A report to the Office of Environment and Heritage (NSW) on the contract: 'Design and analysis of helicopter surveys in the South East New South Wales kangaroo management zone, including the former Bombala Rural Lands Protection Board'.

S. C. Cairns[1], D. Bearup[2] and G. W. Lollback[1]

May, 2013

[1]Zoology,
School of Environmental & Rural Sciences,
University of New England,
Armidale,
NSW, 2351

[2]New South Wales National Parks and Wildlife Service,
P.O. Box 4189,
Forster,
NSW, 2428

Contact

Dr Stuart Cairns
Zoology,
School of Environmental & Rural Sciences,
University of New England,
Armidale,
New South Wales, 2351

Telephone: (02) 67732170 (W)
(02) 67727638 (AH)
0427 454344 (M)
Fax: (02) 67733814
email: scairns@.une.edu.au

Sampling design used or the helicopter line transect survey of the six RLPB districts comprising the South East NSW kangaroo management zone and the adjacent Bombala RLPB district. The survey area is restricted to areas outside National Parks and State Forests and to areas without high relief, which are shown in Fig. 1. The survey area is divided into, in relative terms, high (dark grey), medium (grey) and low (light grey) kangaroo density strata.

Summary

1. Helicopter surveys for kangaroos were conducted using line transect sampling in the six RLPB districts comprising the South East NSW kangaroo management zone and in the adjacent Bombala RLPB district. The population estimates derived from these surveys were intended to be used to set quotas for a commercial harvest of eastern grey kangaroos (*Macropus giganteus*) from within this management zone.
2. In conducting the surveys, each RLPB district was subdivided into two or three strata of increasing kangaroo density in order to facilitate the design process. The two strata identified as possibly supporting the highest numbers of kangaroos were surveyed. The third stratum was not. The surveys were designed using an automated survey design algorithm (Strindberg *et al.* 2004).
3. These surveys were designed with the aim of obtaining eastern grey kangaroo population estimates with coefficients of variation of 20%. The coefficients of variation of the population estimates obtained for eastern grey kangaroos were in the range 11-31%.
4. The density of eastern grey kangaroos in the management zone was estimated to be 24.36 km^{-2}. This density corresponded to a population estimate of 936,040 kangaroos. The density of eastern grey kangaroos in the Bombala RLPB district was estimated to be 11.41 km^{-2}. This density corresponded to a population estimate of 76,700 kangaroos.
5. Between the last survey in this management zone in 2009 and the present survey, the estimated eastern grey kangaroo population has increased by 42.5%. This corresponded to an annual exponential rate of increase in numbers of 11%; similar to the rate increase estimated for the period between the 2006 and 2009 surveys.

1. Introduction

In most instances, commercial harvesting conducted by licensed harvesters is the cornerstone of the management of the populations of the large kangaroo species that are variously widespread and abundant throughout much of the continental Australia (Pople & Grigg 1998). Commercial harvesting is undertaken in Queensland, New South Wales, South Australia, Western Australia and Tasmania. It is not part of kangaroo management in Victoria, nor in either the Australian Capital Territory or the Northern Territory. In those states where harvesting is undertaken, it is within quotas that are set with the intention of ensuring harvest sustainability. It is a legislative requirement that any commercial harvesting of kangaroos be conducted on a sustainable basis (Pople & Grigg 1998). 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 (Pople & Grigg 1998).

In New South Wales (NSW), some or all four of those species of macropod identified as large kangaroos, the red kangaroo (*Macropus rufus*), the eastern grey kangaroo (*M. giganteus*), the western grey kangaroo (*M. fuliginosus*) and the common wallaroo or euro (*M. robustus*), are currently harvested from within 14 kangaroo management zones (Office of Environment and Heritage [NSW] 2011). Eight of these kangaroo management zones are located on the western plains of the state; 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 broad-scale aerial surveys conducted annually using fixed-wing aircraft and the method of strip transect sampling (Payne 2007). Because of the general relief of the landscape of the tablelands management zones, the kangaroo populations there cannot be monitored using fixed-wing aircraft surveys. Instead, estimates of the sizes of the kangaroo populations in these zones are obtained from aerial surveys conducted triennially using a helicopter and the method of line transect sampling (Payne 2007). The suitability and effectiveness of this method has been demonstrated by Clancy *et al.* (1997), Clancy (1999), and Southwell and Sheppard (2000).

One of the six kangaroo management zone along the Great Dividing Range is the South East NSW 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 *et al.* 2010). These RLPB districts now no longer exist as administrative/management units, but they remain as broad strata within this kangaroo management zone. Across NSW, clusters of RLPB districts have now been combined to form Livestock Health and Pest Authority (LHPA) districts (see http://www.lhpa.org.au/districts).

The original five RLPB districts 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 *et al.* 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 RLPB districts comprising the South East NSW 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 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 *et al.* 2010).

