centres, national parks, reserves and some miscellaneous areas of high relief, 70% of the combined area of the seven survey blocks remained available to be surveyed. With the exclusion of the combined low density strata of each survey block, the final survey area was reduced to some 58% of the total area of the management zone. For visual representation of the stratification of the zones, see Figs. 2-8.

3.2 Survey Effort

In line transect sampling, survey effort is defined as the total length of transect surveyed. Although ultimately constrained by cost, survey effort is generally determined in relation to some desired level of precision (i.e. the ratio of standard error to mean). In the conduct of surveys such as the one reported upon here, aiming for a general level precision of 20% would appear to be realistic and reasonably cost-effective (Pople, Cairns & Menke 2003; Cairns 2007; Cairns, Lollback & Bearup, 2010, 2013; Cairns, Bearup & Lollback 2016, 2019, 2022). For the present survey, the target levels of survey precision were varied to some extent in order to maintain cost-effectiveness. For the Bombala block the target level precision was reduced to 25%. For the medium density stratum in the Young block, a block known to support low densities of kangaroos (Cairns, Bearup & Lollback 2022) the target level precision was reduced drastically to 40%. For the high density stratum of the Young block, and for the Braidwood, Goulburn and Gundagai blocks, the target level of precision was set at 20%. For the Cooma and Yass blocks, two blocks known to support higher densities of kangaroos, the target level of precision was set higher at 17.5%.

To determine the survey effort required for the present survey, the method given in Buckland *et al.* (2001, p. 243) was used in relation to the survey effort and precision (measured by the coefficient of determination) averaged over the two most recently conducted surveys of this management zone (Cairns, Lollback & Bearup 2019, 2022). The survey efforts determined for each block in relation to the target levels of precision are listed in Table 2 as the nominal survey effort. For the present survey, the total nominal survey effort was 2,098 km. By comparison, the total nominal survey effort for the previous survey conducted in 2021 was some 25% greater at 2,848 km (Cairns, Bearup & Lollback 2022).

Table 2. Areas of the proportion of each survey block (former RLPB districts) surveyed, the nominal survey effort determined for the purpose of survey design and the actual survey effort applied during the survey. Note that the Young survey block comprised a high and a medium kangaroo density stratum. All the other survey areas were classed as medium density strata. The two survey designs listed are the systematic segmented grid survey (SSGS) and the systematic segmented trackline survey (SSTS).

Survey block	Survey area (km^2)	Nominal survey effort (km)	Actual survey effort (km)	Survey design
Bombala	2,720	250.0	250.0	SSTS
Braidwood	3,987	295.0	290.0	SSGS
Cooma	7,202	275.0	265.0	SSGS
Goulburn	4,608	255.0	255.0	SSG S
Gundagai	5,562	292.5	292.5	SSGS
Yass	4,518	280.0	280.0	SSGS
Young (high)	3,185	225.0	225.0	SSTS
Young (medium)	2,303	225.0	225.0	SSTS

3.3 Automated Survey Design

The principal aim of designing a survey is to obtain optimal estimates of abundance, preferably with high precision and low bias. Achieving this is not straightforward, particularly when designing a survey by hand. However, taking advantage of the information that can be obtained through the use of GIS and by using automated design algorithms such as those offered by DISTANCE 7.5 (Thomas *et al.* 2010) the likelihood of obtaining an optimal design will be increased (Strindberg, Buckland & Thomas 2004).

As with previous version of this package, DISTANCE 7.5 offers four different classes of survey design for surveys of the type to be undertaken here: parallel random sampling, systematic random sampling, systematic segmented trackline sampling and systematic segmented grid sampling (Thomas *et al.* 2010). According to Buckland *et al.* (2001), and Strindberg, Buckland & Thomas (2004), systematic designs produce smaller variation in density estimation from one realisation to the next and negate any problems associated with overlapping samplers (transects). Hence, a systematic survey design with a buffer zone around the boundary of each survey stratum was selected as the most likely design option for the present surveys. Inclusion of a buffer in the design guards against the problem arising whereby the distribution of objects from the transect line is not in general uniform out to the truncation distance if the transect line intersects the stratum boundary (Strindberg, Buckland & Thomas 2004). Based upon comparisons of the outcomes of earlier surveys (Cairns, Lollback & Bearup 2010, 2013; Cairns, Bearup & Lollback 2016), the integrity of individual samplers (transects) was maintained in preference to using split samplers.

Two of the systematic sampling designs, the systematic segmented grid and the systematic segmented trackline designs, were tested in relation to survey coverage. Both designs were tested in relation to survey transects (samplers) that were 10 km, 7.5 km and 5 km in length. For each survey, a series of 999 simulations was run in relation to a 1-km square coverage grid to assess the evenness of the coverage probability of the survey designs selected for comparison (Strindberg, Buckland & Thomas 2004; Thomas *et al.* 2010). The different survey designs were compared and assessed separately for each survey stratum of each survey block using the nominal survey efforts given in Table 2. The outcome of this process was that the segmented grid design with fixed-length samplers provided a more than adequate even coverage of five of the survey areas; better coverage than did the segmented trackline sampling design with fixed-length samplers. The segmented trackline design provided better coverage than did the segmented grid design in the remaining two blocks (Table 2). Once these optimal designs were confirmed, a single realisation of the selected design was generated for each survey stratum within each survey block.

For the Bombala block, the selected survey design resulted in fifty 5-km long transects being allocated to the survey stratum (Fig. 2). For the Braidwood block, the selected survey design resulted in fifty-nine 5-km long transects being allocated to the survey stratum (Fig. 3). For the Cooma block, the selected survey design resulted in fifty-five 5-km long transects being allocated to the survey stratum (Fig. 4). For the Goulburn block, the selected survey design resulted in fifty-one 5-km long transects being allocated to the survey stratum (Fig. 5). For the Gundagai block, the selected survey design resulted in thirty-nine 7.5-km long transects being allocated to the survey stratum (Fig. 6). For the Yass block, the selected survey design resulted in fifty-six

5-km long transects being allocated to the survey stratum (Fig. 7). For the Young block, the selected survey design resulted in thirty 7.5-km long transects being allocated to each of the high and medium density strata (Fig. 8).

4. Survey Methods

The aerial surveys of the seven blocks were undertaken in early spring, during the period 3-17 September, 2024. These surveys were conducted as helicopter surveys in accordance with the survey designs developed above (see Section 3.3), with each survey block being considered a separate entity and, subdivided into two or three strata; one or two of which were surveyed. The method of line transect sampling (Buckland *et al.* 2001; Thomas *et al.* 2002) was used. In the original design for these surveys, there was a total of 370 transects to be flown across the seven survey blocks. The completed surveys resulted in 367 of these transects being flown (see Table 2). Two of the transects not flown because of poor weather conditions were in the Cooma block, the other was in the Braidwood block.

All surveys were conducted within either the three-hour period following sunrise or the three-hour period before sunset. Steve Chapple (NPWS), Scott Seymour (ACT Emergency Services) and Leigh Nolan (NPWS) were the observers for these surveys. The pilots were Tom Menzies, Andrew Wilson and Grant Simpson. The air safety observers were Matt White, Rod Clark and Simon Conarty, and the ground crew was Doug Sandry. Maquel Brandimarti was the officer-in-charge, and Sheridan Maher and Jackie Sawyer acted as flight followers during the course of the survey sessions.

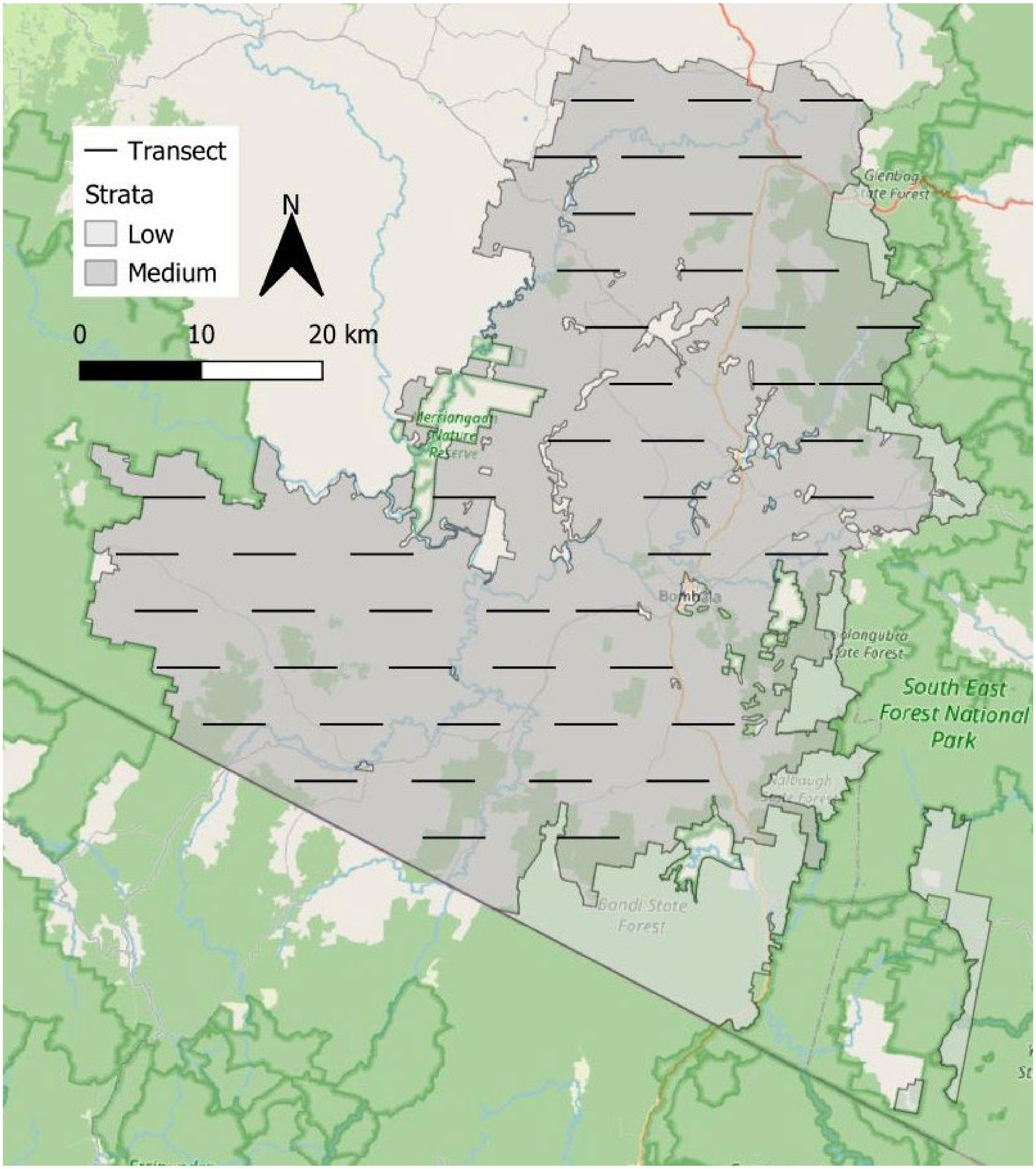

Fig. 2. The Bombala survey block of the South East Tablelands kangaroo management zone. Shown are the two survey strata, reserves and population centres (towns), and the placement of the survey transects within the medium kangaroo density strata. Note that no survey transects were placed into the low density stratum.

