A report to the New South Wales Department of Planning, Industry and Environment on the consultancy: “Design and analysis of helicopter surveys of kangaroo populations in the South East Tablelands kangaroo management zone, 2021”.

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Abstract

1. Helicopter surveys for kangaroos were conducted using line transect sampling in the seven survey blocks that make up the South East Tablelands kangaroo management zone. The population estimates derived from these surveys were intended to be used to set quotas for the 2022-2024 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 7.3 (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 kangaroo density. Those strata identified as most likely to be supporting medium to high densities of kangaroos were then strata 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 35.1 km^{-2} which corresponded to a population estimate of 1,428,800 kangaroos. This compares to a population density of 43.1 km^{-2} estimated from a previous survey conducted in 2018.
5. Since the previous survey conducted in 2018, the eastern grey kangaroo population in this management zone has decreased by 21%. Prior to this decline, 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 finite rate of increase of 11% over the period 2009-2018.
6. Three other species of macropod, the common wallaroo (*Osphranter 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. 2016). 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 (*M. fuliginosus*) and the common wallaroo or euro (*Osphranter robustus*), are currently harvested from within 15 kangaroo management zones (Anon. 2011, 2016). 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. 2016). 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. They are, instead, 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. 2016). 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 inclusion of a sixth RLPB district (Cairns, Lollback & Bearup 2010). These 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 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 Tablelands kangaroo management zone.

Following on from the six surveys conducted to date, a seventh survey was undertaken in early spring, 2021. Reported here, in relation to the survey design and the survey and data analysis methods used, are the results of this seventh triennial survey. The population estimates obtained from this survey will be used to set the 2023-2025 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 Service region. The Gundagai and Young survey blocks are now part of the Riverina Local Land Service 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.

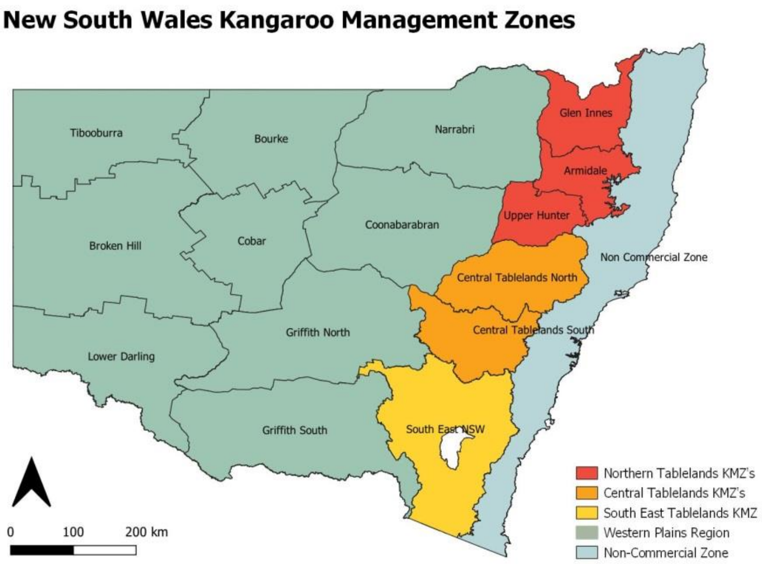

Fig. 1. The 15 kangaroo management zones administered by NSW DPIE.

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 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 and kangaroo occupancy and relative density (see Section 3.1). This subdivision was initially undertaken using information regarding landscape relief, vegetation cover, 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 surveys. An update of these stratifications in relation to national estate lands and urban consolidation has been undertaken for the current survey. In relation to this update, the estimated total area of the management zone remains unchanged at 58,043 km^2. The estimated total area of survey strata is now 40,707 km^2 and the total area of strata to be actually surveyed is 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 7.3 (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, each survey block was divided into two or three strata. This is done using GIS shape files obtained from the NSW OEH. The initial stratification was based upon eight categories of land capability, that extended from cultivation, through to mixed farming and grazing, through to grazing only with decreasing levels of grazing intensity, through to steep, timbered country and, finally, through to rocky outcrops. The boundaries of the strata were further adjusted in relation to coincident knowledge of kangaroo densities. The kangaroo density information used for the first survey of this management zone (Cairns 2004; Pople *et al.* 2006) was anecdotal. 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 & Bearup 2010), 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, Lollback & Bearup 2013).

Following the initial survey of the five blocks other than Bombala and Young (Cairns 2004; Pople *et al.* 2006) a major re-stratification was undertaken, resulting in a reduction in the number of strata within some of the blocks. In the Braidwood, Goulburn, Gundagai and Yass blocks, the original three strata were reduced to two, with the high and medium strata being combined to form single medium density stratum. Also, some changes were made to the boundaries of their respective low density strata. In the Cooma block, the high and medium density strata were combined to form a single high density stratum, while the low density stratum was redefined as a medium density stratum. The three original strata were maintained within the Young survey block, with some minor adjustments being made to their boundaries. The Bombala block was set up on the basis of two strata identified as being of medium and low density.

Using densities and transect counts of eastern grey kangaroos obtained from the surveys conducted in 2009 (Cairns, Lollback & Bearup 2010) and 2012 (Cairns, Lollback & Bearup 2013), the boundaries of the strata within the survey blocks were further redrafted with the aim of improving the design stratification. Reviewing these strata boundaries in relation to the outcome of the surveys conducted in 2009 (Cairns, Lollback & Bearup 2010) resulted in no changes of any significance being made in any of the survey blocks except the Cooma block, where the boundaries delineating the respective density strata were removed, forming the whole block into a single medium density stratum (Cairns, Lollback & Bearup 2013). Recently, the stratification of all seven survey blocks has been further reviewed and updated for the present and future surveys (see Section 2). The breakdown of the area of the management zone into the constituent survey blocks and stratification is given in Table 1.

As has been the case in recent years, only the high and medium density strata were slated to be surveyed on this occasion. That the low density strata supported only trace numbers of kangaroos and did not warrant surveying had previously been confirmed for the original five survey blocks from the survey conducted in 2006 (Cairns 2007). With the exclusion of population centres, national parks, reserves and 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 represented 58% of the whole of the management zone. For visual representation of the stratification of the zones, see Figs. 2-8.

Table 1. Areas (km^2) of the seven survey blocks (former RLPB districts) that constitute the current South East Tablelands kangaroo management zone. The survey areas do not include reserved lands such as National Parks (NPs) or State Forests (SFs), or those areas of high relief outside reserve lands that are unsuitable for aerial survey. 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 areas surveyed comprise 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	30,260
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

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; Cairns, Bearup & Lollback 2013, 2016). For all survey blocks except Young, survey effort was determined broadly in relation to a target level of precision of 17.5%. For the Young block, survey effort was determined broadly in relation to a target level of precision of 20% for both the high and medium density strata. Overall cost was a constraining factor here.

To determine the survey effort required, the method proposed by Buckland *et al.* (2001, p. 243) was used in relation to the precision (measured by the coefficient of determination) averaged over the two most recently conducted surveys of this management zone, a standard scheduled survey conducted in 2018 (Cairns, Bearup & Lollback 2019) and a low intensity survey conducted in 2020 (Cairns, Bearup & Lollback 2021). The survey efforts determined for each survey block are listed in Table 2 as the nominal survey effort.

Table 2. Areas of the portion 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. All eight surveys were conducted as the systematic segmented trackline surveys.

Survey block	Survey area (km^2)	Nominal survey effort (km)	Actual survey effort (km)
Bombala	2,631	320.0	320.0
Braidwood	3,811	315.0	150.0
Cooma	7,074	375.0	292.5
Goulburn	4,462	450.0	450.0
Gundagai	5,502	360.0	360.0
Yass	4,486	360.0	262.5
Young (high)	3,140	300.0	292.5
Young (medium)	2,294	367.5	367.5

In the first survey conducted in the South East Tablelands management zone (Cairns 2004), survey effort across the then five blocks surveyed totalled 735 km. With the inclusion in the second survey of the low density strata (Cairns 2007), the total survey effort increased to 1,155 km. This was increased to a nominal total effort of 2,067 km for the third survey, with only the high and medium density strata being surveyed (Cairns, Lollback & Bearup 2010). For the fourth survey conducted in 2012, the nominal total survey effort was determined as 2,755 km (Cairns, Lollback & Bearup 2013). For the 2015 survey (Cairns, Lollback & Bearup 2016), this was reduced to 2,650 km. For the 2018 survey, which now included the Bombala survey block, the total nominal survey effort was 2,278 km. For the present survey, the total nominal survey effort was 2,848 km (Table 2).

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 7.3 (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 7.3 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 and 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 appropriate 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.

Three systematic sampling designs, the systematic random, the systematic segmented grid and the systematic segmented trackline designs were tested for survey coverage. 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). Where it was applicable, survey designs were compared separately for the high and medium density strata of each of survey block using the nominal survey efforts given in Table 2. The outcome of this process was that the systematic segmented trackline sampling design with fixed-length samplers provided a more than adequate even coverage of all survey areas. Once this was 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 sixty-four 5-km long transects being allocated to the survey stratum (Fig. 2). For the Braidwood block, the selected survey design resulted in sixty-three 5-km long transects being allocated to the survey stratum (Fig. 3). For the Cooma block, the selected survey design resulted in fifty 7.5-km long transects being allocated to the survey stratum (Fig. 4). For the Goulburn block, the selected survey design resulted in sixty 7.5-km long transects being allocated to the survey stratum (Fig. 5). For the Gundagai block, the selected survey design resulted in forty-eight 7.5-km long transects being allocated to the survey stratum (Fig. 6). For the Yass block, the selected survey design resulted in forty-eight 7.5-km long transects being allocated to the survey stratum (Fig. 7). For the Young block, the selected survey design resulted in forty 7.5-km long transects being allocated to the high density stratum and forty-nine 7.5-km long transects being allocated to the medium density stratum (Fig. 8). For the total nominal survey efforts used in the design process along with the total survey efforts of the completed surveys, see Table 2.

4. Survey Methods

The aerial surveys of the seven blocks were conducted in early to mid-spring during the two periods, 7-17 September (Bombala, Cooma, Goulburn, Gundagai, Yass and Young) 11-13 October (Braidwood and Goulburn), 2021. 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 422 transects to be flown across the seven survey blocks. The completed surveys resulted in 363 of these transects being flown (see Table 2). The 59 transects not flown because of poor weather conditions and time constraints were in the Braidwood block and, to a lesser extent, the Cooma and Yass blocks.

All surveys were conducted within either the three-hour period following sunrise or the three-hour period before sunset. David Bearup (NPWS), Mika Saunders (NPWS) and Leigh Nolan (NPWS) were the observers used for these surveys. The pilot used for these survey sessions was Tom Bull.

4.1 Helicopter Line Transect Surveys

In conducting the surveys, the aircraft, a Eurocopter AS350 Écureuil (*Squirrel*) single-engine light 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 61 m (200 ft) above ground level. Navigation was by a global positioning system (GPS) receiver. The two observers occupying the rear seats of the helicopter counted 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).