With this kangaroo management zone now established operationally, a fourth survey was conducted in early spring 2012. This fourth survey was redesigned in relation to the density distributions of eastern grey kangaroos reported as a result of the second and third surveys. As well as surveying designated strata with the six RLPB districts comprising the current kangaroo management zone, an additional survey was conducted in the adjacent Bombala RLPB district. This report outlines the methods used to conduct these survey and the results obtained. The resulting population estimates will be used to set the harvest quota for eastern grey kangaroos in the South East kangaroo management zone.

2. Study Area: South East NSW Kangaroo Management Zone

In its current configuration, the South East NSW kangaroo management zone (Fig. 1) comprises six of the former Rural Lands Protection Board (RLPB) districts; those of Braidwood, Cooma, Goulburn, Gundagai, Yass and Young. It may, in future, be expanded to include the former Bombala RLPB district.

The South East management zone takes in parts of the South Eastern Highlands Biogeographic Region (IBRA) and the South Western Slopes Biogeographic Region (IBRA) (Sahukar *et al.* 2003). The Braidwood, Cooma and Goulburn RLPB districts, along with the Bombala, RLPB district, are all inside the South Eastern Highlands Biogeographic Region. The Gundagai and Yass RLPB districts lie substantially within this biogeographic region, with their western edges of some extending into the South Western Slopes Biogeographic Region. The Young RLPB district is entirely within the South Western Slopes Biogeographic Region.

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 to the southwest (Sahukar *et al.* 2003). In the east, this region extends to the Great Escarpment, while its western slopes comprise part of the inland drainage basin. The topography of this bioregion comprises relatively steep, hilly and undulating terrain giving way towards 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 extending from the western fall of the Great Dividing Range to the edge of the Riverina bioregion (Sahukar *et al.* 2003). The topography of this bioregion also comprises relatively steep, hilly and undulating terrain giving way towards the west to hilly ranges and peaks set in wide valleys.

Further descriptions of the Braidwood, Cooma, Goulburn, Gundagai and Yass RLPB districts are given in Pople *et al.* (2003). The Goulburn and Yass RLPB districts now comprise part of the Tablelands LHPA district. The Bombala, Braidwood and Cooma RLPB districts now comprise part of the South East LHPA district. The Gundagai RLPB district now comprises part of the Hume LHPA district, while the Young RLPB districts now comprise part of the Lachlan LHPA district.

For the purpose of this survey, each of these districts was subdivided into either two or three strata based upon the suitability of the terrain for the conduct of aerial surveys and prospective kangaroo density (see Section 3.1). This subdivision was undertaken using available information regarding landscape relief, vegetation cover and land use (Pople *et al.* 2003; Cairns *et al.* 2009), and the outcome of helicopter kangaroo surveys that have been conducted previously in this kangaroo management zone (Cairns 2004, 2007; Pople *et al.* 2006; Cairns *et al*. 2010). High relief areas were excluded from the survey protocol. The estimated total area of the management zone (excluding the Bombala RLPB district) was 51,321 km^2; the estimated total area of the survey strata was 31,429 km^2 (see Table 1). The total area of the Bombala RLPB district was 6,722 km^2; the estimated area surveyed being 2,719 km^2.