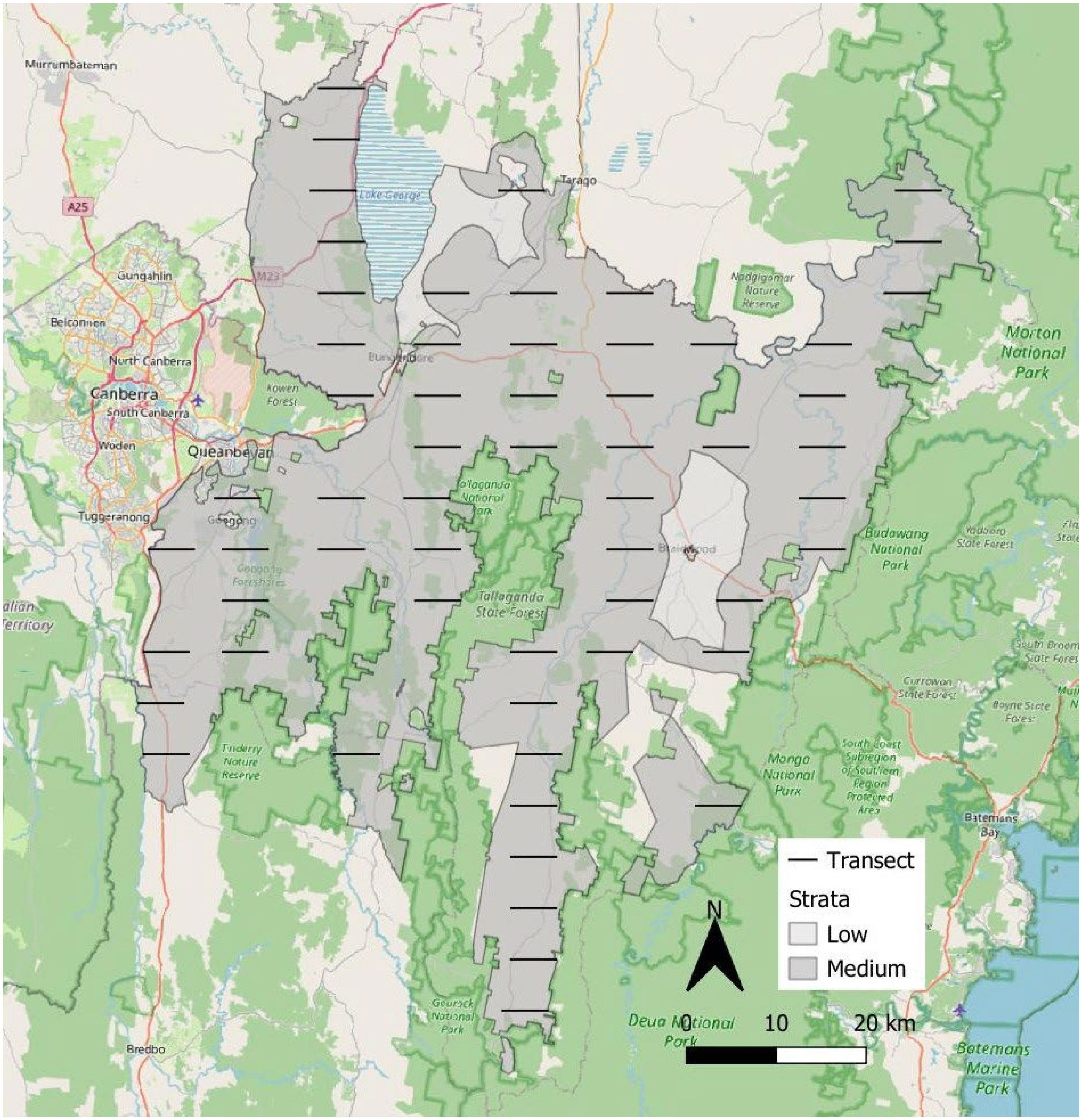

Fig. 3. The Braidwood survey block of the South East Tablelands kangaroo management zone. Shown are the two survey strata, reserves and population centres (towns), and the placement of the survey transects within the medium kangaroo density strata. Note that no survey transects were placed into the low density stratum.

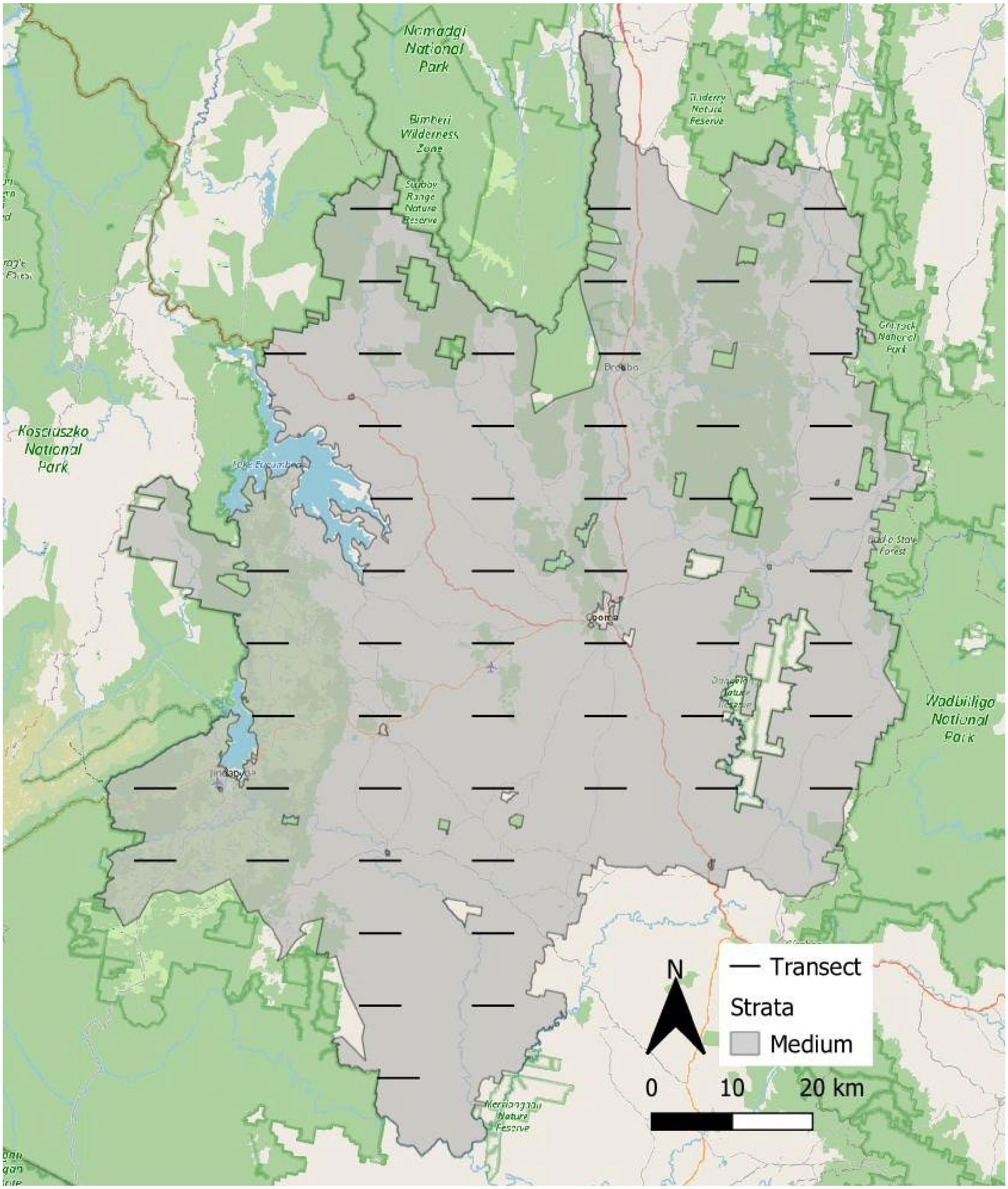

Fig. 4. The Cooma survey block of the South East Tablelands kangaroo management zone. There is no stratification of this block. Shown are reserves and population centres (towns), and the placement of the survey transects within the single, medium kangaroo density stratum.

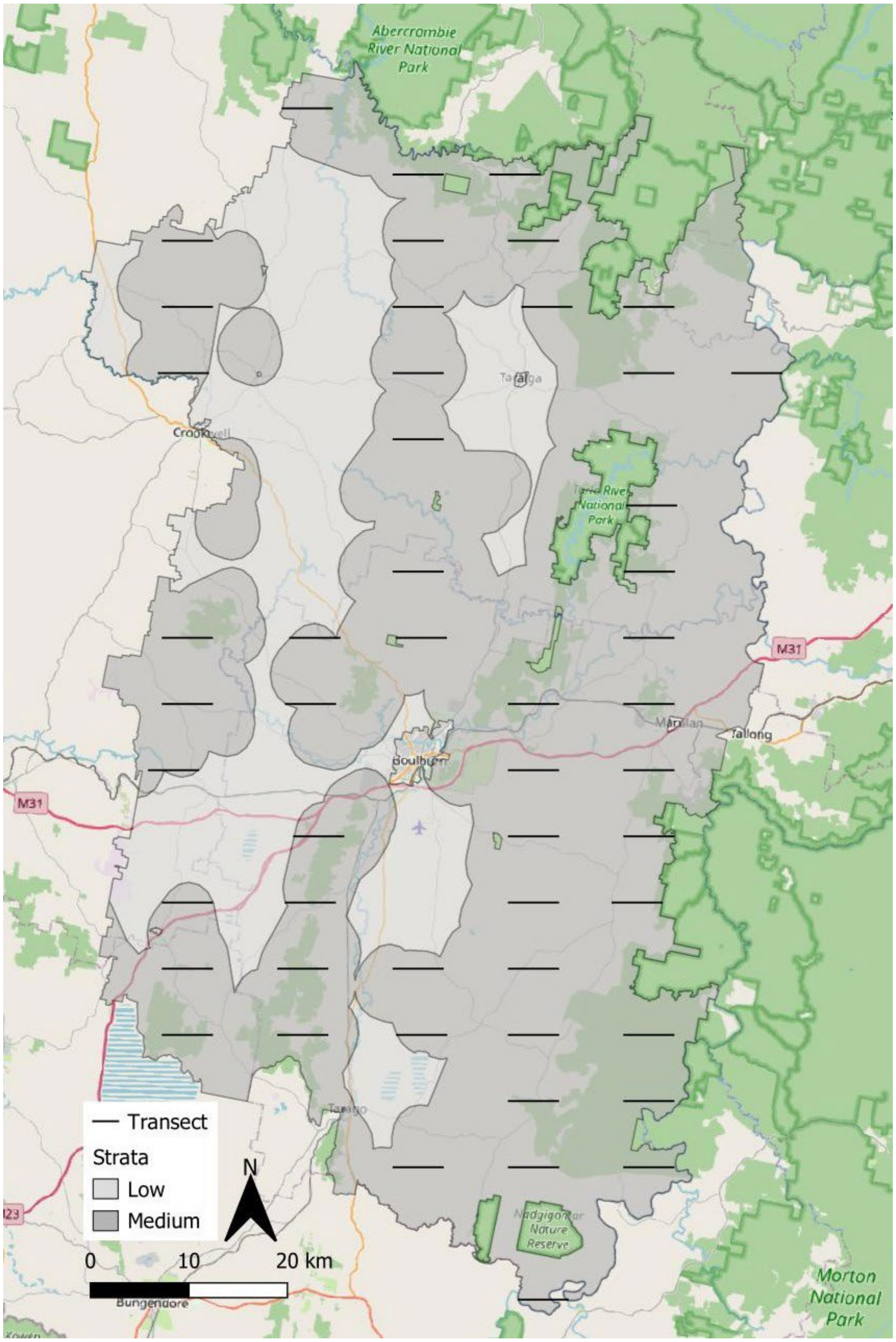

Fig. 5. The Goulburn survey block of the South East Tablelands kangaroo management zone. Shown are the two survey strata, reserves and population centres (towns), and the placement of the survey transects within the medium kangaroo density stratum. Note that no survey transects were placed into the low density stratum.

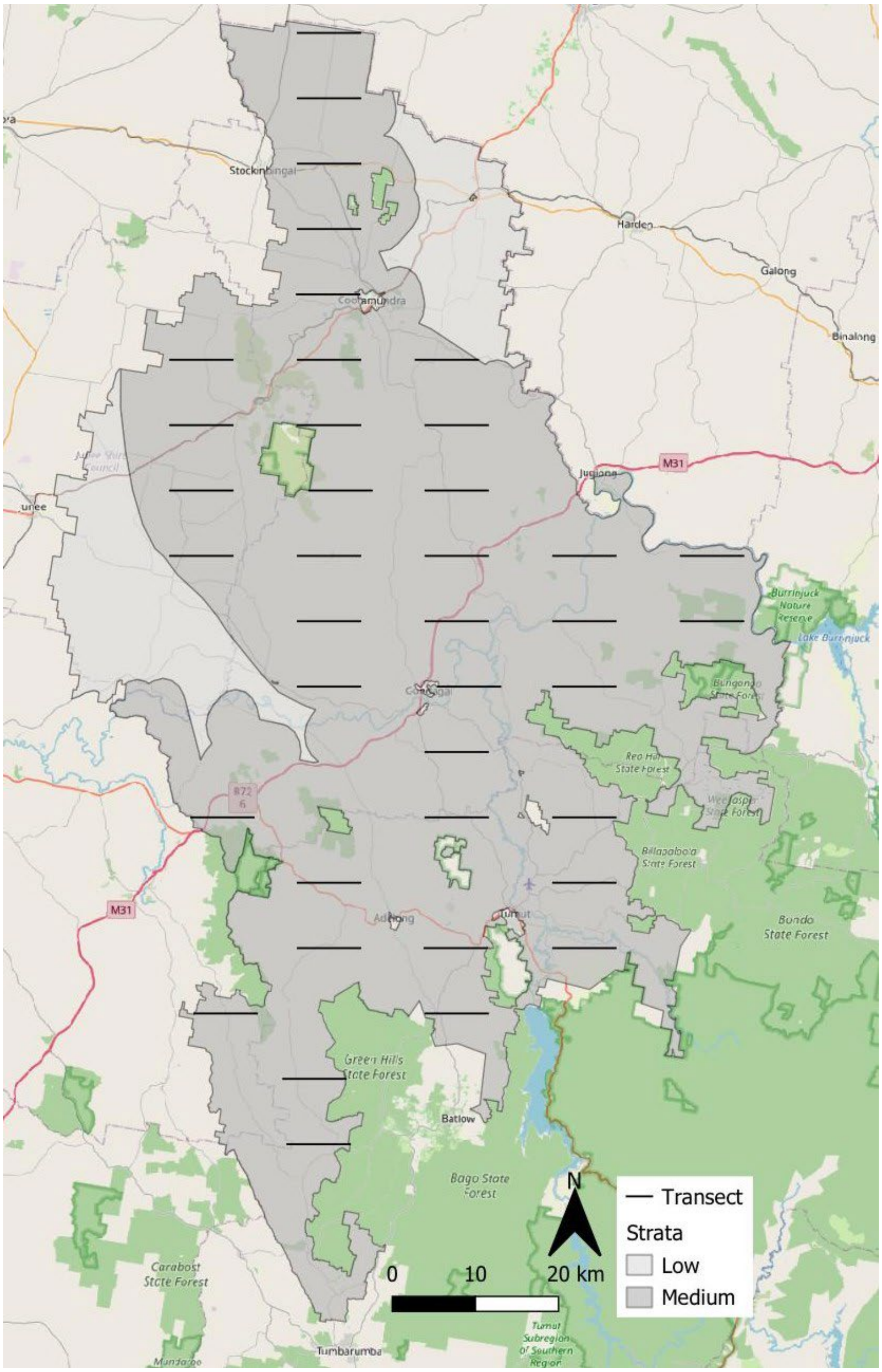

Fig. 6. The Gundagai survey block of the South East Tablelands kangaroo management zone. Shown are the two survey strata, reserves and population centres (towns), and the placement of the survey transects within the medium kangaroo density stratum. Note that no survey transects were placed into the low density stratum.