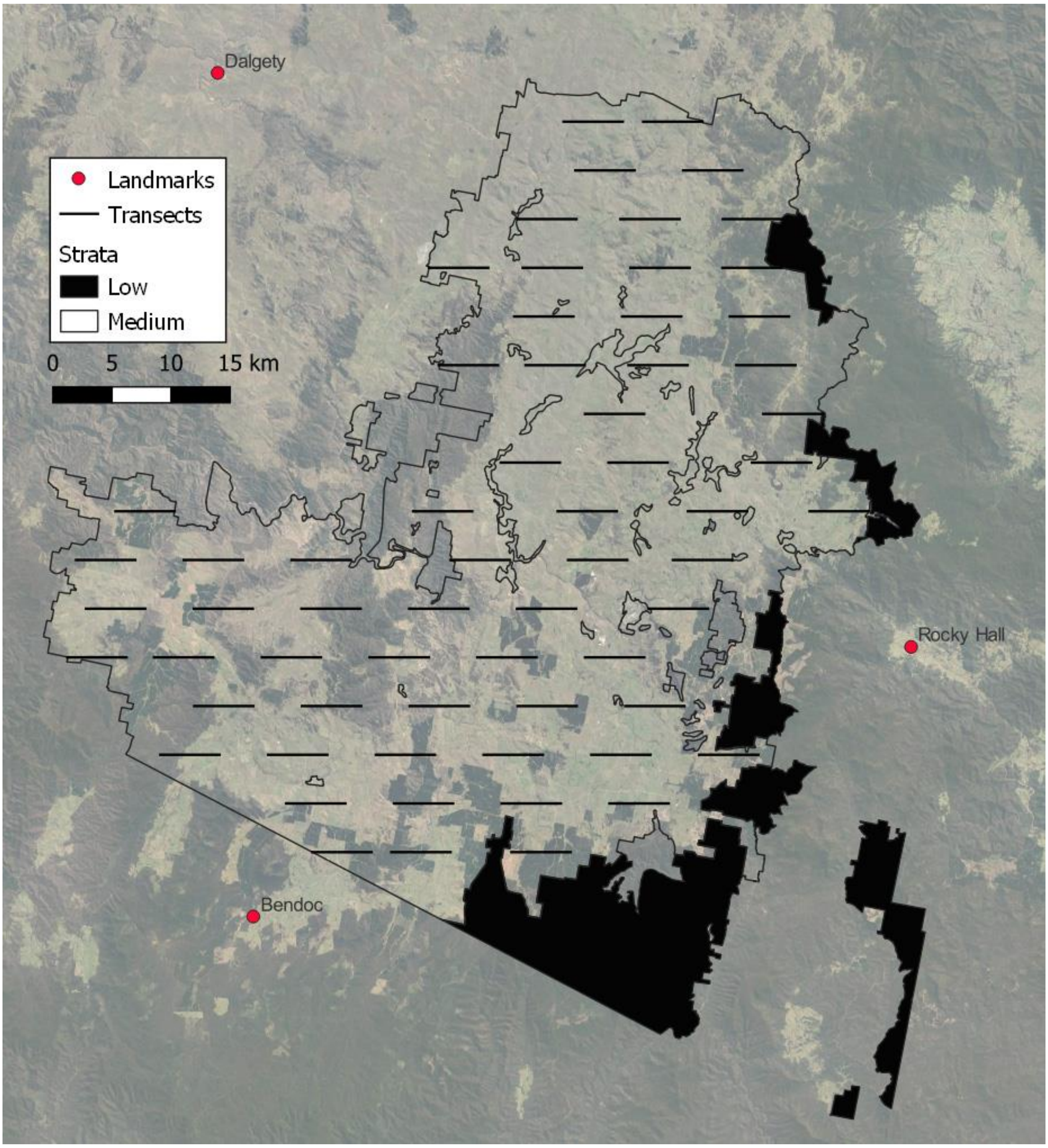

Fig. 2. The Bombala survey block of the South East Tablelands kangaroo management zone. Shown are the two survey strata, landmarks and population centres (towns), and the placement of the survey transects within the medium kangaroo density strata. Note that no survey transects were placed into the low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

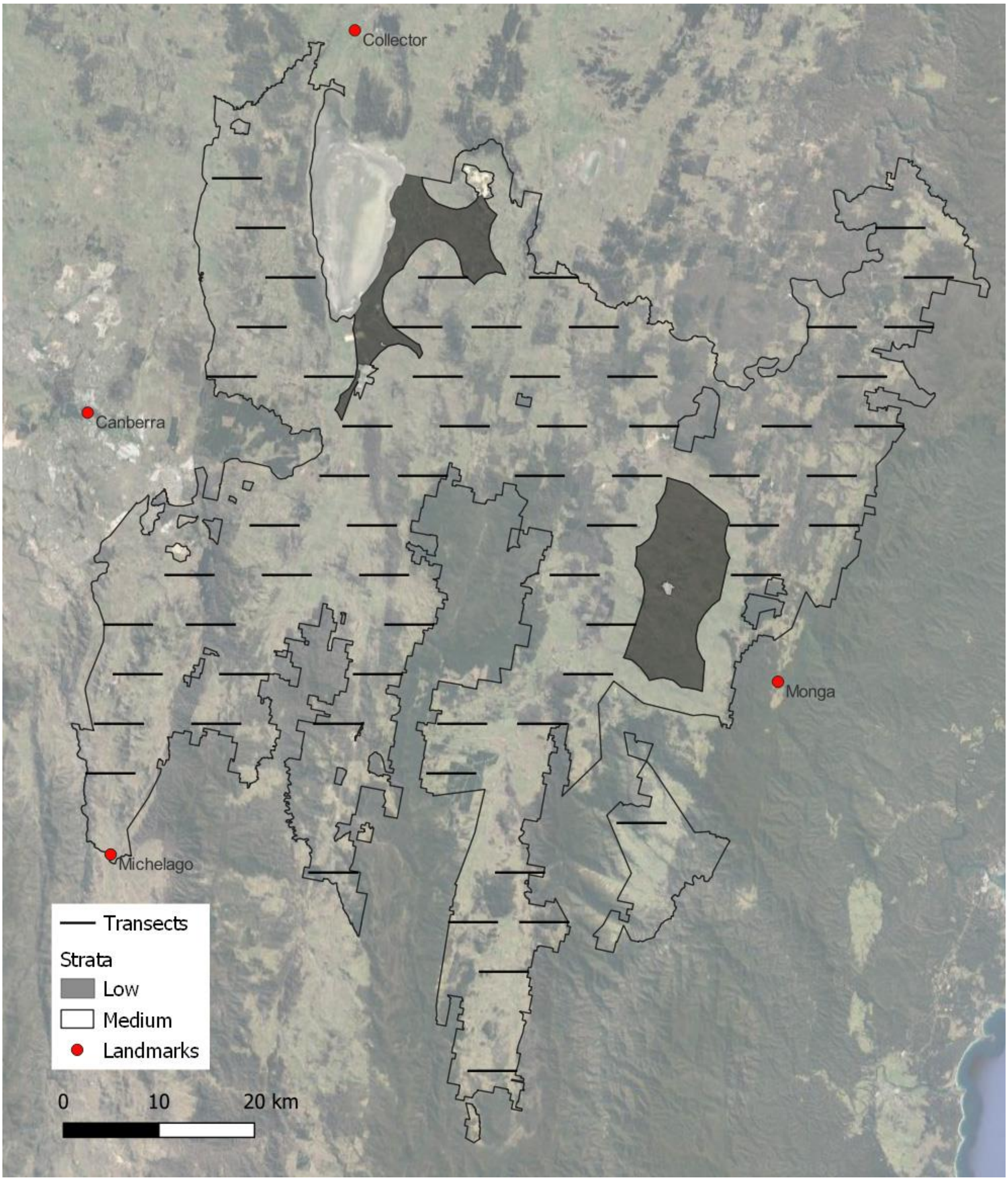

Fig. 3. The Braidwood survey block of the South East Tablelands kangaroo management zone. Shown are the two survey strata, landmarks and population centres (towns), and the placement of the survey transects within the medium kangaroo density strata. Note that no survey transects were placed into the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

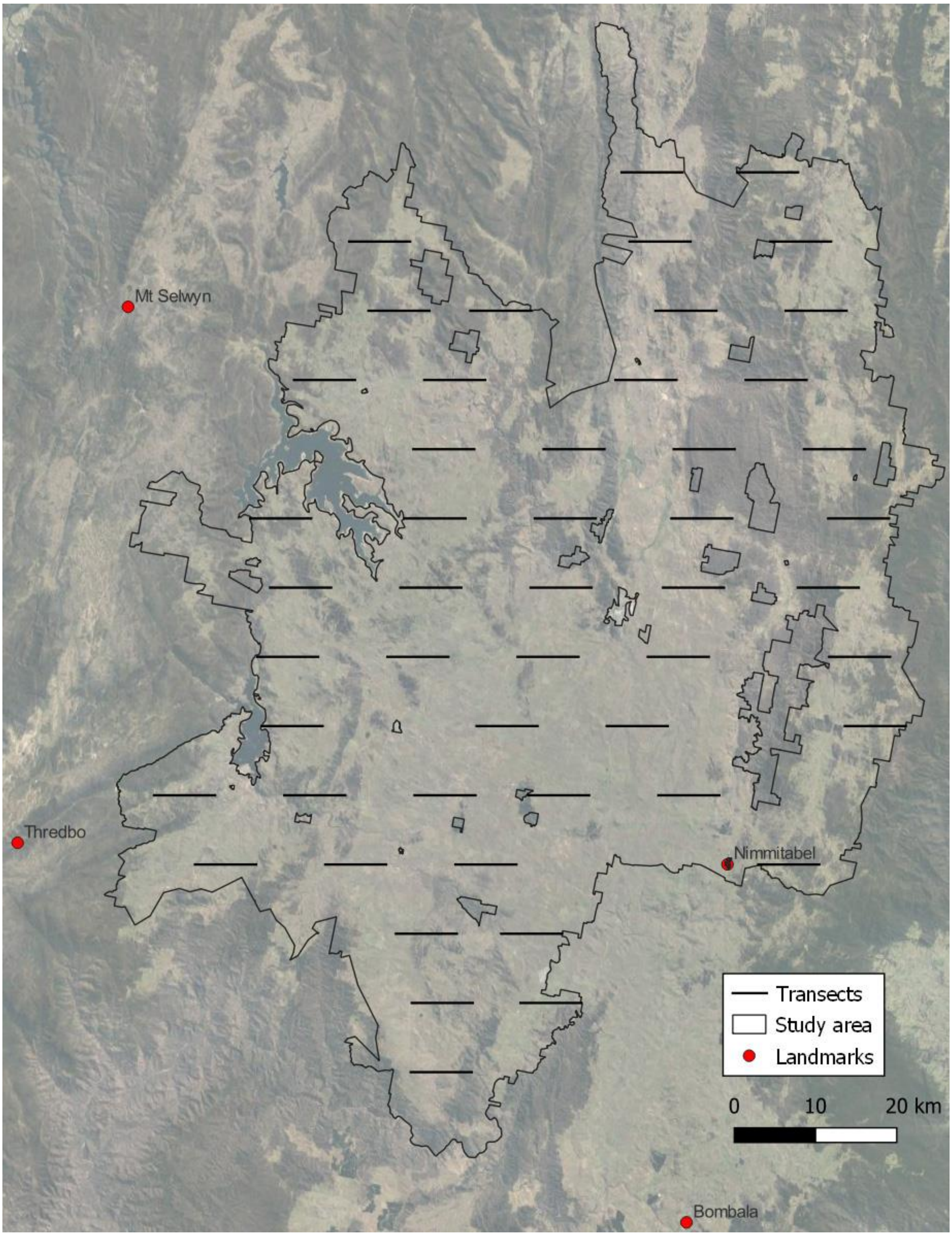

Fig. 4. The Cooma survey block of the South East Tablelands kangaroo management zone. There is no stratification of this block. Shown are landmarks and population centres (towns), and the placement of the survey transects within the single, medium kangaroo density strata.