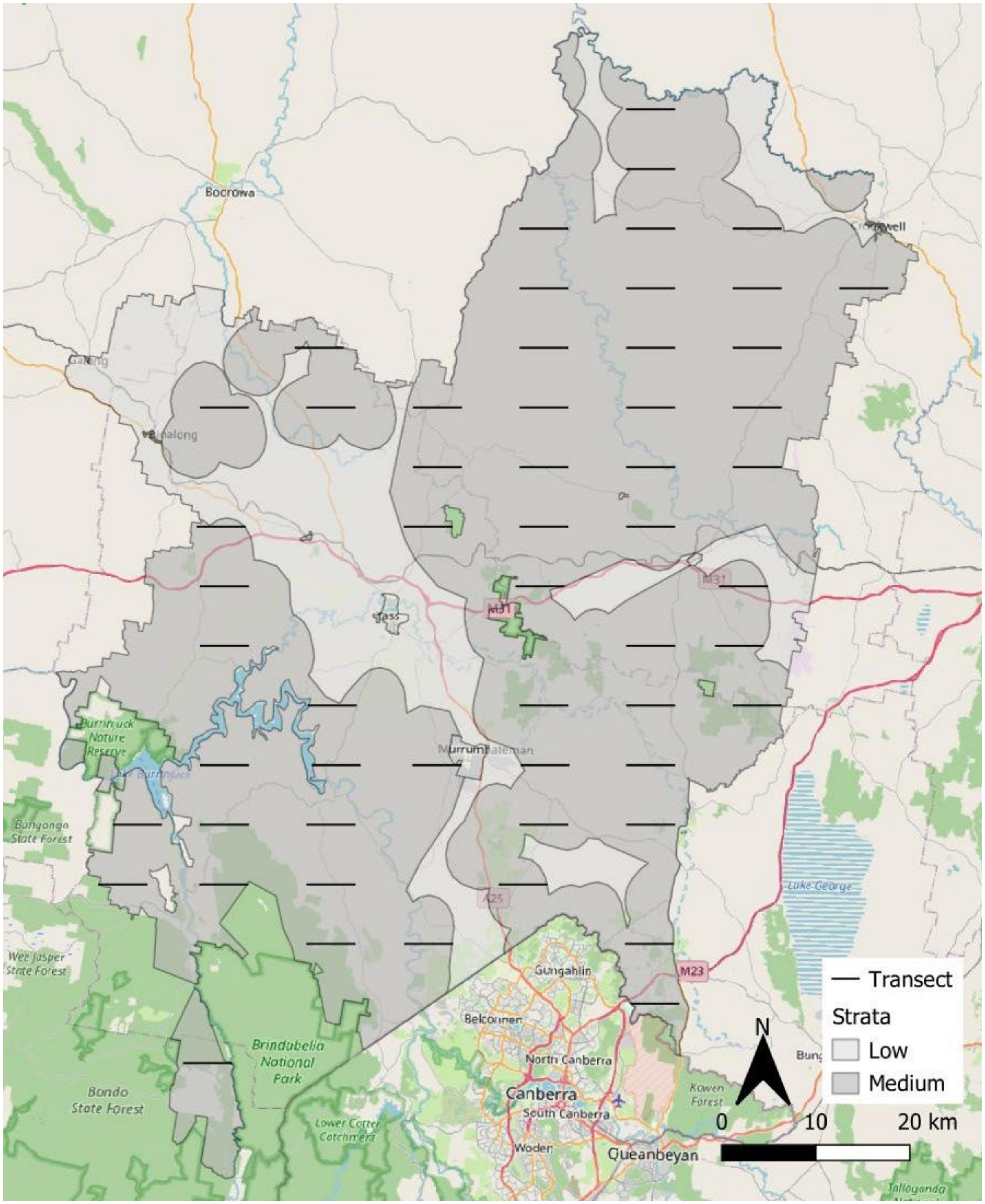

Fig. 7. The Yass survey block of the South East Tablelands kangaroo management zone. Shown are the two survey strata, reserves and population centres (towns), and the placement of the survey transects within the medium kangaroo density stratum. Note that no survey transects were placed into the low density stratum.

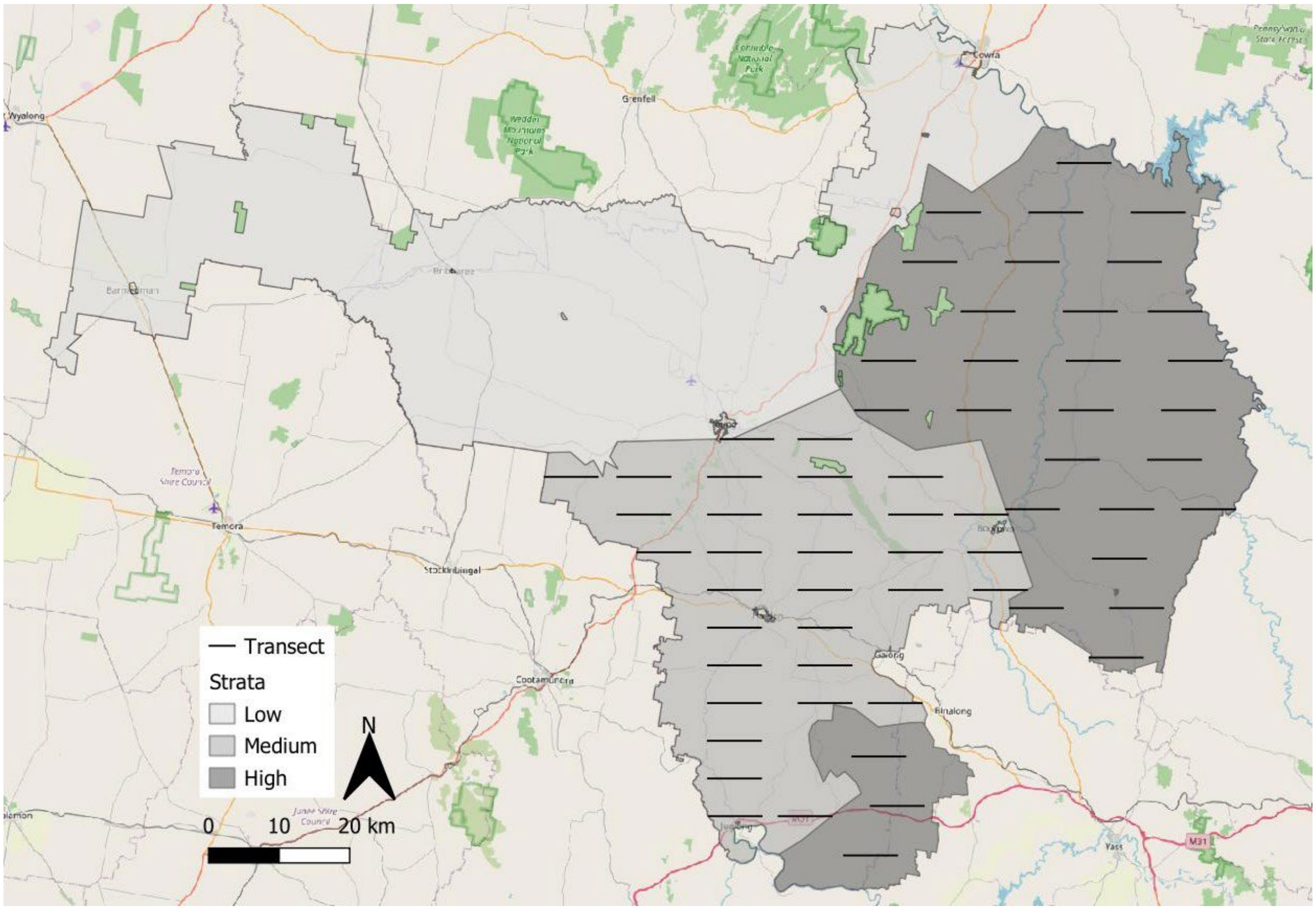

Fig. 8. The Young survey block of the South East Tablelands kangaroo management zone. Shown are the three survey strata, reserves and population centres (towns), and the placement of the survey transects within the high and medium kangaroo density strata. Note that no survey transects were placed into the low density stratum.

4.1 Helicopter Line Transect Surveys

In conducting the survey, the aircraft, a Eurocopter AS350 Écureuil (*Squirrel*) single-engine light helicopter with the two rear doors open was flown along each transect line at a ground speed of 93 km h^{-1} (50 kts) and at a height of 91 m (300 ft) above the ground. Navigation was by a global positioning system (GPS) receiver. The two observers occupying the rear seats of the helicopter counted kangaroos seen on either side of the aircraft. 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. Sightings of kangaroos 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. The distance classes were delineated on metal booms extending from either side of the helicopter (Fig. 9).

Fig. 9 Distance boom mounted on the left-hand side of the Eurocopter AS350 Écureuil helicopter used in the survey. 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 counts of the numbers within clusters (groups of one or more individuals) of eastern grey kangaroos (*Macropus giganteus*), common wallaroos (*Osphranter robustus*), red-necked wallabies (*Macropus rufogriseus*) and swamp wallabies (*Wallabia bicolor*) observed in the different delineated distance classes within the survey strip were voice-recorded. The presence and raw abundance of other, nontarget mammalian species was also recorded. Voice-recorded information was transcribed at the end of each survey session.

4.2 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 area covered during the survey is estimated as:

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

where, n_a is the number of clusters of animals 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 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 it is assumed that $g(0) = 1$) needs to be modelled and evaluated (Thomas *et al.* 2002). To do this, the sampling data, the counts of clusters of animals (kangaroos) within each of the five distance bins used in these surveys, were analysed using DISTANCE 7.5 (Thomas *et al.* 2010). Basing the analysis on the sightings of clusters in preference to the sightings of individual animals has been found to ensure against the overestimation of the true variances (Southwell & Weaver 1993).

In analysing the results of surveys such as those undertaken here, it is important that the recommended minimum sample sizes of both transect lines and observations are at least attained. According to Buckland *et al.* (2001), the recommended minimum number of samplers (replicate transect lines) should be >10 in order to ensure reasonably reliable estimation of the variance of the encounter rate, and the recommended number of observations, clusters of kangaroos in this instance, should be, if possible, >60 for reliable modelling of the detection function.

For eastern grey kangaroos, the survey results from each management zone were analysed separately. Stratification was incorporated into the analyses, with the option of either fitting a common (global) detection function to the data for the two survey strata within each management zone, or fitting separate detection functions to the high and medium density strata, respectively. For the other three macropod species, to ensure the required threshold number of observations for the reliable modelling of the detection function, the data from the seven survey blocks were pooled for analysis.

DISTANCE 7.5 has three different analysis engines that can be used to model the detection function (Thomas *et al.* 2010). Two of these, the conventional distance sampling (CDS) analysis engine and the multiple-covariate distance sampling (MCDS) analysis engine were used here. In analysing survey results using the CDS analysis engine, there is no capacity to include any covariates other than the perpendicular distance of a cluster of animals 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, Anderson & Laake 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 (suitable) model and, hence, which were the most likely and accurate estimates of population density and abundance determined in relation to this detection function. The model with the lowest value for a penalised log-likelihood in the form of Akaike's Information Criterion ($AIC = -2ln(L) + 2[k + 1]$; where, L is the maximised value of the likelihood function for the model and k is the number of parameters in the model: Burnham & Anderson 2002) 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 centreline, being likely to be rejected. Although available as an option to improve goodness-of-fit, no manipulation of the grouping intervals was undertaken.

For analyses using the CDS analysis engine, comparisons were made amongst a suite of four detection function models. Each of these models comprised a key function that, if required, can be adjusted by a cosine or polynomial series expansion containing one or more parameters (Buckland *et al.* 2001). 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 adjustments incorporated into the model was determined via the sequential addition of up to three terms.

The MCDS analysis engine allows for the inclusion in the detection function model of covariates other than the perpendicular distance from the line (Thomas *et al.* 2010). These can be either factor (qualitative or categorical) or non-factor (continuous) covariates and have the effect of altering the scale but not the shape of the detection function (Thomas *et al.* 2010). The covariates used in these analyses were related to individual detections of clusters of kangaroos and were identified as observer, habitat cover at point-of-detection, survey aspect and cloud cover. These covariates were all factor covariates. To avoid over-parameterisation, only single covariates were included in the models tested. Two key functions are available with the MCDS analysis engine: the Half-normal and the Hazard-rate functions.