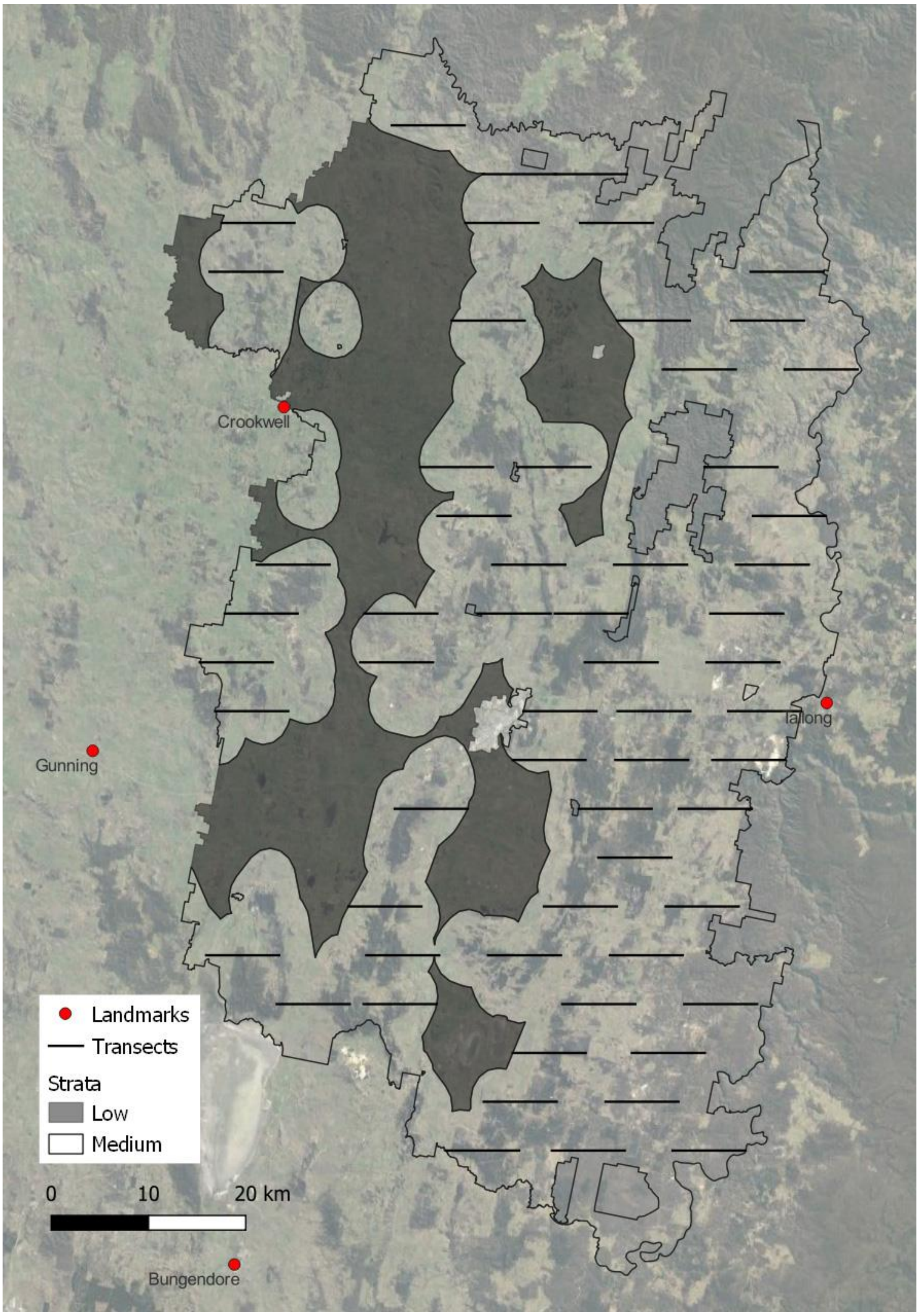

Fig. 5. The Goulburn survey block of the South East Tablelands kangaroo management zone. Shown are the two survey strata, landmarks and population centres (towns), and the placement of the survey transects within the medium kangaroo density stratum. Note that no survey transects were placed into the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

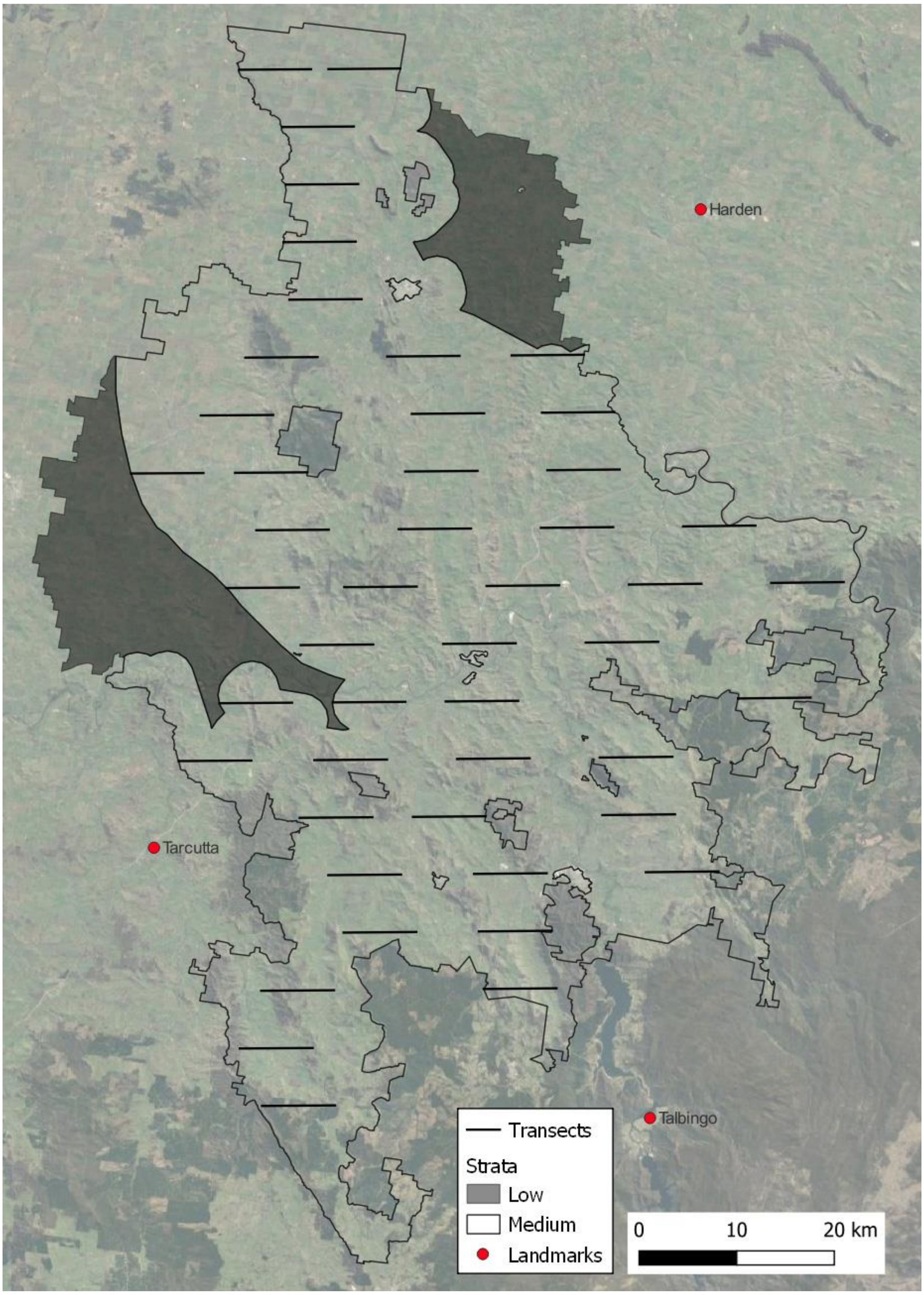

Fig. 6. The Gundagai survey block of the South East Tablelands kangaroo management zone. Shown are the two survey strata, landmarks and population centres (towns), and the placement of the survey transects within the medium kangaroo density stratum. Note that no survey transects were placed into the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