In estimating kangaroo densities using these two analysis engines, if the observed sizes of detected clusters (c) are independent of distance from the transect centreline (i.e. if $g(x)$ does not depend upon c), then the sample mean cluster size is taken as an unbiased estimator of the mean size of the n_a clusters observed in the study area. If, however, the observed sizes of detected clusters are found to be dependent upon the perpendicular distance from the transect centreline, then the sample mean cluster size is replaced by a value determined using a regression of this relationship (Buckland *et al.* 2001).

While densities and abundances were determined empirically, the upper and lower confidence limits (UCL and LCL), and the associated coefficients of variation (cv%) for these estimates were determined from bootstrapping the data. The data were bootstrapped 999 times in relation to all model options in the analysis engine used (CDS or MCDS) and not just the model selected to determine the empirical estimates. It was expected that bootstrapping the data in this way would improve the robustness of the estimation of these statistics (Buckland *et al.* 2001). The 95% confidence limits given with the empirical estimates were the 2.5% and 97.5% quantiles of the respective bootstrap estimates. Bootstrapping the data was necessary in order to estimate confidence intervals for management zone estimates based on combining estimates determined at the survey stratum level when using the MCDS analysis engine.

5. Results and Discussion

5.1 Survey Data Summaries

Five of the seven survey blocks listed in Table 1 were divided into two strata based on land capability and knowledge of eastern grey kangaroo densities (see Section 3.1). Of the other two blocks, the Young survey block was divided into three strata and the Cooma block was not stratified at all on the basis that the whole of its area generally supported comparatively high and relatively evenly numbers of kangaroos. Only those strata identified as supporting high and medium densities of kangaroos were surveyed. These comprised a single stratum in all blocks except Young, in which two strata were surveyed.

In the Bombala survey block, all 50 transects shown in Fig. 2 were flown in the medium density stratum on which 362 clusters of eastern grey kangaroos were observed. In the Braidwood block, 58 of the 59 transects shown in Fig. 3 were flown in the medium density stratum on which 523 clusters of eastern grey kangaroos were observed. The Cooma block was surveyed as a single stratum. Of the 53 transects shown in Fig. 4, 51 were flown on which 495 clusters of eastern grey kangaroos were observed. In the Goulburn block, all 51 transects shown in Fig. 5 were flown in the medium density stratum on which 429 clusters of eastern grey kangaroos were observed. In the Gundagai block, all 39 transects shown in Fig. 6 were flown in the medium density stratum on which 304 clusters of eastern grey kangaroos were observed. In the Yass survey block, all 56 transects shown in Fig. 7 were flown in the medium density stratum on which 599 clusters of eastern grey kangaroos were observed. The Young block was subdivided into a low, a medium and a high density stratum (Fig. 8). All 60 transects shown in Fig. 8 were flown; 30 in the high density stratum on which 499 clusters of eastern grey kangaroos were observed, and 30 in the medium density stratum on which 149 clusters of eastern grey kangaroos were observed.

As well as eastern grey kangaroos, sightings were also made in these survey blocks of common wallaroos, red-necked wallabies and swamp wallabies. There were also some sightings of emus (*Dromaius novaehollandiae*) and common wombats (*Vombatus ursinus*), along with significant numbers of sightings of introduced deer (*Cervus* sp., *Dama* sp. and *Rusa* sp.) and feral goats (*Capra hircus*). There were also a lesser number of sightings of feral pigs (*Sus scrofa*) and introduced foxes (*Vulpes vulpes*) and horses (*Equus caballus*). A summary of the raw counts of the four species of macropods observed in each of the survey blocks is given in Table 3.

Table 3. Number of transects flown, total survey effort (km) and raw counts of macropods for each of the seven survey blocks. Note that the Young block comprised two survey strata.

Survey block	No. of transects	Effort (km)	Raw counts			
			Eastern grey kangaroos	Common wallaroos	Red-necked wallabies	Swamp wallabies
Bombala	50	250.0	1,126	7	59	69
Braidwood	59	295.0	1,798	9	12	33
Cooma	53	265.0	1,635	4	44	33
Goulburn	51	255.0	1,523	16	21	36
Gundagai	39	292.5	913	21	3	9
Yass	56	280.0	2,481	7	16	21
Young						
Young (high)	30	225.0	1,885	6	3	33
Young (medium)	30	225.0	497	2	1	4

5.2 Line Transect Analysis

To estimate the population densities and abundances of kangaroos, the counts in clusters of kangaroos observed during line transect sampling were recorded for analysis into the five distance categories set on the survey booms mounted on the helicopter (Fig. 9). The method used for analysis conforms to a general and well-understood framework for analysing distance sampling data, as outlined in Buckland *et al.* (2001).

Key to the analysis is the modelling of the detection of clusters of kangaroos in relation to at least one covariate, the perpendicular distance of a cluster from the transect centreline, as defined by the boundaries of the five distance classes on the survey booms. Analyses involved the use of both the CDS and the MCDS analysis engines of DISTANCE 7.5 (Thomas *et al.* 2010), with the most parsimonious (preferred) detection function model being selected from a number of candidate models principally on the basis of the comparison of AIC statistics. Eastern grey kangaroo density and abundance estimates were determined separately for each survey block. For analysis for the Young block, the survey results for the two survey strata were incorporated into a single stratified analysis. The density and abundance estimates obtained for the seven survey blocks were combined to provide estimates for the South East Tablelands kangaroo management zone. The densities and abundances of common wallaroos, red-necked wallabies and swamp wallabies were determined on the basis of the survey results being pooled to produce single density and abundance estimates for the whole management zone. For details of the analysis method, see Section 4.2.

With the model selection process, a number of candidate detection function models were fitted to the data and compared, with the preferred model being selected as the one that yields the smallest value of the AIC statistic. In comparing any two models, where the difference between the two AIC values (ΔAIC) increases beyond the nominal value of 2.00, it can be concluded that there is evidence that it is becoming increasingly less plausible that the fitted model with the larger AIC could be considered the more likely of the two models, given the data. The converse of this is that when ΔAIC <2.00, then it can be thought that there can be some level of empirical support for the model with the larger AIC in comparison with the one associated with the smaller AIC, given the data. If thought necessary, such ambiguity could be dealt with using model averaging. For further information on the use of AIC in model selection, see Burnham & Anderson (2002).

In analysing the results of surveys such as those undertaken here, it is important that the recommended minimum sample sizes of both transect lines and observations are at least attained. According to Buckland *et al.* (2001), the recommended minimum number of samplers (replicate transect lines) should be at least in the range 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 kangaroos in this instance, should be at least in the range 60-80 for reliable modelling of the detection function. These two criteria were met in all instances. The numbers of replicate transects flown across the survey strata of the seven survey blocks are given in Table 3 and the numbers of clusters of eastern grey kangaroos observed are given in Table 4.

The most parsimonious detection function models fitted to the results of the surveys of eastern grey kangaroos in the seven survey blocks are given in Table 4. For each of the Bombala, Braidwood, Cooma and Goulburn blocks, the most parsimonious detection function model was the MCDS-derived Half-normal function with habitat vegetation cover at point-of-detection (COVER) included as an added covariate. For the Gundagai block, the most parsimonious detection function model was a Hazard-rate function also with habitat vegetation cover at point-of-detection included as an added covariate. For the Yass and Young blocks, the most parsimonious detection function models with both CDS-derived. For the Yass block, the most parsimonious detection function model was a Half-normal model, while for the Young block, it was a Hazard-rate model.

Table 4. The number of sightings of clusters of eastern grey kangaroos (n), the DISTANCE 7.5 analysis engine used (see text), the detection function model (including covariates), the encounter rate (n/L) and the probability that a cluster of kangaroos in the survey strip is detected (P_a) for the surveys conducted in the seven survey blocks. CDS is the conventional distance sampling engine and MCDS is the multiple-covariate distance sampling engine. COVER is the covariate vegetation cover at point-of-detection.

Survey block	n	Analysis engine	Model	Covariates	n/L	P_a
Bombala	362	MCDS	Half-normal	COVER	1.45	0.35
Braidwood	523	MCDS	Half-normal	COVER	1.77	0.43
Cooma	495	MCDS	Half-normal	COVER	1.87	0.37
Goulburn	429	MCDS	Half-normal	COVER	1.68	0.43
Gundagai	304	MCDS	Hazard-rate	COVER	1.04	0.31
Yass	599	CDS	Half-normal	–	2.14	0.32
Young	648	CDS	Hazard-rate	–	1.44	0.29

With the final MCDS-derived models, the differences between the preferred models and a corresponding CDS-derived models were in most instances quite substantial (2.49 ≤ ΔAIC ≤ 54.10), with the inclusion of the vegetation cover covariate proving to be important to the modelling process. The general forms of the detection functions determined for each of the seven survey blocks are shown in Appendix 1, Figs. A1.1-A1.7. With these detection functions, it should be noted that where covariates are included in the models, they have the effect of altering the scale but not the general form of the detection function (Marques & Buckland 2004).

Given in relation to each of the detection function models for eastern grey kangaroos listed in Table 4 are estimates of encounter rates (n/L) and probabilities (P_a) that a randomly selected cluster of kangaroos in the nominal survey strip (150 m) will be detected. The encounter rate, the number of clusters of kangaroos detected per unit (km) of survey effort is considered, in some respects, to be a more informative statistic than is n itself (Buckland *et al*. 2001). 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 and the observers and conditions on the survey platform. They would therefore have some comparative value.

The encounter rates were reasonably similar across all of the survey blocks. Except for the Gundagai block, >1.45 clusters of eastern grey kangaroos were sighted per kilometre of survey transect (Table 4). This points to there being some degree of consistency in the spatial distribution of eastern grey kangaroos across the management zone. The variances of these encounter rates were also, proportionally, reasonably similar, with coefficients of variation (cv%) in the range 11-19%. In distance sampling, encounter rate variance is usually the dominant component of the overall variance of object (kangaroo) density. Low variance in the encounter rate can be taken as an indicator of low bias in a density estimate; indicating its closeness to the true density.

The probability that a randomly selected cluster of eastern grey kangaroos in the survey strip will be detected (P_a) showed some variation across survey strata, ranging from 0.29 to 0.43, with a median value of 0.35. No pattern exists across the survey blocks which supports the suggestion that each estimate of P_a is a function of the conditions and circumstances associated with the conduct of each survey. There was no association between P_a and n/L (r_5 = 0.33 P = 0.470). Comparisons of the P_a estimates from these surveys with those obtained from the previous surveys conducted in this management zone cannot be meaningfully made because the current surveys were conducted at a height of 91 m, which amounted to an increase of some 50% in survey height in relation to previous surveys, all of which had been conducted at a height of 61 m.

The survey results for common wallaroos, red-necked wallabies and swamp wallabies were analysed at the level of management zone rather than survey block. The detection function models and analysis statistics for these three species are given in Table 5. For all three species, the most parsimonious detection function models were each MCDS-derived models with Half-normal key functions and the observer covariate. The general forms of the detection functions for these three species are shown in Appendix 1, Figs. A1.8-A1.10. The encounter rates for these three species were all much lower than those for eastern grey kangaroos. The values of P_a were similar for all three species and lower than those determined for eastern grey kangaroos.

Table 5. The number of sightings of clusters of animals (n), the DISTANCE 7.5 analysis engine used (see text), the detection function model used (including covariates), the encounter rate (n/L) and the probability that a randomly-selected cluster of animals in the survey strip is detected (P_a) for common wallaroos, red-necked wallabies and swamp wallabies in the Southern Tablelands kangaroo management zone. MCDS is the multiple-covariate distance sampling engine.

Species	n	Analysis engine	Model	Covariate	n/L	P_a
Common wallaroos	51	MCDS	Half-normal	OBSERVER	0.02	0.21
Red-necked wallabies	101	MCDS	Half-normal	OBSERVER	0.06	0.24
Swamp wallabies	218	MCDS	Half-normal	OBSERVER	0.10	0.20

Table 6. Survey stratum area, density of clusters of eastern grey kangaroos sighted (D_s) and kangaroo population density (D). Given also are empirical and bootstrap coefficients of variation (cv), and bootstrap confidence intervals for each of these two density statistics.

Survey block	Area (km^2)	Cluster density (km^{-2})				Kangaroo density (km^{-2})			
		D_s	cv (%)	95% bootstrap confidence interval	cv_{boot} (%)	D	cv (%)	95% bootstrap confidence interval	cv_{boot} (%)
Bombala	2,631	13.61	19.2	8.51-19.83	21.6	35.50	19.7	19.84-53.83	24.7
Braidwood	3,811	13.71	12.0	10.67-17.13	11.9	41.46	12.5	30.78-54.19	14.9
Cooma	7,074	16.66	12.4	12.87-20.91	12.5	46.54	12.8	34.01-60.66	14.9
Goulburn	4,462	13.08	11.7	10.05-16.06	11.6	41.66	12.5	27.34-61.76	21.5
Gundagai	5,502	11.18	14.6	6.93-14.15	19.0	33.59	15.1	17.81-42.02	22.0
Yass	4,486	22.27	12.4	17.460-28.08	12.3	68.95	12.9	49.80-89.76	15.2
Young									
High	3,140	25.17	16.0	18.67-33.52	15.1	66.57	16.4	46.22-93.02	17.9
Medium	2,294	7.52	19.0	5.26-10.36	17.3	25.07	19.7	15.24-35.33	20.4

5.3 Population Estimates

The baseline estimates for eastern grey kangaroos in the form of cluster and population densities obtained are given in Table 6. Empirical and bootstrap coefficients of variation and bootstrap confidence intervals are given with these estimates. In relation to these densities, average cluster size was found to be in the range 3.0-4.1 kangaroos per group, similar to the estimated average cluster sizes recorded in previous surveys of this management zone (Cairns, Bearup & Lollbeck 2019, 2022). As has been the case with the results of most previous surveys, cluster density was found to be correlated with population density ($r_6 = 0.97$; $P << 0.001$), with a weighted average cluster size of 4.0 kangaroos per group for the whole management zone.