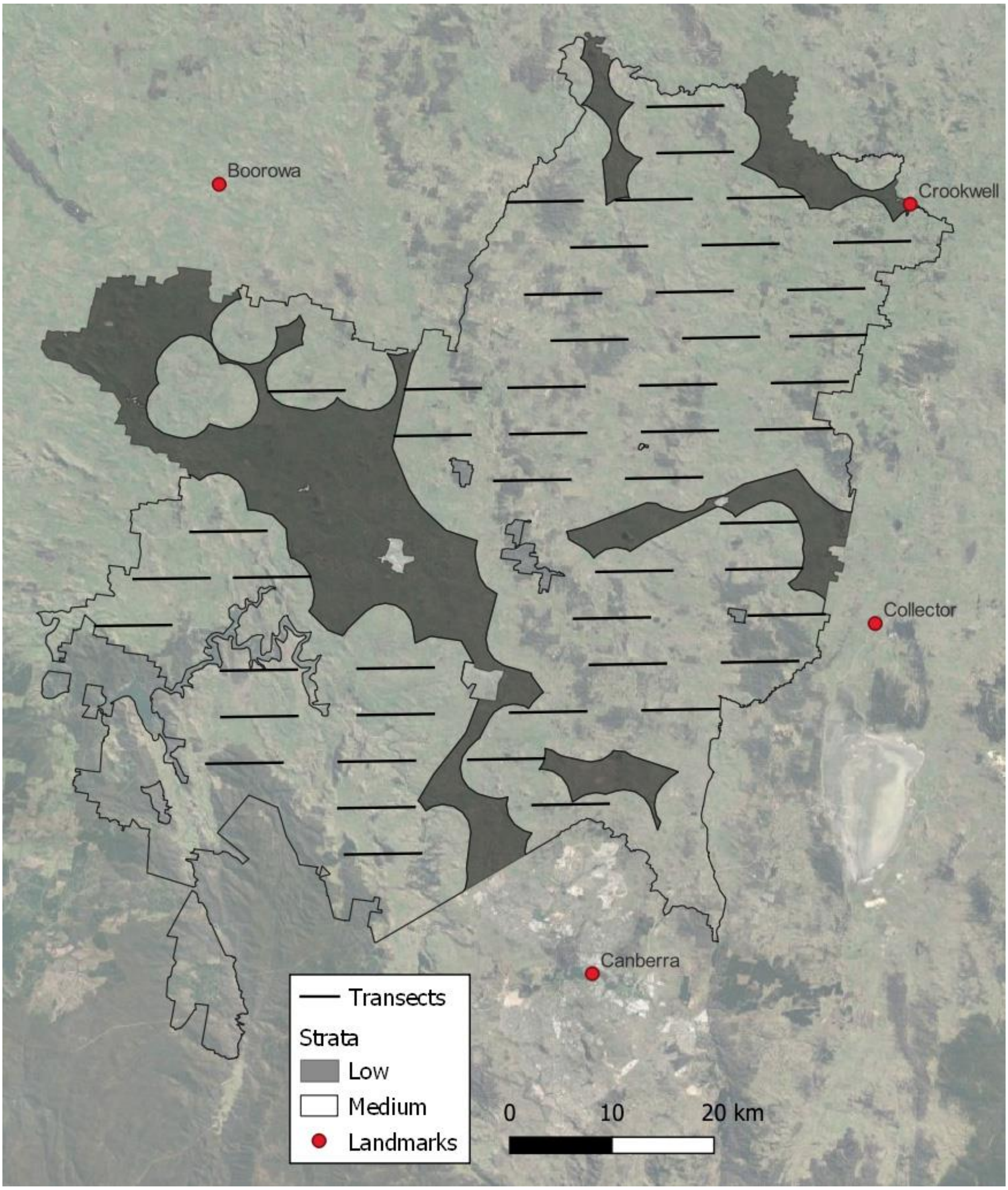

Fig. 7. The Yass survey block of the South East Tablelands kangaroo management zone. Shown are the two survey strata, landmarks and population centres (towns), and the placement of the survey transects within the medium kangaroo density stratum. Note that no survey transects were placed into the low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

Fig. 8. The Young survey block of the South East Tablelands kangaroo management zone. Shown are the three survey strata, landmarks 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.

Data in the form of the numbers of clusters (groups of one or more individuals) of eastern grey kangaroos, common wallaroos (*O. r. robustus*), red-necked wallabies (*M. rufogriseus*) and swamp wallabies (*Wallabia bicolor*) observed in the different delineated distance classes on the nominal survey strip were voice-recorded. The presence of other, non-target species was noted. Voice-recorded information was transcribed at the end of each survey session.

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.

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 covered area is estimated from:

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

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

In order to estimate the probability (P_a) of detecting a cluster of the animals within w, the detection function g(x), the probability that a cluster of animals at perpendicular distance x from the survey transect centreline is detected (where, $0 \leq x \leq w$ and $g(0) = 1$) needs to be modelled and evaluated at x = 0, directly on the transect centreline (Thomas *et al.* 2002). To do this, the sampling data, the counts of clusters of animals (kangaroos) 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 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 60-80 for reliable modelling of the detection function.

For eastern grey kangaroos, the results from each survey block were analysed separately. Where required, stratification was incorporated into the analyses, with the two options 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 species of macropod, in order to meet the above analysis criteria, the survey results were analysed at the level of the management zone.

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 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= -2 x log-likelihood + 2[p + 1]; where p is the number of parameters in the model) was, as is generally the case, selected as the most likely detection function. 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.

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, survey aspect and cloud cover. To avoid over-parameterisation, only single covariates were included in the analyses separately. Two key functions are available with the MCDS analysis engine: the Half-normal and the Hazard-rate functions. Cosine, Simple Polynomial and Hermite Polynomial series expansions were available be used in relation to these two key 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 line (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 line, 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, and their associated statistics of variation were determined empirically, confidence limits (LCL and UCL) and coefficients of variation (cv%) were also determined by bootstrapping the data. The data were bootstrapped 999 times in relation to all model options in the analysis engines and not just the model selected to determine the empirical estimates. This was expected to improve the robustness of the estimation of these statistics (Buckland *et al.* 2001). The 95% confidence limits presented were the 2.5% and 97.5% quantiles of the respective bootstrap estimates.

For eastern grey kangaroos, the data were analysed to determine separate density and population estimates for each survey block. These estimates were combined to produce density and abundance estimates for the whole of the South East Tablelands kangaroo management zone. For common wallaroos, red-necked wallabies and swamp wallabies, the data were analysed at the level of management zone.

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 relation to the conduct of this survey, the survey effort originally allocated in the Braidwood, Cooma and Yass blocks was higher than the actual total length of transect flown (Table 2). Poor weather and time constraints precluded the full allocation of transect from being flown.

In the Bombala survey block, all 64 transects shown in Fig. 2 were flown in the medium density stratum on which 380 clusters of eastern grey kangaroos were observed. In the Braidwood block, only 30 transects of the 63 transects shown in Fig. 3 were flown in the medium density stratum on which 207 clusters of eastern grey kangaroos were observed. The Cooma block was surveyed as a single stratum. Of the 50 transects shown in Fig. 4, 39 were flown on which 332 clusters of eastern grey kangaroos were observed. In the Goulburn block, all 60 transects shown in Fig. 5 were flown in the medium density stratum on which 506 clusters of eastern grey kangaroos were observed. In the Gundagai block, all 48 transects shown in Fig. 6 were flown in the medium density stratum on which 327 clusters of eastern grey kangaroos were observed. In the Yass survey block, of the 48 transects shown in Fig. 7, 35 were flown in the medium density stratum on which 431 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 but one of the 89 transects shown in Fig. 8 were flown; 39 in the high density stratum on which 76 clusters of eastern grey kangaroos were observed, and 49 in the medium density stratum on which 29 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 sightings of introduced deer (*Dama* sp.and *Cervus* sp.) and a reasonable number of feral goats (*Capra hircus*), feral pigs (*Sus scrofa*) and introduced foxes (*Vulpes vulpes*). A summary of the raw counts of the four species of macropods observed in the survey areas is given in Table 3.

5.2 Line Transect Analysis

To estimate the population densities and abundances of kangaroos, the counts of clusters of kangaroos observed during line transect sampling were grouped into the five distance categories set on the survey booms mounted on the helicopter (Fig. 9). The method of analysis used conformed to a general and well-understood framework for analysing distance sampling data, as outlined in Buckland *et al.* (2001). Key to distance sampling analysis is the modelling of the detection of objects (clusters of kangaroos) in relation to their perpendicular distances from the survey transect centreline. Analyses involved the use of both the CDS and the MCDS analysis engines of DISTANCE 7.3 (Thomas *et al.* 2010), with the most parsimonious (specific) detection function model being selected principally on the basis of comparison of the AIC statistic (see Section 4.2). 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 SE NSW 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 each analysis, the most parsimonious (specific) detection function model, global or stratified, was selected principally on the basis of it being the one that yielded the smallest value of the AIC statistic (see Section 4.2). With regard to the calculation of the AIC statistic for a particular model, it should be noted that an individual AIC value is, by itself, not interpretable due to the unknown interval scale to which it is related (Burnham & Anderson 2002). Hence, for a given model, the value of the AIC statistic is only comparative, relative to the values of other AIC statistics in the set of models tested. It is the AIC differences (ΔAIC) that are important. In comparing any two models, when ΔAIC >2.00, the interpretation is that there is mounting evidence that it is increasingly less plausible that the fitted model with the larger AIC statistic could be considered the better of the two models, given the data. The converse to this is that when ΔAIC $\leq$2.00, it can then be thought that, in this instance, there is some level of empirical support for the model with the larger AIC statistic as well as for the model associated with the smaller AIC statistic, given the data. 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. Despite the truncation of the survey in some of the blocks, the required minimum number of replicate transects was attained for each survey stratum as was the required minimum number of replicate observations. The numbers of replicate transects flown across the survey strata of the seven survey blocks are given in Table 3 and the replicate numbers of clusters of eastern grey kangaroos observed are given in Table 4.

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 comprises two survey strata.

			Raw counts			
Survey block	No. of transects	Effort (km)	Eastern grey kangaroos	Common wallaroos	Red-necked wallabies	Swamp wallabies
Bombala	64	320.0	1,973	2	51	36
Braidwood	30	150.0	1,079	2	18	17
Cooma	39	292.5	1,487	–	47	32
Goulburn	60	450.0	1,992	49	18	26
Gundagai	48	360.0	1,225	26	–	20
Yass	35	262.5	1,589	8	7	19
Young						
Young (high)	39	292.5	1,504	85	2	20
Young (medium)	49	367.5	415	13	1	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 the Goulburn and Gundagai blocks, robust CDS-derived models without the inclusion of any covariates proved to be the most parsimonious models of those tested. These two models were Half-normal and Hazard-rate in form. For the other five survey blocks, the detection function models were MCDS-derived models, each incorporating the covariate of observer. The key function of the models fitted to the survey data from each of these four blocks were also either Half-normal or Hazard-rate in form (Table 4).

Table 4. The number of sightings of animals (n), the DISTANCE 7.3 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 of the eastern grey kangaroo populations in the seven survey blocks. CDS is the conventional distance sampling engine and MCDS is the multiple-covariate distance sampling engine.

Survey block	n	Analysis engine	Model	Covariates	n/L	P_a
Bombala	380	MCDS	Hazard-rate	OBSERVER	1.19	0.30
Braidwood	207	MCDS	Hazard-rate	OBSERVER	1.38	0.32
Cooma	332	MCDS	Hazard-rate	OBSERVER	1.12	0.30
Goulburn	506	CDS	Hazard-rate	–	1.12	0.31
Gundagai	327	CDS	Half-normal	–	0.91	0.25
Yass	431	MCDS	Half-normal	OBSERVER	1.64	0.39
Young	555	MCDS	Hazard-rate	OBSERVER	1.49	0.37

With the final MCDS-derived models, the differences between the selected models and the corresponding CDS-derived models were in most instances quite substantial ($1.84 \leq \Delta AIC \leq 24.06$), with the inclusion of the covariate proving important to the modelling process. The general forms of the detection functions for the seven survey blocks are shown in Appendix 1, Figs. A1.1-A1.7. Although not shown in these graphics, it should be noted that where covariates are included in the models, they have the effect of altering the scale of the detection function, but not its general form (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, in some respects, a more informative statistic than is n itself (Buckland *et al*. 2001). Encounter rate variance usually dominates the overall variance of object (kangaroo) density. 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, with, on average, approximately one or more clusters of eastern grey kangaroos 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. 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 0.25 to 0.39, with a median value of 0.32. The variability in P_a is comparable to that found across these survey block in relation to previous surveys, where the value of P_a has been estimated to have ranged from as low as 0.21 to as high as 0.54 (Cairns, Lollback & Bearup 2010, 2013; Cairns, Bearup & Lollback 2016, 2019, 2021). 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. However, there does exist a strong association between P_a and n/L (r_5 = 0.96).