The precision of the estimates of both cluster and kangaroo density, as indicated by the coefficients of variation, were all considered to be more than acceptable, being, in all instances, <20% (empirical) and <25% (bootstrap). The overall level of precision for the population estimate for the management zone derived from the combined results for the survey blocks was a high 6.7% (see Table 8). This overall level of survey precision is comparable to the levels of precision of the last three surveys (Cairns, Bearup & Lollback 2016, 2019, 2022).

Population abundances derived using the densities determined for the surveyed strata of each block are given in Table 7. Using these abundances, density estimates were determined in relation to the total area of each survey block which included, where applicable, the high, medium and low density survey strata. These densities are given in Table 8. With regard to the conduct of the survey, it should be noted that the low density strata were not surveyed and, based on the outcome of surveys conducted in 2006 (Cairns 2007), were assumed to support, at the most, only trace numbers of kangaroos. An overall population size and density estimate for the whole of the South East Tablelands management zone is also given in Table 8.

Table 7. The areas of the survey strata within the seven survey blocks, and the densities (D) and abundances (N) of eastern grey kangaroos in these strata. Given also are the bootstrap confidence intervals and coefficients of variation (cv) for each of these estimates.

Survey block	Area (km^2)	D (km^{-2})	95% bootstrap confidence interval	N	95% bootstrap confidence interval	cv_{boot} (%)
Bombala	2,631	35.50	19.84-53.83	93,390	52,200-141,620	24.7
Braidwood	3,811	41.46	30.78-54.19	158,010	117,300-206,520	14.9
Cooma	7,074	46.54	34.01-60.66	329,190	240,610-429,140	14.9
Goulburn	4,461	41.66	27.34-61.76	185,900	121,980-275,570	21.5
Gundagai	5,502	33.59	17.81-42.02	184,800	97,970-231,170	22.0
Yass	4,486	68.95	49.80-89.76	309,310	223,410-402,650	15.2
Young						
High	3,140	66.57	46.22-93.02	209,020	145,120-292,080	17.9
Medium	2,294	25.07	15.24-35.33	57,510	34,960-81,040	20.4
Pooled	5,434	49.05	36.51-64.57	266,530	198,400-350,880	14.6

Table 8. The total area, total number (N) and density (D) of eastern grey kangaroos for each of the survey blocks and the whole Southern Tablelands kangaroo management zone.

Survey block	Area (km^2)	N	D (km^{-2})	cv_{boot} (%)
Bombala	3,039	93,390	30.73	24.7
Braidwood	4,067	158,010	38.85	14.9
Cooma	7,074	329,190	46.54	14.9
Goulburn	5,865	185,900	31.70	21.5
Gundagai	6,282	184,800	29.42	22.0
Yass	5,557	309,310	55.66	15.2
Young	8,823	266,530	30.21	14.6
ST NSW zone	40,707	1,527,130	35.52	6.7

Eastern grey kangaroo densities varied across the seven survey blocks within the management zone (Table 8). However, although total numbers have not increased significantly ($z = 0.88$; $P > 0.379$) over the three-year period since the last survey was conducted in this management zone (Cairns, Bearup & Lollback 2022), there were recorded significant, substantial increases in numbers in two of the north-central survey blocks, the Yass and Young blocks (Table 9). In parallel with this, there were no significant ($P > 0.10$) changes in numbers within any of the other five survey blocks. Previously, densities have been relatively high in the eastern survey blocks within the zone (Bombala, Braidwood and Cooma) compared with the Goulburn, Gundagai and Yass blocks, and also compared with the western, Young block, which generally supported the lowest numbers of kangaroos (Cairns, Bearup & Lollback 2019, 2022). Significant or not, the increases and decreases in numbers that occurred at the level of survey block were probably the result of the movement of animals within in the management zone rather the result of any fine-scale demographic processes.

Table 9. The 2021 and 2024 estimates of the eastern grey kangaroo population abundances (N) in the survey blocks within the Southern Tablelands are tested using a z statistic test. The P-values are two-tailed levels of significance associated with testing the null hypothesis of equality of abundance between successive surveys (H_o: $N_{2021} = N_{2024}$).

Survey block	N_{2021}	$cv\%_{2021}$	N_{2024}	$cv\%_{2024}$	z	P-value
Bombala	125,470	22.3	93,390	24.7	1.15	0.250
Braidwood	251,050	27.7	158,010	14.9	1.34	0.180
Cooma	315,720	16.9	329,190	14.9	0.25	0.803
Goulburn	191,390	15.2	185,900	21.5	0.19	0.849
Gundagai	204,820	18.1	184,800	22.0	0.54	0.589
Yass	195,370	17.8	309,310	15.2	3.28	0.001
Young	144,980	16.3	266,030	14.6	3.45	0.001
KMZ	1,428,800	7.8	1,527,130	6.7	0.88	0.379

At the broader scale of the management zone, there has been no change in the eastern grey kangaroo population over the three years leading up to the present survey, with the total number of kangaroos being estimated to be 1,527,130. This compares to a population estimate obtained in 2021 of 1,428,800 kangaroos (Cairns, Bearup & Lollback 2022). Statistically, there was no change in numbers over this period (Table 9). Prior to 2021, in the middle of the 2017-2019 drought, the population had been estimated in 2018 to be 1,807,510 (Cairns, Lollback & Bearup 2019). The decline in numbers between 2018 and 2021 was of the order of some 21% ($z = 1.80$, $P = 0.071$) and, although this decline was not conventionally statistically significant, it was, nevertheless, substantial. This decline in the population is discussed in Cairns, Lollback and Bearup (2022).

Surveys in the South East Tablelands kangaroo management zone have been conducted on a triennial basis since 2003. Since 2009, following the end of the millennium drought (http://www.bom.gov.au/climate/drought/knowledge-centre/previous-droughts.shtml), eastern grey kangaroo numbers in this management zone had increased steadily over the nine-year period to 2018. A full breakdown of the progress of this population increase is given in Cairns, Bearup and Lollback (2019).

In terms of an annual finite rate of population increase (Krebs 1994), the population increased at a rate of ~11% per annum over the nine-year period 2009-2018. In the three-year period between 2015 and 2018, prior to, and leading into the first half of the 2017-2019 drought, the eastern grey kangaroo population in the South East Tablelands management zone was recorded to have increased overall by some 32%, an increase that would have had to have involved some movement of kangaroos into the zone from the surrounding districts. This increase occurred in association with the two particularly wet and productive years that preceded the descent into drought in the spring of 2017. The sequence of annual population increases that extended from 2009 to 2018 was halted, and was later reversed presumably by the deepening of the drought through into 2019. The annual decline that has occurred between the conduct of the 2018 and 2021 surveys was of the order of 7.5%. There would appear to be a lag in this response to the drought which had begun in the spring of 2017, one year prior to the conduct of the 2018 survey.

The negative demographic response to the onset of drought in semi-arid and arid regions is fairly rapid and well-defined (Bayliss 1985; Cairns & Grigg 1993; Cairns *et al.* 2000). However, in more mesic environments such as those enveloping the South East Tablelands kangaroo management zone, such demographic responses are thought to be somewhat lagged (Pople 2003, 2008). Following on from 2021 through to 2024, if the population had increased as recorded, it would have increased at a rate of 2.2% per annum; at a rate much lower than that estimated for the period 2009-2018.

In relation to the demographic changes recorded here for the eastern grey kangaroo population in the South East Tablelands kangaroo management zone, comparisons can be made with other eastern grey kangaroo populations in the tablelands and western slopes of NSW. In the three Northern Tablelands management zones, the overall annual rates of population increase for the eastern grey kangaroos were of the order of ~10% over the period 2004-2016 (Cairns, Bearup & Lollback 2020a). The progressive increase in numbers that took place over this twelve-year period was followed by essentially no changes occurring in the densities of the eastern grey populations in the northern-most Glen Innes and Armidale management zones, but a substantial decline in numbers of the order of some 36% occurred in the Upper Hunter management zone over the period 2016-2019. This equated to a 9.5% annualised decline in numbers over this period. In the two Central Tablelands management zones, the overall annual rates of population increase for the eastern grey kangaroos were also of the order of ~10% over the period 2008-2017 (Cairns, Bearup & Lollback 2020b). This progressive increase was followed by a substantial 48% decline in numbers over the period 2017-2020. This equated to a 19.5% annualised decline in numbers over this period. In both instances, these population changes were first in response to the ending in 2009 of the Millennium drought, and then in response to the onset and impact of the 2017-2019 drought that affected eastern Australia.

With some of the previous surveys conducted in this management zone, there has not always been enough sightings of macropod species, other than eastern grey kangaroos, to allow population estimates to be determined for these species. This time, however, there were enough sighting of common wallaroos, red-necked wallabies and swamp wallabies to enable population estimates to be determined. The density and abundance estimates for these three species are given in Table 10. Two densities are given; one being the survey densities (D) from which the whole-zone abundances were determined and the other being the whole-zone densities (D_z) which have been estimated from these abundances.

In general, the sightability of wallaroos has usually been reported to be lower than it is for eastern grey kangaroos. Clancy, Pople and Gibson (1997) originally found that this was the case and, because of this, suggested that helicopter line transect surveys of wallaroos in southwestern Queensland would likely underestimate wallaroo numbers by a factor of 1.85 when compared with the results of walked line transect sampling. Supportive of this was the outcome of a similar study conducted in the Barrier Ranges of western NSW in 1998 from which it was found that helicopter line transect sampling underestimated euro (*M. r. erubescens*) numbers by a factor of 1.50 in undulating terrain and 1.88 in steep terrain, when compared with the results of walked line transect surveys (S. C. Cairns, A. R. Pople & J. Gilroy, *unpubl. data*). Taking this into account, if required for management purposes, the estimates for wallaroos should be adjusted up by a factor of 1.85. Doing this would increase the estimated population of wallaroos from 17,830 (Table 10) to 27,810.

Wallaroos are present in all of the six tablelands kangaroo management zones, but in densities much lower than those estimated for eastern grey kangaroos. In the South East Tablelands kangaroo management zone, the estimated density of wallaroos (D_z) was found to be some 15% lower than densities that were recorded of this species in the Northern Tablelands management zones in 2022 (Cairns, Bearup & Lollback 2020a). Wallaroos are harvested only in the Northern Tablelands management zones but not in the other tablelands management zones (Anon. 2016).

Of the minor species, the densities of both red-necked wallabies and swamp wallabies were relatively low and approximately similar those determined in relation to the 2021 survey (Cairns, Bearup & Lollback 2022). In both instances, these density estimates for wallaroos and the two minor species were determined with barely adequate levels of precision.

6. Acknowledgements

As with any project, the job is never completed without the support of others who either wittingly or unwittingly are drawn in to provide assistance. David Bearup and Greg Lollback both provided invaluable GIS support, without which projects such as this would have foundered. As well as filling the role of a very able observer during the conduct of the surveys, Steve Chapple also provided invaluable support with regard to day-to-day management and survey planning. Along with Steve Chapple, Leigh Nolan and Scott Seymour more than ably filled seats as observers during the survey. The flight and ground crews, and the remote flight managers all provided excellent and obliging service with the helicopter and remote flight supervision. Their attention to OH&S issues was important and well appreciated.

Table 10. Estimates of the density (D) and abundance (N) of common wallaroos, red-necked wallabies and swamp wallabies in the SE NSW kangaroo management zone. Given with these estimates are the 95% bootstrap confidence intervals and coefficients of variation (CV%). D is the density estimate for the survey area; D_Z is the density estimate for the whole management zone.

	n	D (km^{-2})	95% bootstrap confidence interval	N	95% bootstrap confidence interval	cv_{boot} (%)	D_Z (km^{-2})
Common wallaroos	51	0.53	0.35-0.83	17,830	11,710-27,730	27.2	0.44
Red-necked wallabies	130	1.03	0.71-1.83	34,370	23,800-61,050	28.9	0.84
Swamp wallabies	218	1.83	1.49-4.12	61,100	49,830-137,450	36.9	1.50

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Appendix 1

The detection function models for eastern grey kangaroos (*Macropus giganteus*) in the seven survey blocks, and common wallaroos (*Osphranter robustus*), red-necked wallabies (*Macropus rufigrisus*) and swamp wallabies (*Wallabia bicolour*) in Southern Tablelands kangaroo management zone.

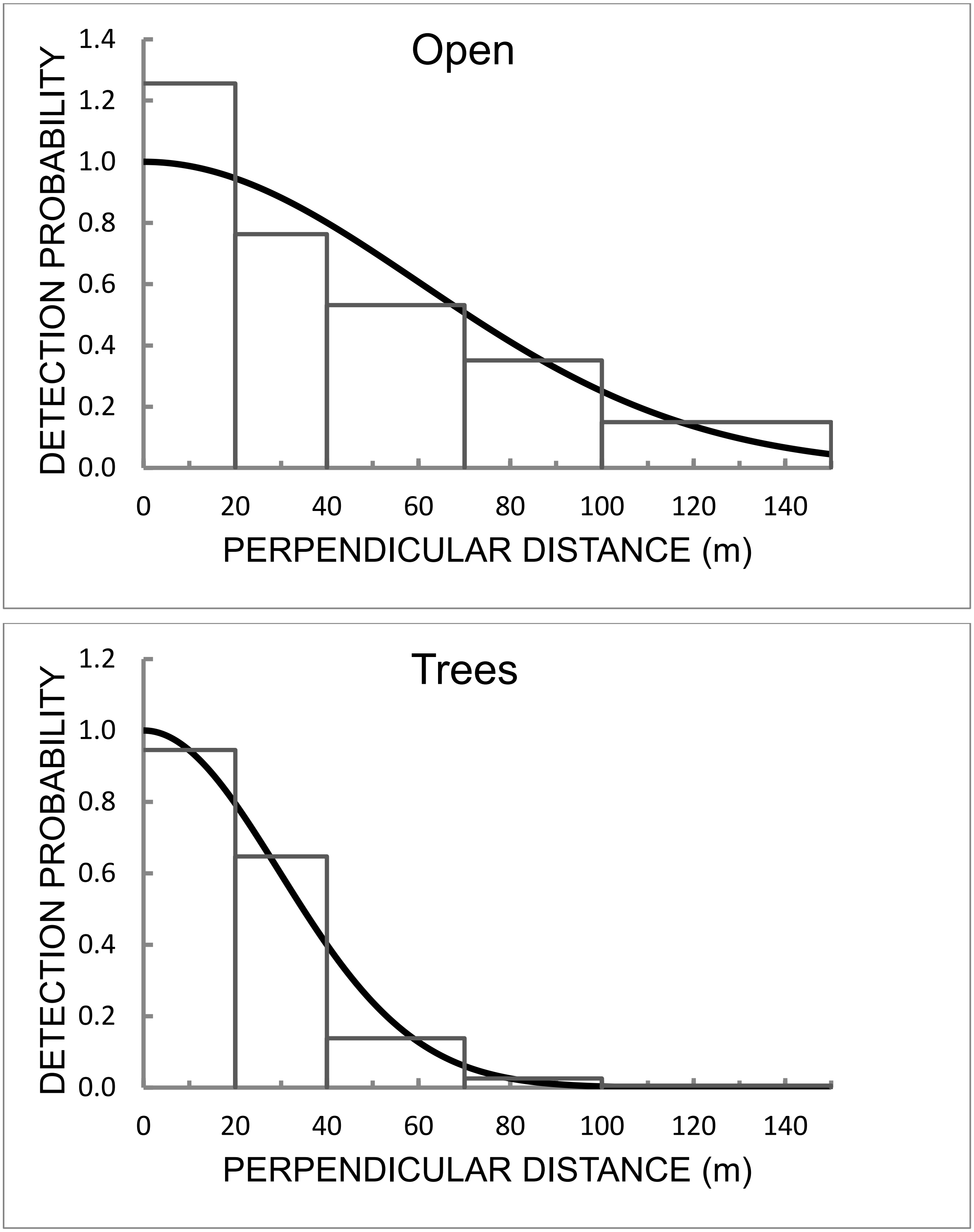


Fig. A1.1. The Half-normal detection functions for eastern grey kangaroos in the Bombala survey block. For details of the model fitted using the MCDS analysis engine with cover at point-of-detection as a covariate, see text and Table 4.

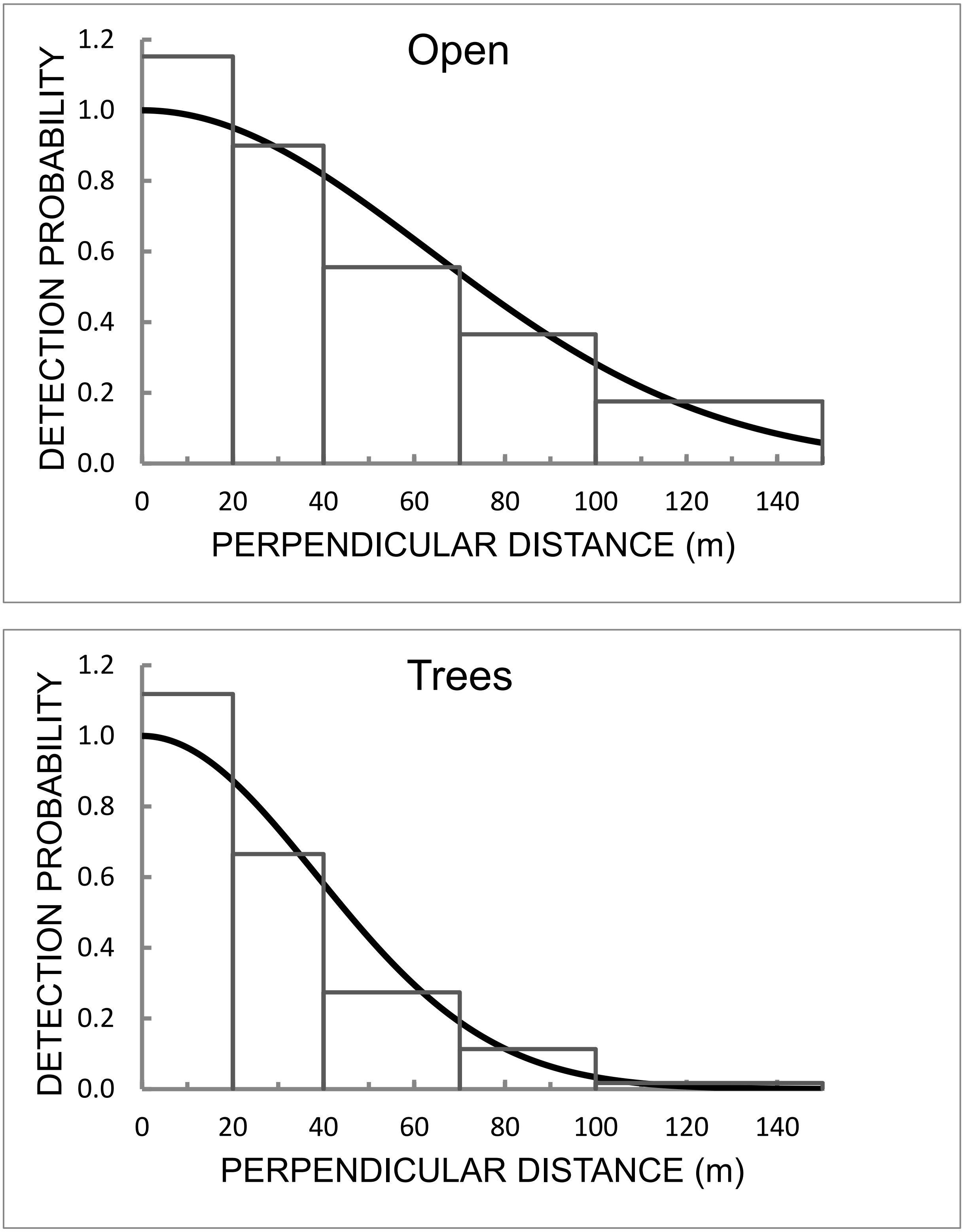
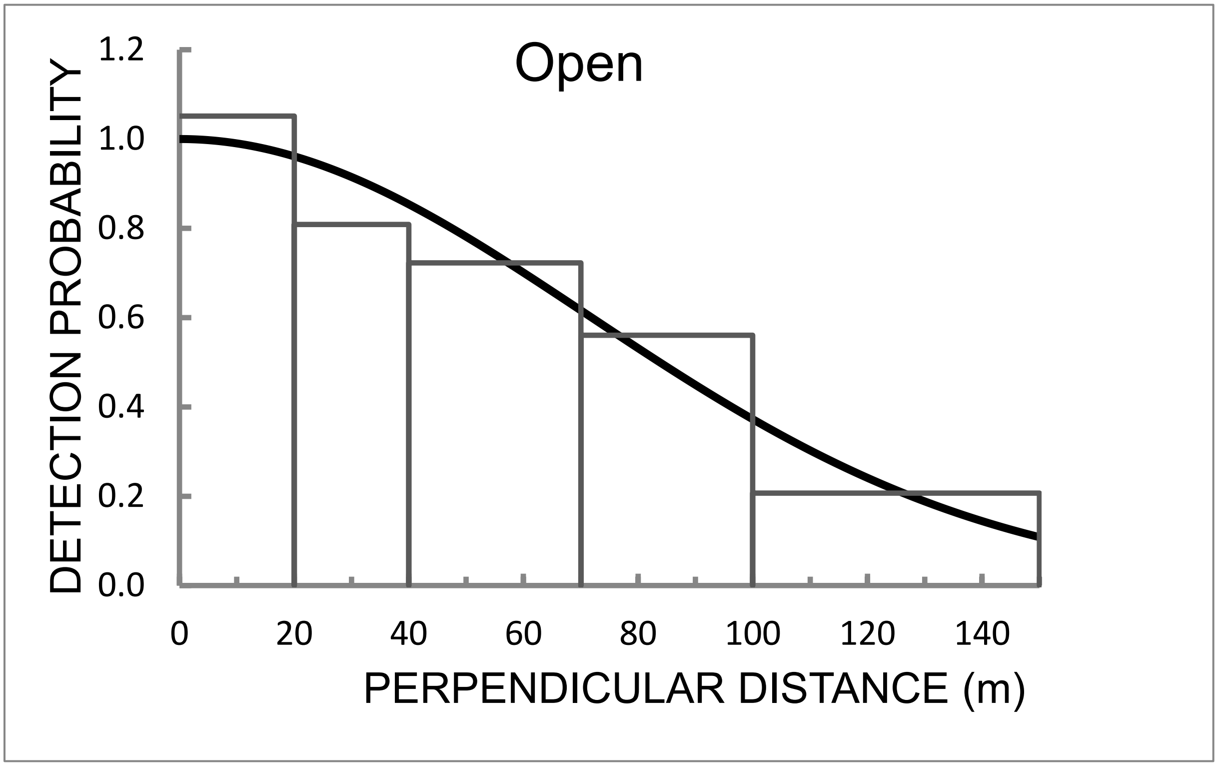


Fig. A1.2. The Half-normal detection functions for eastern grey kangaroos in the Braidwood survey block. For details of the model fitted using the MCDS analysis engine with cover at point-of-detection as a covariate, see text and Table 4.