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 common wallaroos and red-necked wallabies, the most parsimonious detection function models were CDS-derived models with Hazard-rate and Half-normal key functions, respectively. For swamp wallabies, the most parsimonious detection function model was an MCDS-derived model with a Half-normal key function and the observer covariate. The general forms of the detection functions for these three species are shown in Appendix 2, Figs. A1.8-A1.10. The encounter rates for these three species were all similarly much lower than those for eastern grey kangaroos. The values of P_a were similar for wallaroos and swamp wallabies, but much lower for red-necked wallabies. In all three instances these values were lower than those determined for eastern grey kangaroos.

Table 5. The number of sightings of clusters of animals (n), the DISTANCE 7.3 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 South East Tablelands kangaroo management zone. CDS is the conventional distance sampling engine and MCDS is the multiple-covariate distance sampling engine.

Species	n	Analysis engine	Model	Covariate	n/L	P_a
Common wallaroos	89	CDS	Hazard-rate	–	0.04	0.28
Red-necked wallabies	101	CDS	Half-normal/Cosine	–	0.04	0.17
Swamp wallabies	149	MCDS	Half-normal	OBSERVER	0.06	0.25

5.3 Population Estimates

The baseline population estimates for eastern grey kangaroos obtained from the analyses of the survey results are given in Table 6. These estimates are densities of the clusters of kangaroos observed and corresponding population densities determined at the level of survey stratum. Empirical and bootstrap coefficients of variation and bootstrap confidence intervals are given with these estimates. In relation to these densities, average cluster size was in the range 2.9-4.5 kangaroos per group; similar to the estimated average cluster sizes from the two most recent surveys of these blocks (Cairns, Bearup & Lollback 2019, 2020). As has also been found on these previous occasions, cluster density was strongly correlated with population density (r_6 = 0.90; P = 0.002).

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 most instances, <20%. Precision was below this level in the Braidwood block, for which the planned survey was truncated, and in the medium density stratum of the Young block, which had a much lower kangaroo density than the other strata in the survey (Table 6). This overall survey precision is comparable with that of the previous 2015 and 2018 surveys (Cairns, Bearup & Lollback 2016, 2019), and an overall marked improvement on the precision obtained in two earlier surveys conducted in this management zone (Cairns, Lollback & Bearup 2010, 2013).

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			Cluster density (km^{-2})				Kangaroo density (km^{-2})		
	Area (km^2)	D_s	cv (%)	95% bootstrap confidence interval	cv_{boot} (%)	D	cv (%)	95% bootstrap confidence interval	cv_{boot} (%)
Bombala	2,631	13.25	16.5	7.89-18.25	21.8	47.69	17.2	30.66-72.42	22.3
Braidwood	3,811	14.50	21.9	8.97-21.41	22.1	65.88	22.6	34.80-104.00	27.7
Cooma	7,074	12.50	14.7	8.58-15.87	15.9	44.63	15.4	31.60-60.76	16.9
Goulburn	4,462	11.91	12.2	9.40-15.05	12.2	42.89	12.7	31.59-56.52	15.2
Gundagai	5,502	12.10	15.1	8.45-15.35	15.3	37.22	15.5	24.89-51.41	18.1
Yass	4,486	13.91	19.5	10.14-18.89	15.8	43.55	19.8	31.55-62.13	17.8
Young									
High	3,140	13.74	17.1	8.60-27.78	17.7	40.45	17.4	25.52-52.82	17.6
Medium	2,294	2.49	28.7	1.26-4.03	30.4	7.83	29.4	3.96-13.29	31.9

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	47.69	30.66-72.42	125,470	80,670-190,530	22.3
Braidwood	3,811	65.88	34.80-104.00	251,050	132,610-396,340	27.7
Cooma	7,074	44.63	31.60-60.76	315,720	223,540-429,850	16.9
Goulburn	4,461	42.90	31.59-56.52	191,390	140,960-252,180	15.2
Gundagai	5,502	37.23	24.89-51.41	204,820	136,950-282,860	18.1
Yass	4,486	43.55	31.55-62.13	195,370	141,560-278,740	17.8
Young						
High	3,140	40.45	25.52-52.82	127,020	80,130-165,840	17.6
Medium	2,294	7.83	3.96-13.29	17,960	9,090-30,490	31.9
Pooled	5,434	26.68	17.37-34.33	144,980	94,360-186,560	16.3

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

Survey block	Area (km^2)	N	D (km^{-2})
Bombala	3,039	125,470	41.29
Braidwood	4,067	251,050	61.73
Cooma	7,074	315,720	44.63
Goulburn	5,865	191,390	32.63
Gundagai	6,282	204,820	32.60
Yass	5,557	195,370	35.16
Young	8,823	144,980	16.43
SE NSW zone	40,707	1,428,800	35.10

Population abundances derived using the eastern grey kangaroo 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 strata area of each survey block (i.e. including, where applicable, high, medium and low density strata) were also determined. 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 SE NSW management zone is also given in Table 8.

Eastern grey kangaroo densities varied across the survey blocks within the management zone (Table 8). However, although total numbers have decreased over the three-year period since the last full survey conducted in this management zone (Cairns, Bearup & Lollback 2019), densities remain relatively high in the eastern survey blocks within the zone (Bombala, Braidwood and Cooma) compared with the Goulburn Gundagai and Yass blocks, and the western Young block, which generally had the lowest density. Until the conduct of the present survey, the Cooma block had consistently supported the highest eastern grey kangaroo density of all the survey blocks. At the survey block level, numbers declined in the Bombala, Cooma, Goulburn and Young survey blocks in relation to the estimates obtained from the 2018 survey (Cairns, Bearup & Lollback 2019). Although there was an overall decline in the size of the population in the management zone, at the survey block level, increases in numbers were registered in the Braidwood, Gundagai and Yass blocks. Comparisons of the changes in numbers recorded at the level of survey block are given in Table 9. Although none of the changes were statistically significant ($P > 0.05$), some of them were quite substantial. For instance, the increase in numbers in the Gundagai block was a substantial 60% compared to the population estimate obtained from the 2018 survey. Significant or not, the increases and decreases in numbers that occurred at the level of survey block are probably the result of the movement of animals within the management zone rather the result of any fine-scale demographic processes.

Table 9. The 2018 and 2021 estimates of the eastern grey kangaroo population abundances (N) in the survey blocks within the South East Tablelands kangaroo management zone. The differences between the two estimates given for each block 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: $N_{2018} = N_{2021}$).

Survey block	N_{2018}	$cv\%_{2018}$	N_{2021}	$cv\%_{2021}$	z	P-value
Bombala	131,050	21.1	125,470	22.3	0.142	0.887
Braidwood	218,840	22.2	251,050	27.7	0.380	0.704
Cooma	587,700	22.0	315,720	16.9	1.945	0.052
Goulburn	362,400	24.9	191,390	15.2	1.804	0.071
Gundagai	126,960	14.7	204,820	18.1	1.876	0.061
Yass	170,550	21.6	195,370	17.8	0.490	0.624
Young	210,010	21.1	144,980	16.3	1.295	0.195
SE NSW zone	1,807,510	9.8	1,428,800	7.8	1.803	0.071

The demographic change registered at the broader scale was an overall decline in numbers from the level recorded in the 2018 survey. The total number of eastern grey kangaroos in the South East Tablelands kangaroo management zone was estimated to be 1,428,800 (Table 8). Compared to this, in 2018 the size of the eastern grey kangaroo population in this management zone was estimated to be 1,807,510 (Cairns, Lollback & Bearup 2019). This represents a proportional decline in numbers of 21% (Table 9: $z = 1.803$, $P = 0.071$). Although not conventionally statistically significant, this overall decline in numbers was, nevertheless, substantial.

The reason for the decline in numbers over the period 2018-2021 would almost certainly be the impact of the 2017-2019 drought and, possibly, the 2019-2020 bushfires that ravaged parts of south-eastern NSW. The drought was particularly severe and was characterised by its impact mainly through the cooler months (April-September) of each of the three years it lasted, with rainfalls for these periods being registered in the category of lowest on record (http://www.bom.gov.au/climate/drought/knowledge-centre/previous-droughts.shtml). Hot conditions at the end of the spring of 2019 combined with the dry landscape and strong prevailing winds combined to produce the dangerous fire weather conditions of December 2019 and early January 2020. The ensuing bushfires had a severe effect in various parts of south-eastern NSW, including parts of the South East Tablelands kangaroo management zone.

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 leading up to 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 management zone increased by 32%. This increase would probably have occurred in association with the two particularly wet and productive years that preceded the descent into drought in 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. What impact the bushfires might have had on the kangaroo population cannot really be separated from that of the drought. The annual decline that has occurred between the conduct of the 2018 and 2021 surveys was 7.5%. There would appear to be a lag in this response to the drought which began in mid-2017. 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).

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 ~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 sizes of the eastern grey populations in the northern-most Glen Innes and Armidale management zones, but a substantial decline in numbers of 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 ~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 in response to the ending of the millennium drought in 2009 and the onset and impact of the 2017-2019 drought that affected eastern NSW.

Compared to previous surveys of this management zone, there have not always been enough sightings of other species of macropod to determine population estimates. This time, however, there were enough sighting of common wallaroos, red-necked wallabies and swamp wallabies to enable estimates to be determined. The density and population estimates for these three species are given in Table 9.

Two densities are given, one being the survey densities (D) from which the whole-zone abundances and whole-zone densities (D_z) have been estimated.

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, the estimates for wallaroos have been adjusted up by a factor of 1.85 and given in Table 10 as such. Compared to the population estimate determined in the 2018 survey (N = 23,670; Cairns, Bearup & Lollback 2019), wallaroo numbers have declined by 11% over the three-year period between successive surveys.

Wallaroos are present but not as numerous as eastern grey kangaroos in all of the six tablelands kangaroo management zones. In the SE NSW kangaroo management zone, the estimated density of wallaroos (D_z) was found to be some 15-30% lower than densities that were recorded of this species in the Northern Tablelands management zones in 2019 (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 density of swamp wallabies was approximately similar to that determined in relation to the 2018 survey (Cairns, Bearup & Lollback 2019). For red-necked wallabies, the density recorded in relation to the 2021 survey was oddly enough broadly twice that estimated in relation to the 2018 survey. This is somewhat odd in relation to the impact of the drought and bushfires during the intervening period between surveys. In both instances, however, these two density estimates were determined with reasonable levels of precision.

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.