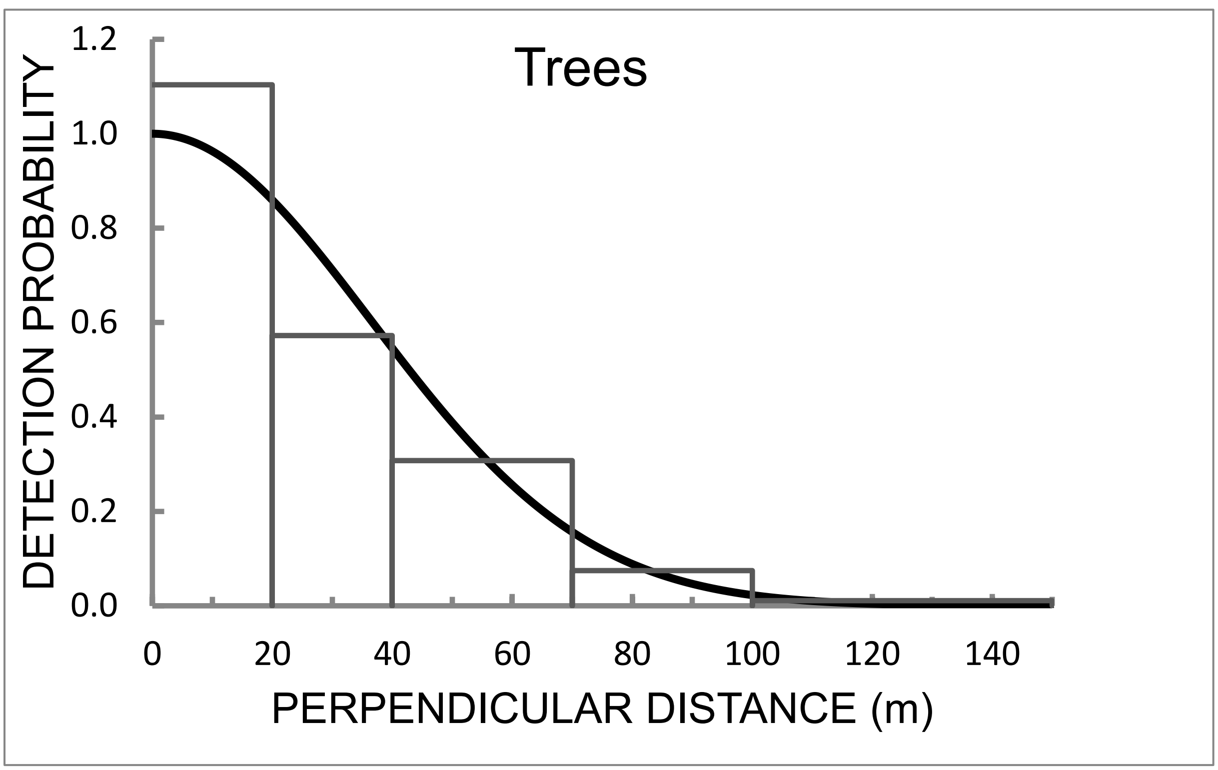
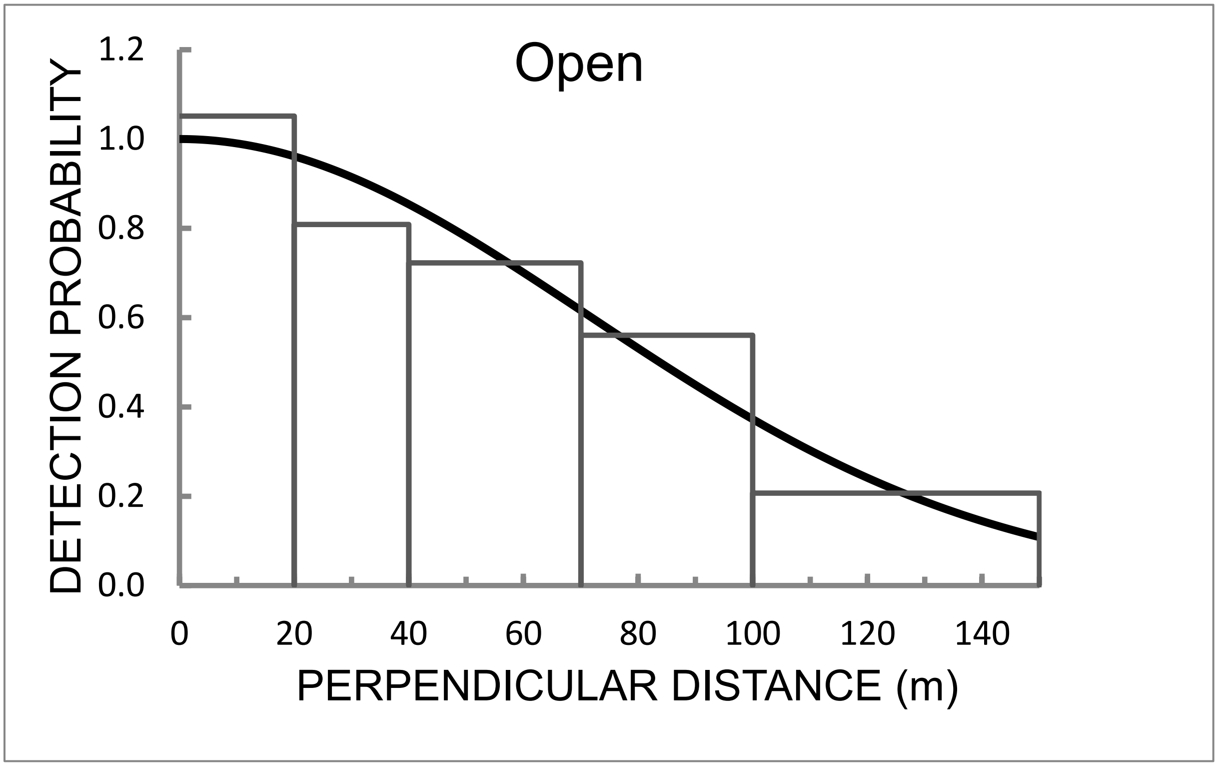


Fig. A1.3. The Half-normal detection functions for eastern grey kangaroos in the Cooma survey block. For details of the model fitted using the MCDS analysis engine with cover at point-of-detection as a covariate, see text and Table 4.



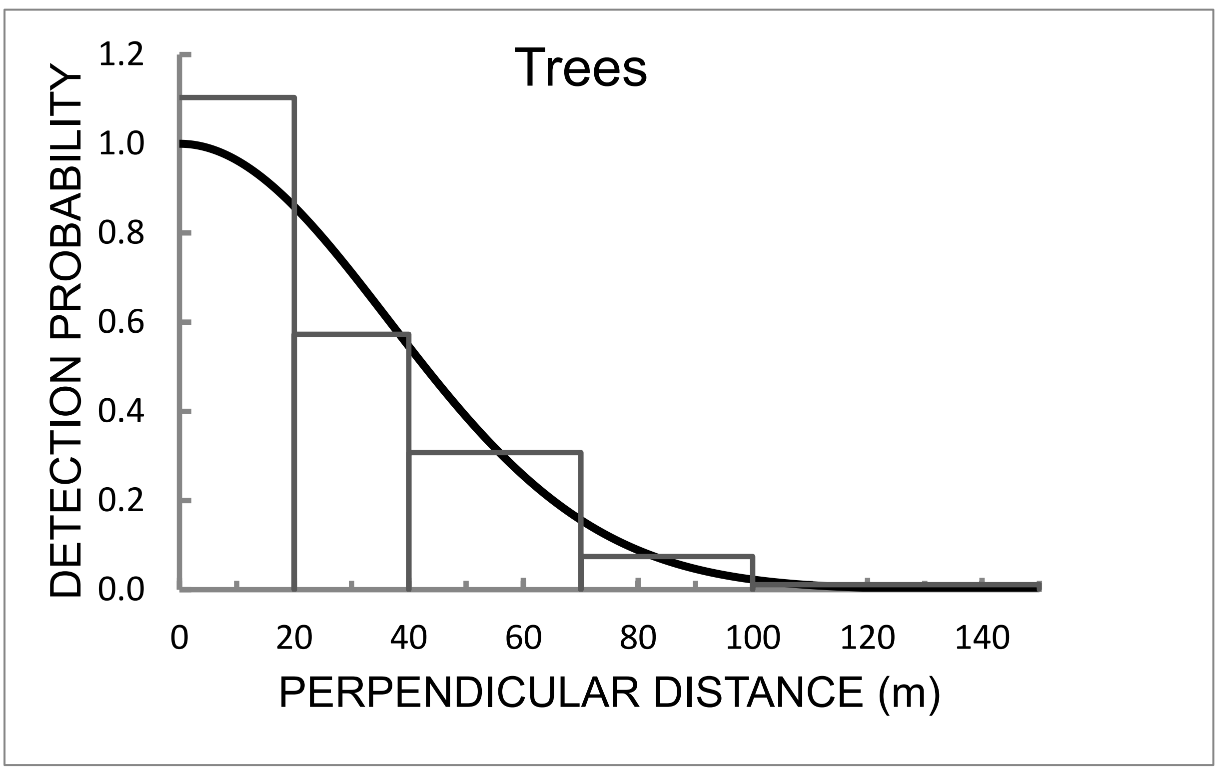


Fig. A1.4. The Half-normal detection functions for eastern grey kangaroos in the Goulburn survey block. For details of the model fitted using the MCDS analysis engine with cover at point-of-detection as a covariate, see text and Table 4.

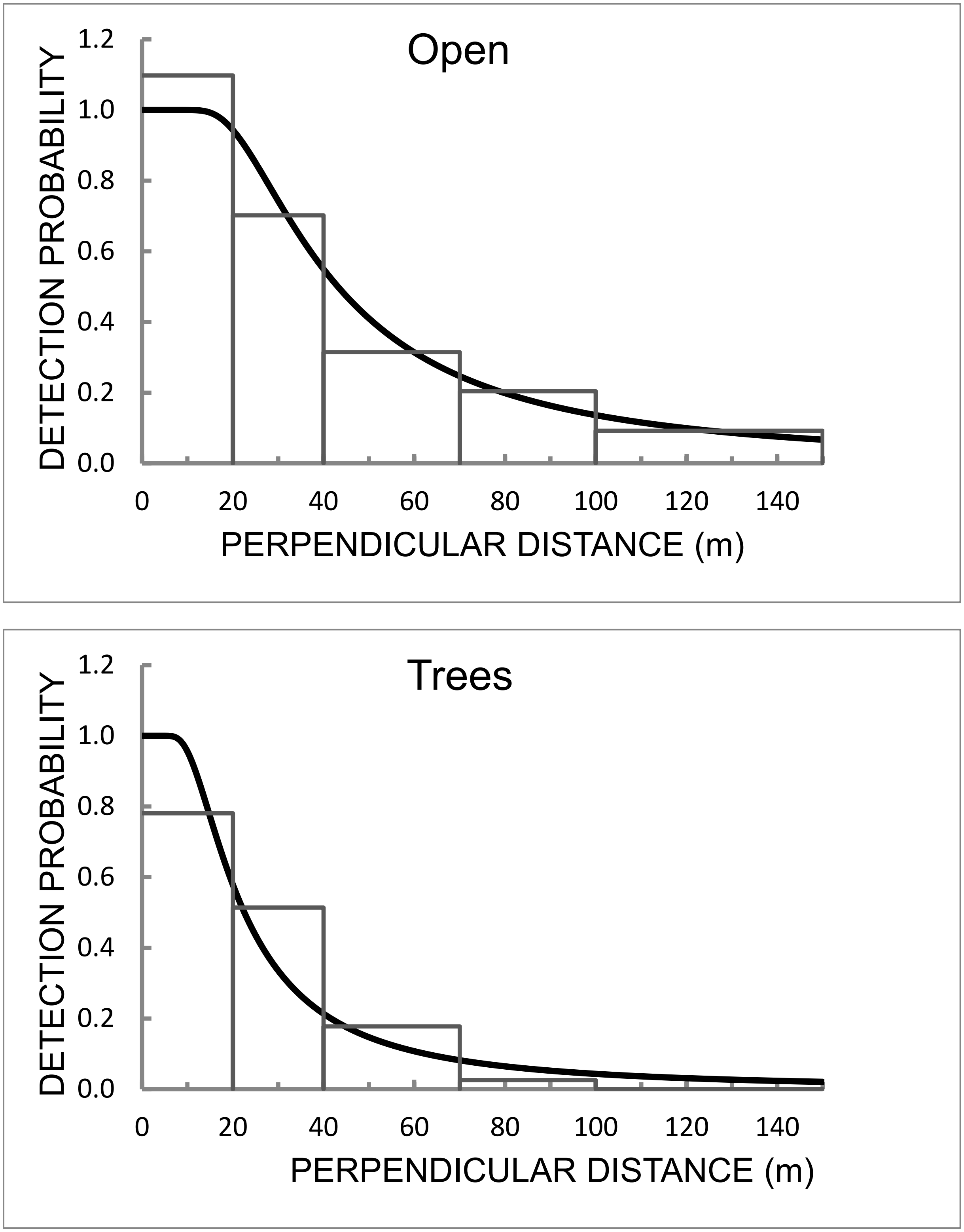


Fig. A1.5. The Hazard-rate detection functions for eastern grey kangaroos in the Gundagai survey block. For details of the model fitted using the MCDS analysis engine with cover at point-of-detection as a covariate, see text and Table 4.

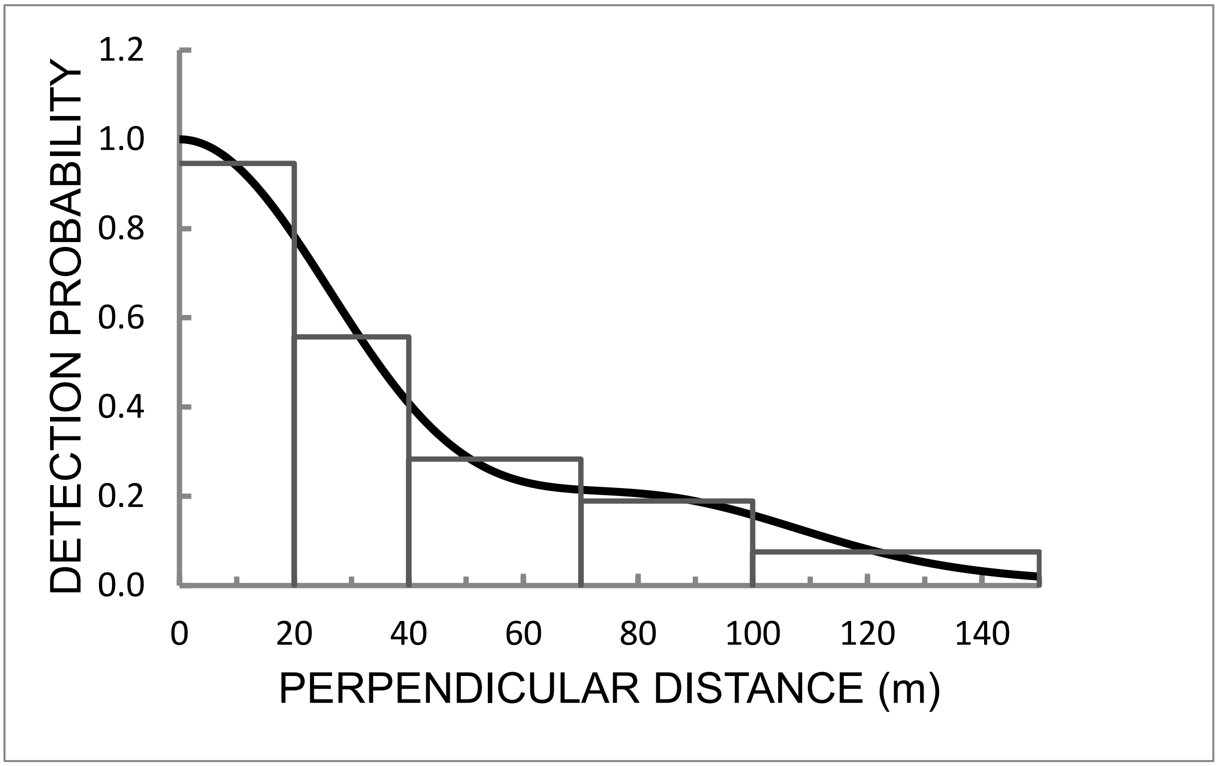


Fig. A1.6. The Half-normal/Cosine detection function for eastern grey kangaroos in the Yass survey block. For details of the model fitted using the CDS analysis, see text and Table 4.