Species	n	D (km^{-2})	95% bootstrap confidence interval	N	95% bootstrap confidence interval	CV_{boot} (%)	D_Z (km^{-2})
Common wallaroos	89	0.630	0.396-0.958	21,060	13,210-31,980	26.3	0.517
Wallaroos (adjusted)	–	1.166	–	38,961	–	–	0.957
Red-necked wallabies	101	1.393	0.766-1.780	46,520	25,600-59,440	22.2	1.143
Swamp wallabies	220	1.381	1.038-1.852	46,130	34,650-61,870	19.7	1.133

6. Acknowledgements

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Appendix 1

The detection function models for eastern grey kangaroos (*M. giganteus*) in the seven survey blocks, and common wallaroos (*O. robustus*), red-necked wallabies (*M. rufogriseus*) and swamp wallabies (*W. bicolour*) in the South East Tablelands kangaroo management zone.

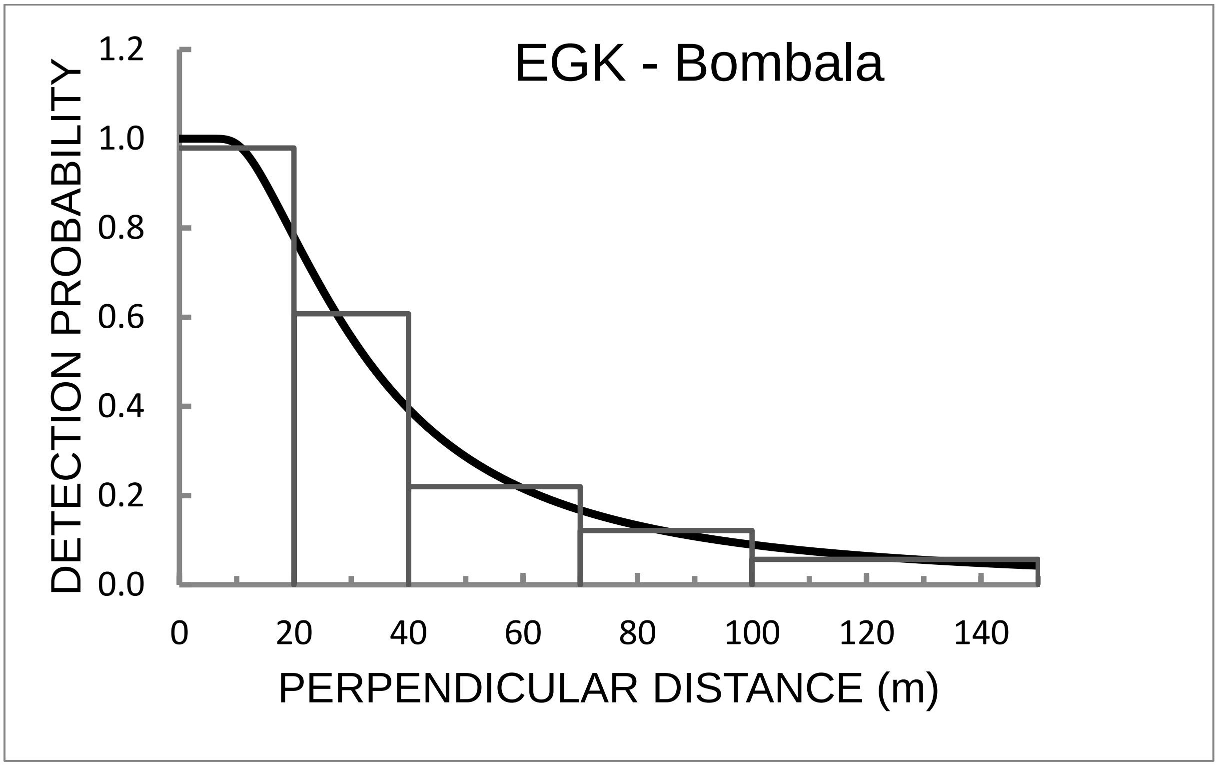

Fig. A1.1. The Hazard-rate detection function for eastern grey kangaroos (EGK) in the Bombala survey block. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details, see Table 4).

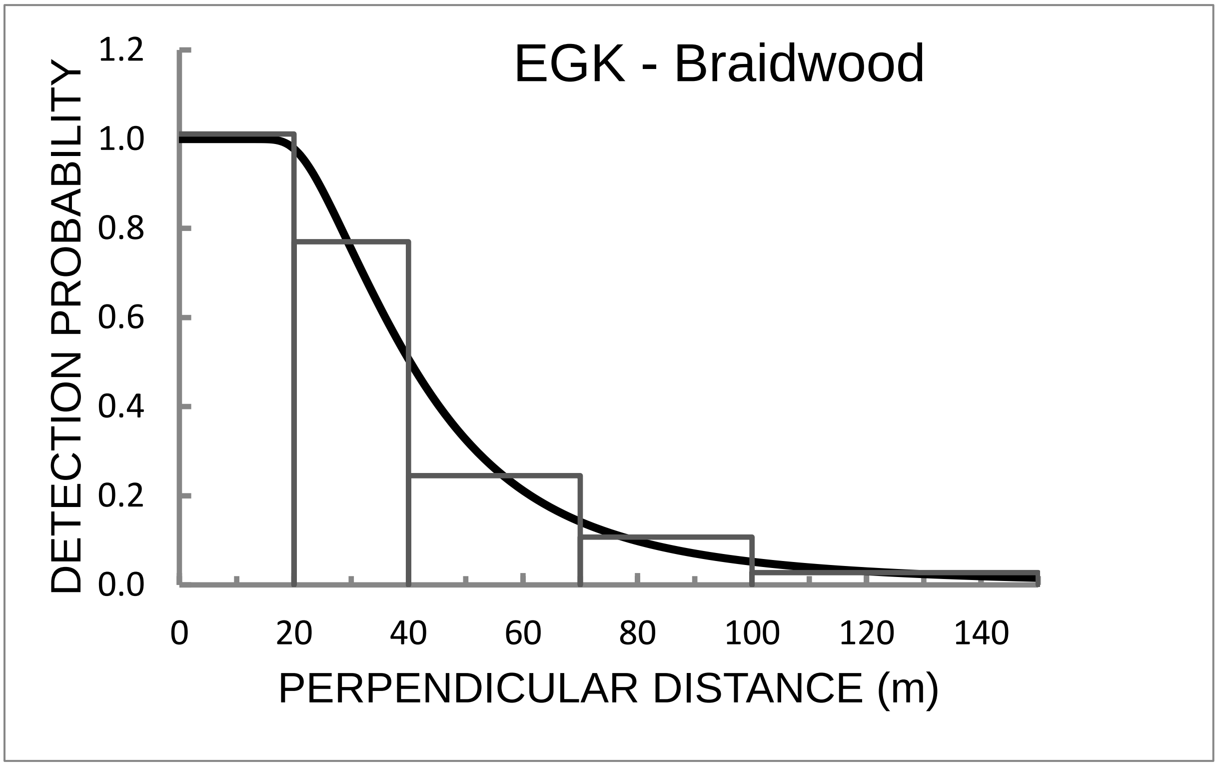

Fig. A1.2. The Hazard-rate detection function for eastern grey kangaroos (EGK) in the Braidwood survey block. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details, see Table 4).

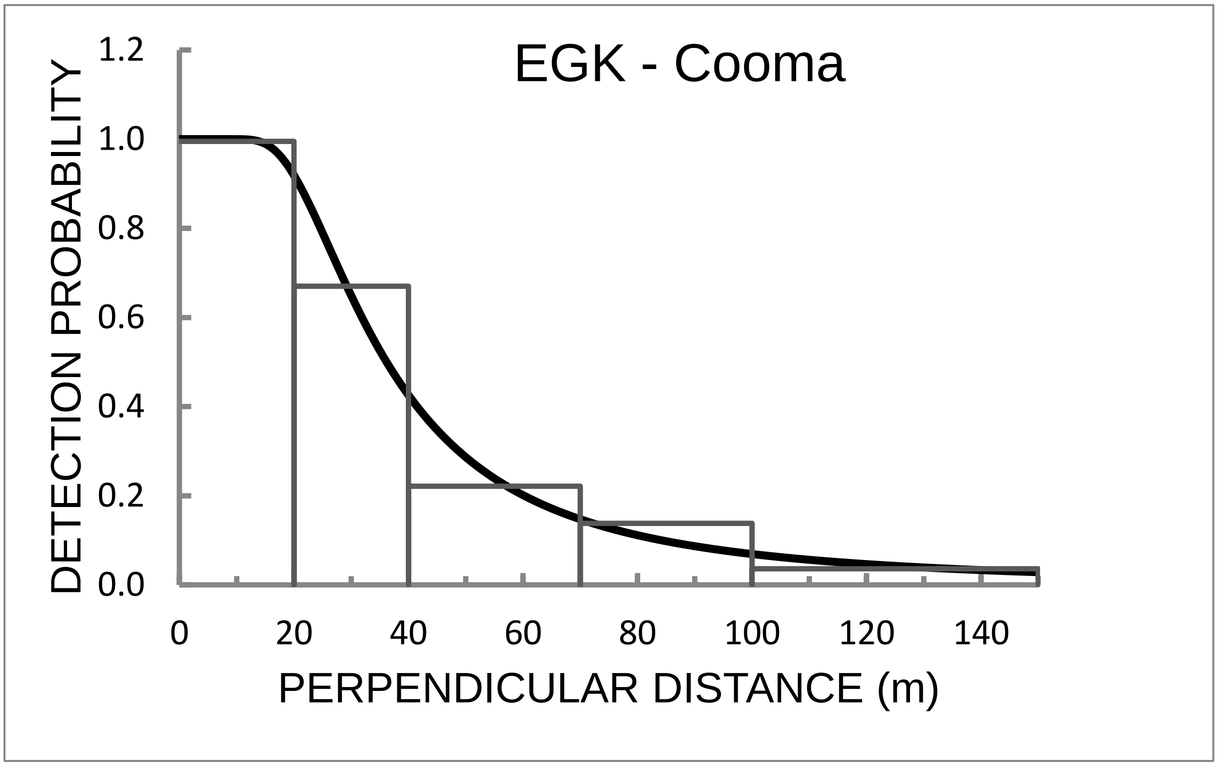

Fig. A1.3. The Hazard-rate detection function for eastern grey kangaroos (EGK) in the Cooma survey block. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details, see Table 4).