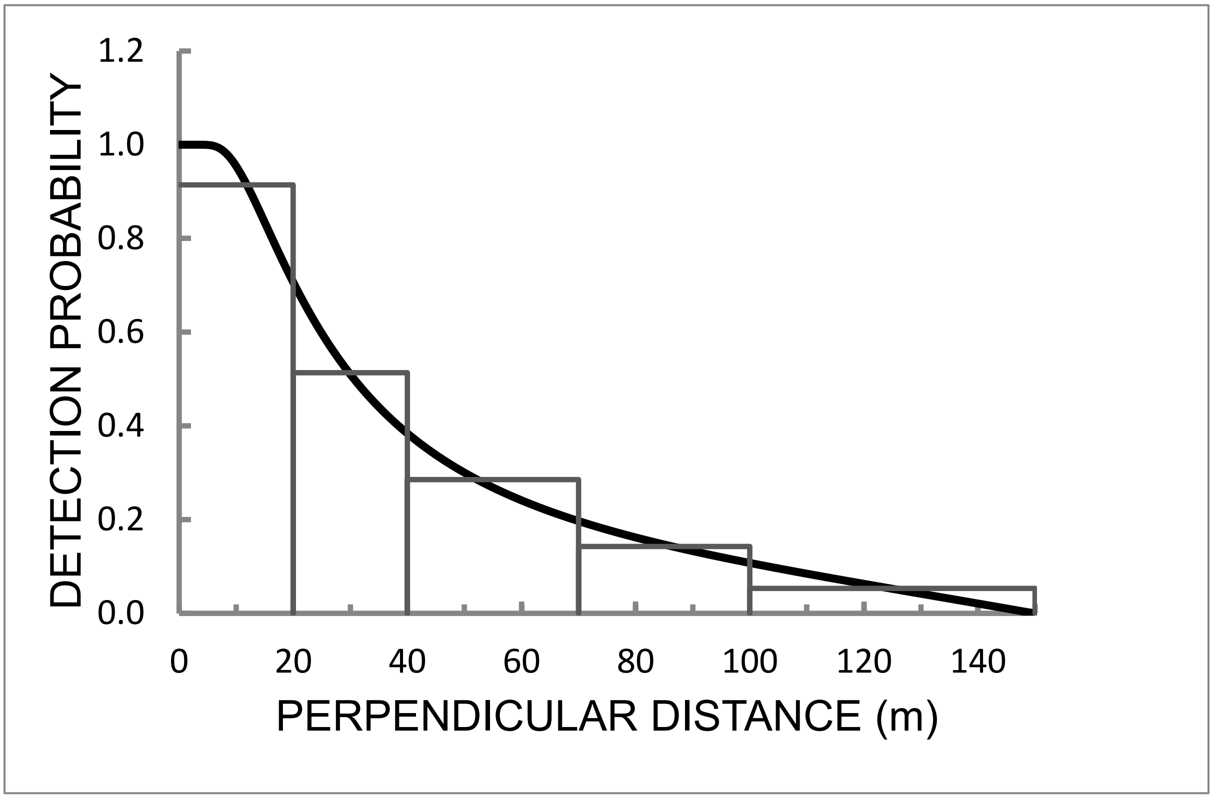


Fig. A1.7. The Hazard-rate/Cosine detection function for eastern grey kangaroos in the Young survey block. For details of the model fitted using the CDS analysis engine, see text and Table 4.

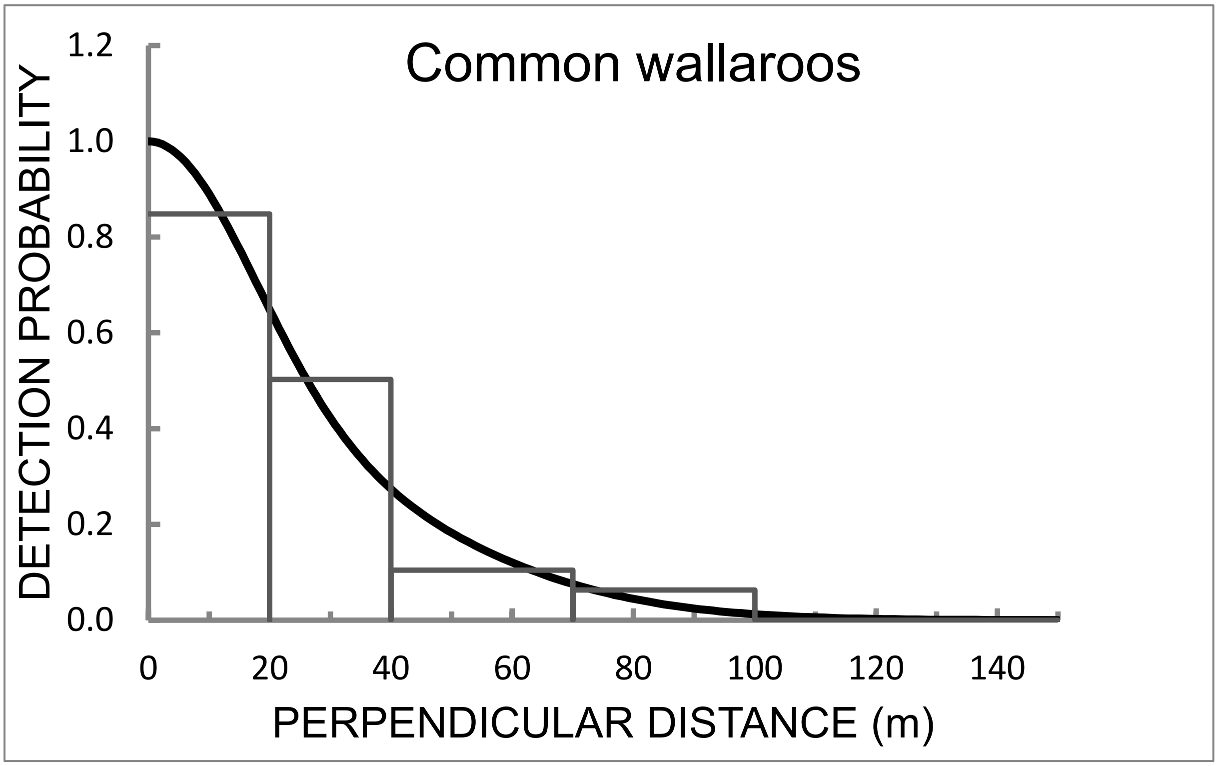


Fig. A1.8. The Half-normal detection function for common wallaroos in the South East Tablelands kangaroo management zone. For details of the model fitted using the MCDS analysis engine with observer as a covariate, see text and Table 5.

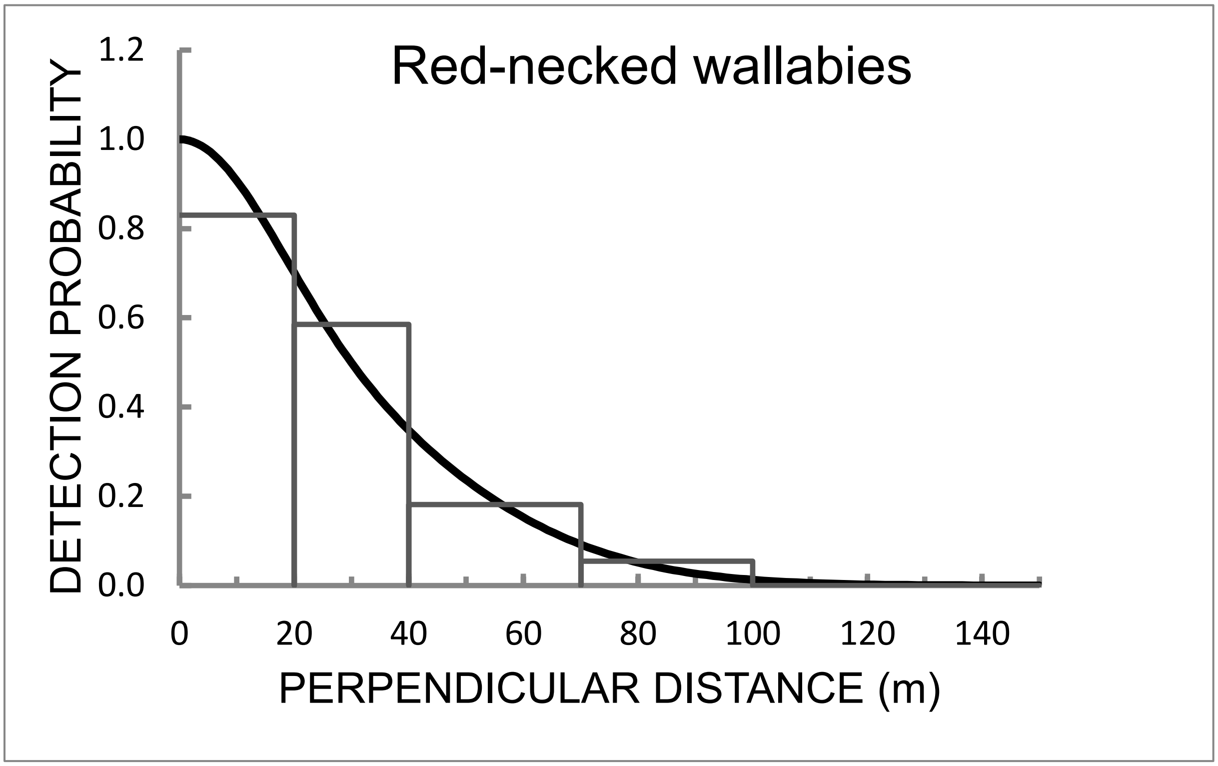


Fig. A1.9. The Half-normal detection function for red-necked wallabies in the South East Tablelands kangaroo management zone. For details of the model fitted using the MCDS analysis engine with observer as a covariate, see text and Table 5.

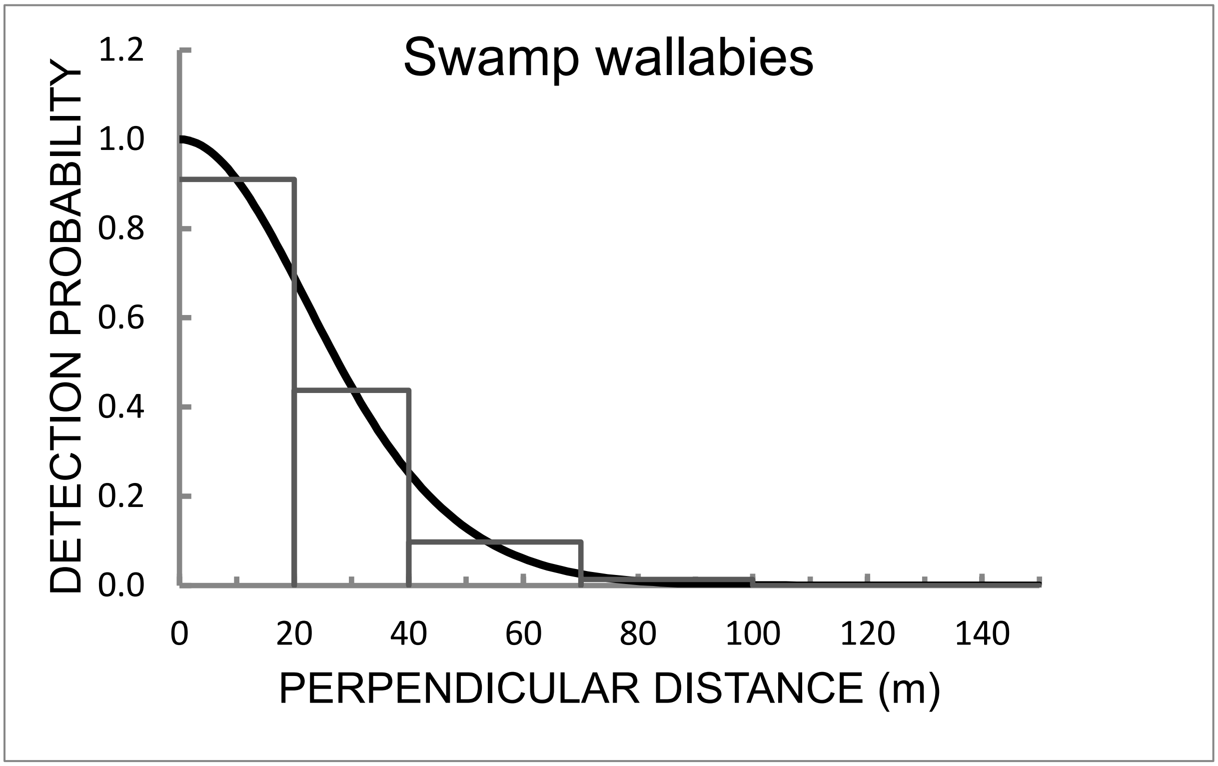


Fig. A1.10. The Half-normal detection function for swamp wallabies in the South East Tablelands kangaroo management zone. For details of the model fitted using the MCDS analysis engine with observer as a covariate, see text and Table 5.