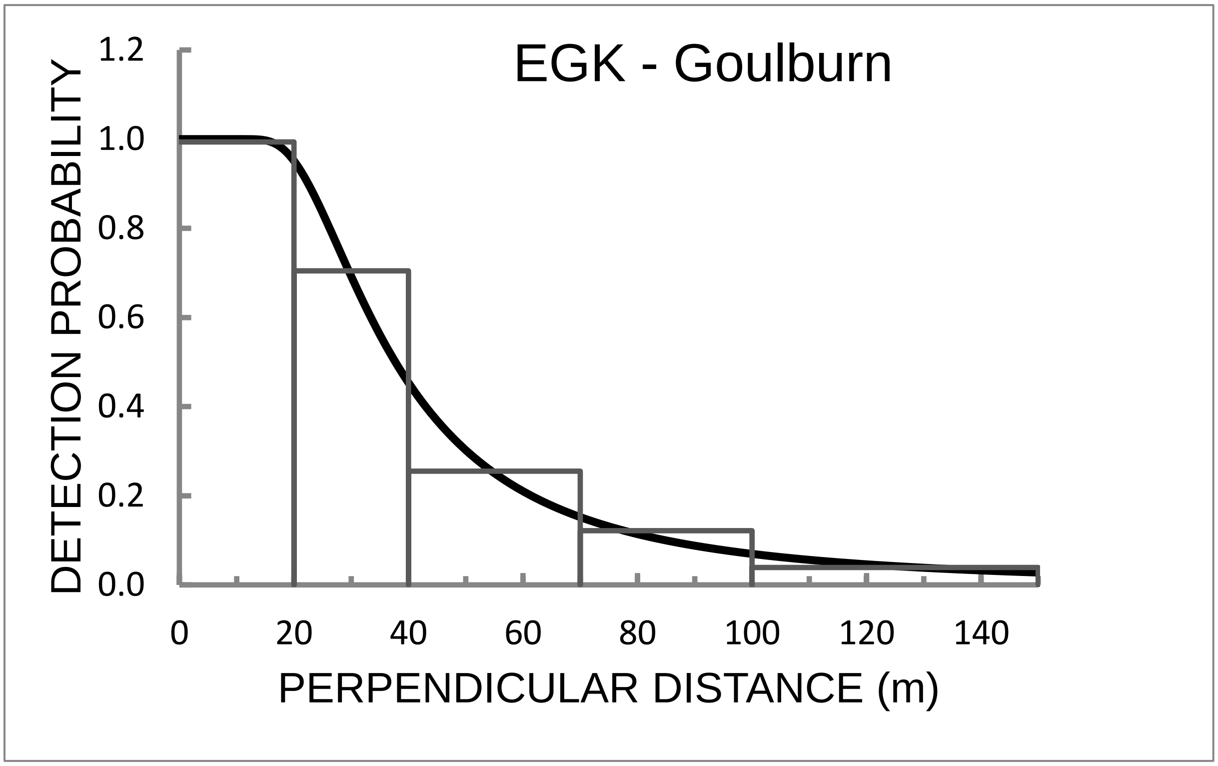

Fig. A1.4. The Hazard-rate detection function for eastern grey kangaroos (EGK) in the Goulburn survey block. This detection function was derived using the CDS analysis engine of DISTANCE 7.3 (for further details, see Table 4).

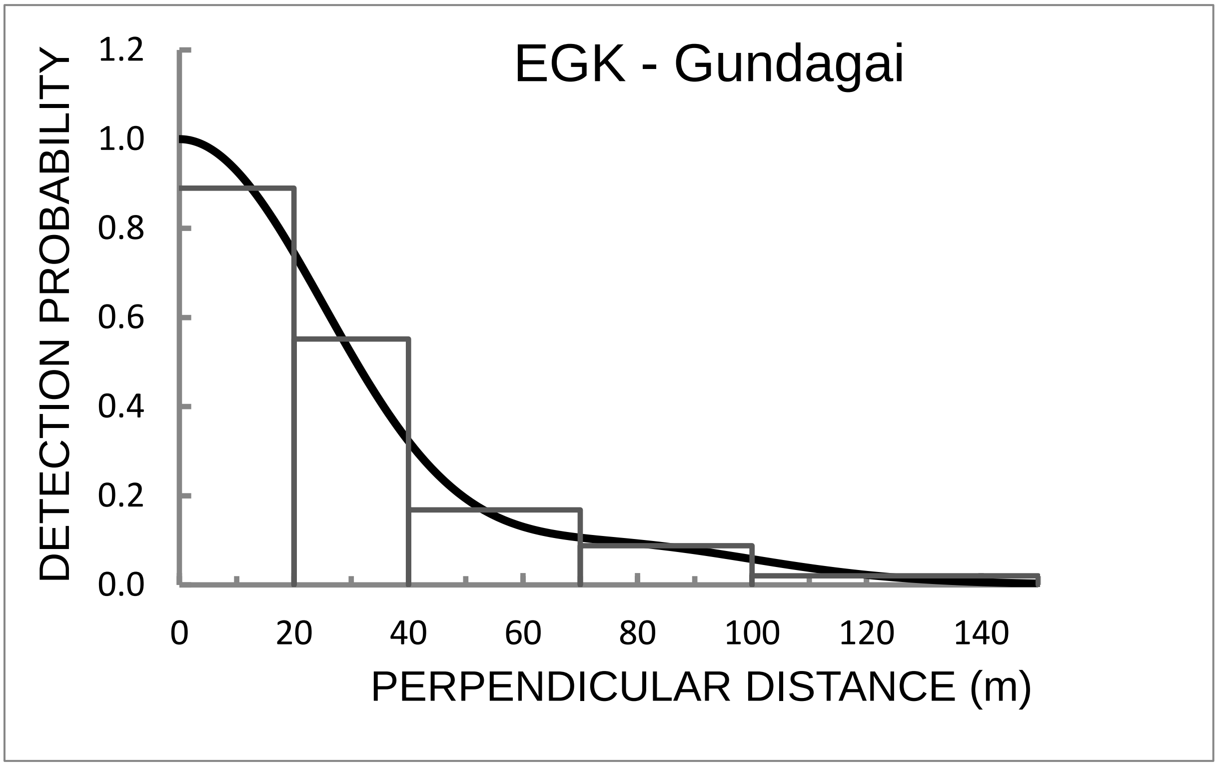

Fig. A1.5. The Half-normal/Cosine detection function for eastern grey kangaroos (EGK) in the Guindagai survey block. This detection function was derived using the CDS analysis engine of DISTANCE 7.3 (for further details, see Table 4).

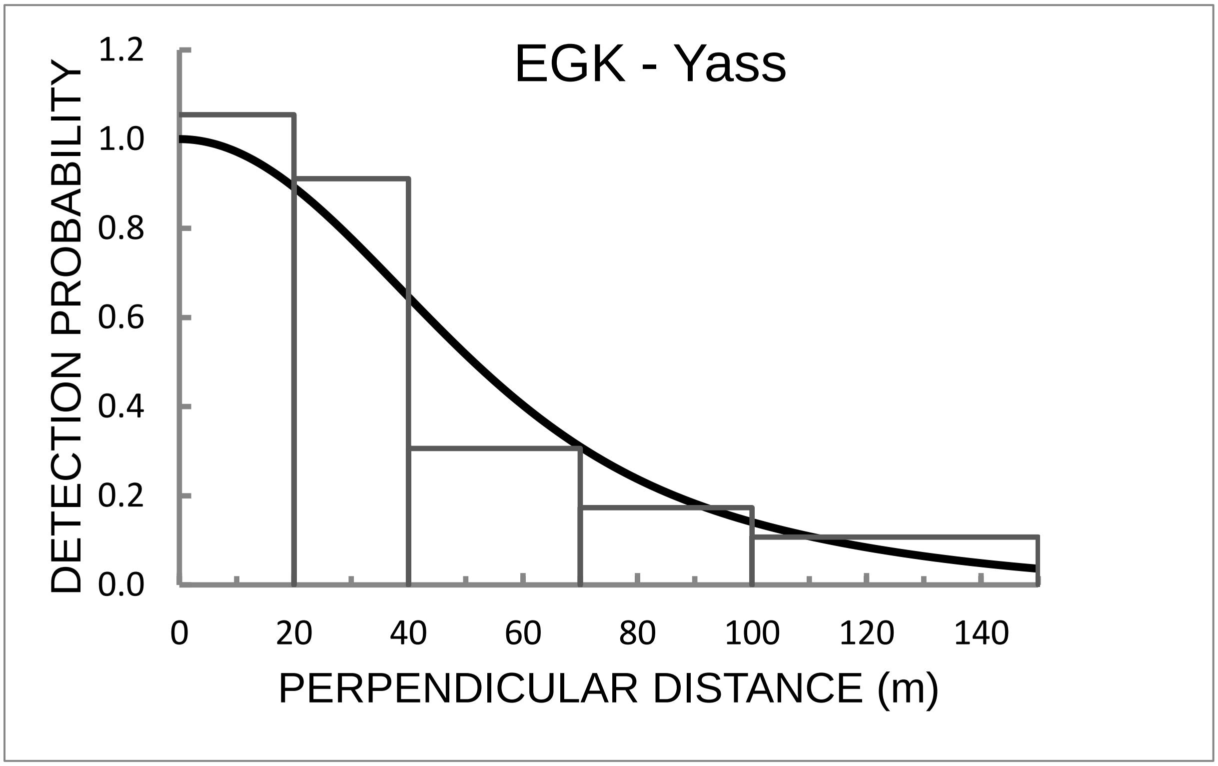

Fig. A1.6. The Half-normal detection function for eastern grey kangaroos (EGK) in the Yass survey block. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details, see Table 4).

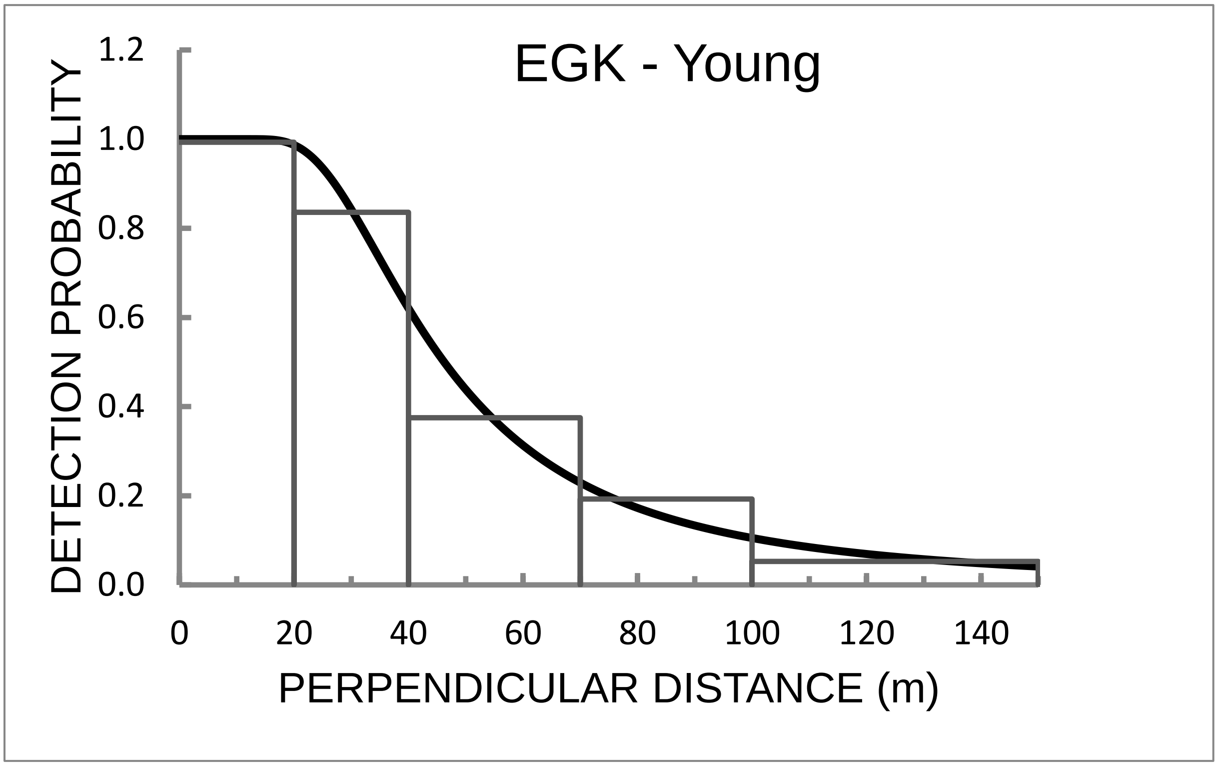

Fig. A1.7. The Hazard-rate detection function for eastern grey kangaroos (EGK) in the Young survey block. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details, see Table 4).

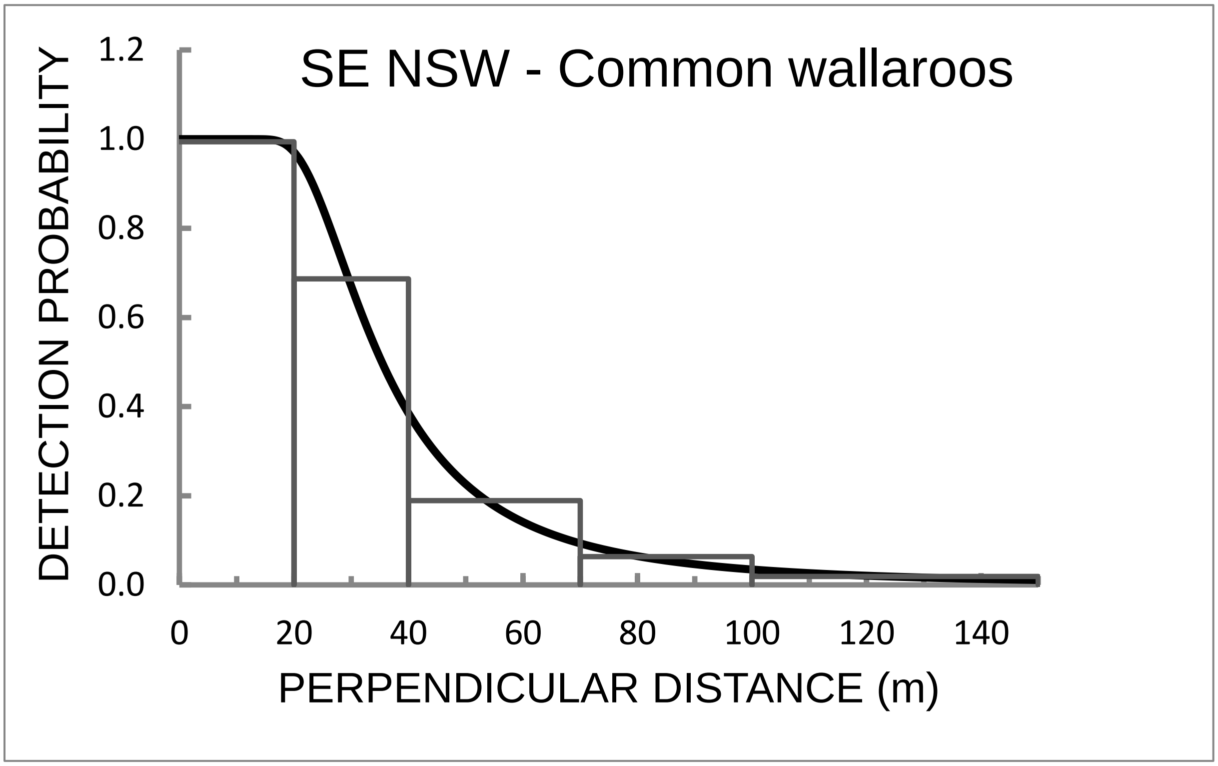

Fig. A1.8. The Hazard-rate detection function for common wallaroos in the South East Tablelands kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 7.3 ((for further details, see Table 5).

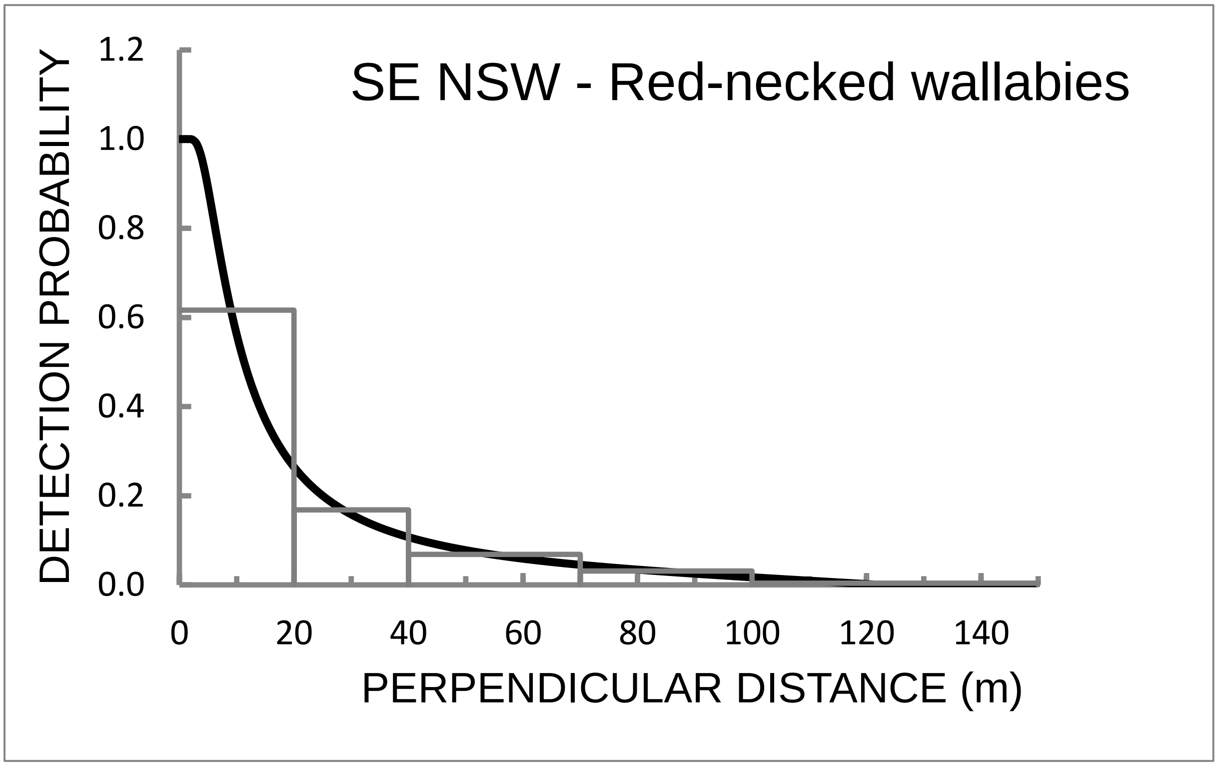

Fig. A1.9. The Hazard-rate detection function for red-necked wallabies in the South East Tablelands kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 7.3 (for further details, see Table 5).

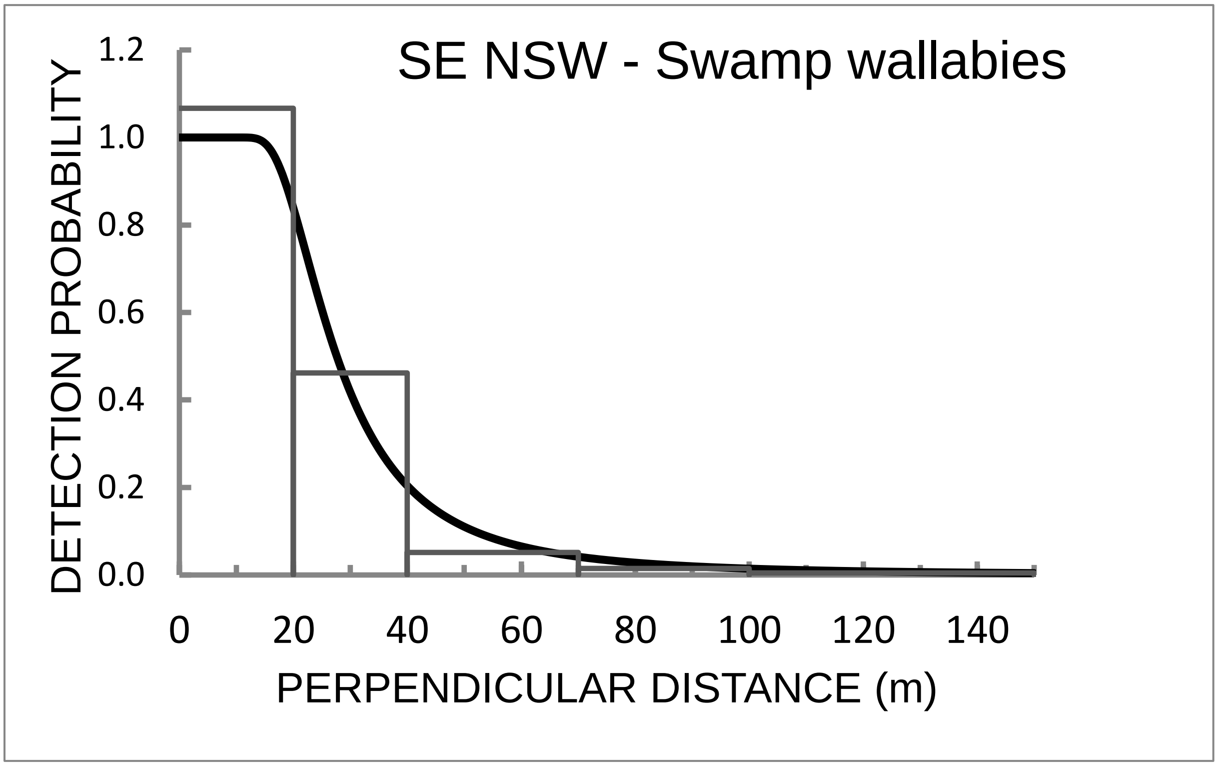

Fig. A1.10. The Hazard-rate detection function for swamp wallabies in the South East Tablelands kangaroo management zone. This detection function was derived using the MCDS analysis engine of DISTANCE 7.3 (for further details, see Table 5).