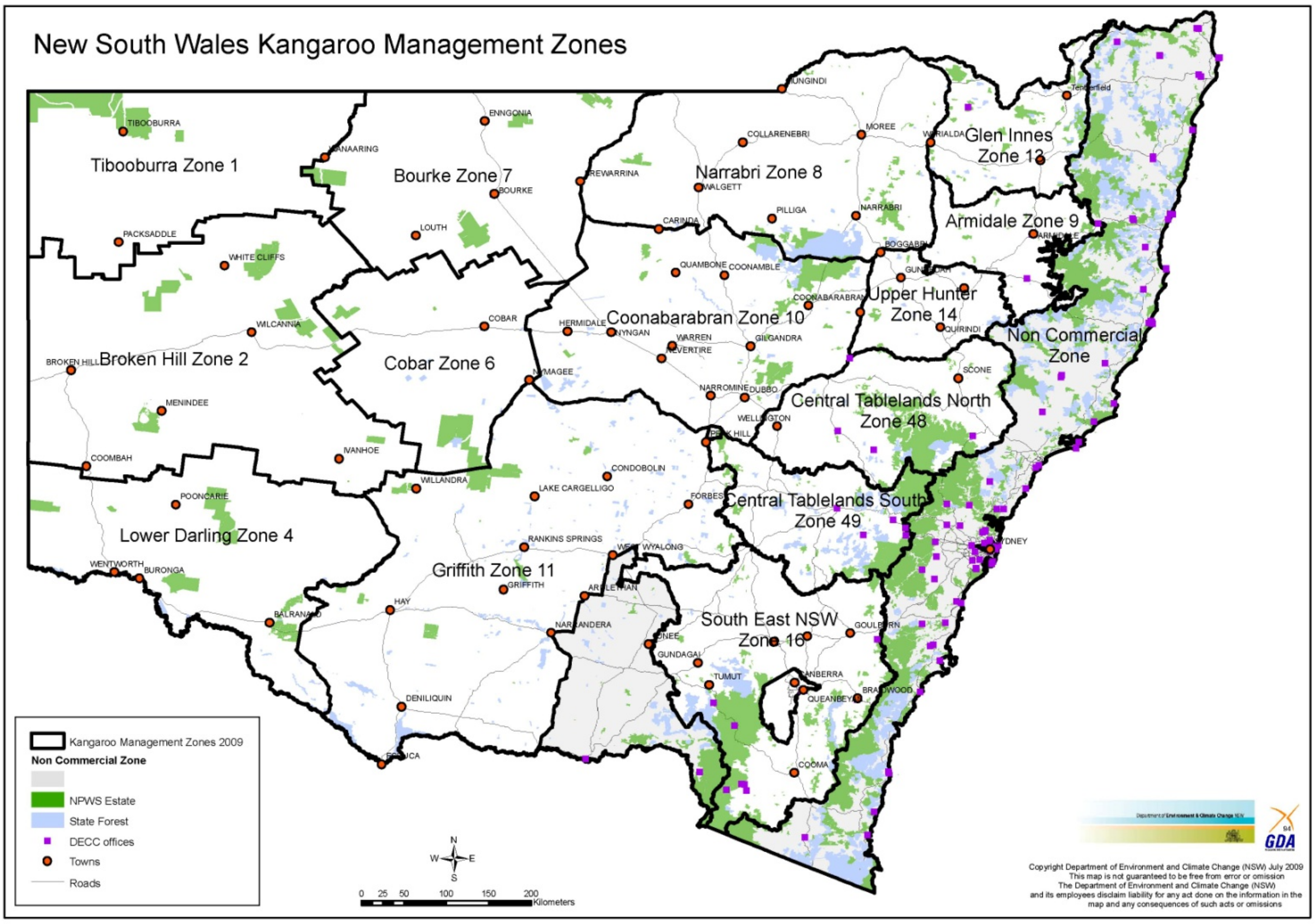


Fig. 1. The 14 kangaroo management zones administered by NSW OEH.

3. Survey Design

As has been the case with the previous aerial surveys conducted in the South East NSW kangaroo management zone (Cairns 2004, 2007; Cairns *et al.* 2010) and those conducted recently in the Northern Tablelands kangaroo management zones (Cairns *et al*. 2011) and the Central Tablelands management zones (Cairns and Bearup 2012), the surveys reported on here were designed using the automated design capabilities of the of the DISTANCE 6.0 Release 2 software package (Thomas *et al.* 2009).

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 on previous occasion in the South East kangaroo management zone (see below). For each new survey conducted in the RLPB districts comprising the current management zone, the boundaries of density strata were redefined in relation to density and survey count information obtained previously. The boundaries of the two strata in the Bombala RLPB district were defined on the basis of landscape relief, vegetation cover and land use only. The process of redefining the density strata before designing a survey is consistent with taking an adaptive management approach to the conduct of aerial surveys in the tablelands management zones.

3.1 Zone Stratification

The current management zone comprises the whole or part of six RLPB districts which in itself represents a form of stratification, with each district being surveyed as a separate entity. The Bombala RLPB district is added as a seventh stratum of this type. To increase both the efficiency and the precision of the surveys a second level of stratification was applied within each of the RLPB districts. This is done using GIS shape files of each of the RLPB districts obtained from the NSW OEH.

For the design of previous surveys (Cairns 2007; Cairns *et al.* 2010), the shape file of each RLPB district was divided into strata likely to support high, medium and low densities of kangaroos. This stratification was based upon eight categories of land capability, extending from cultivation, through to mixed farming and grazing, through to grazing only with decreasing levels of grazing intensity, through to steep, timbered country and through to rocky outcrops, and adjusted in relation to coincident knowledge of kangaroo densities. The kangaroo densities used for the first survey of this management zone (Cairns 2004; Pople *et al.* 2006) were anecdotal. The densities used in conjunction with transect line counts of kangaroos to readjust the stratum boundaries for the second survey (Cairns 2007) were taken from the results of the aforementioned survey. This applies to all of the RLPB districts, except the Young district which was not incorporated into the management zone until 2009. A preliminary survey, however, conducted in the Young RLPB district in 2008 (Cairns *et al.* 2009) provided the necessary information.

Following the initial survey of the five RLPB districts other than the Young district (Cairns 2004; Pople *et al.* 2006) a major re-stratification was undertaken, resulting in a reduction in the number of strata within each RLPB district from three to two. In the Goulburn, Braidwood, Yass and Gundagai RLPB districts, the original high and medium strata were combined to form single medium density stratum; with some changes being made to the boundaries with the low density strata. In the Cooma RLPB district, these two strata were combined to form a single high density stratum and the low density stratum was upgraded to a medium density stratum. Three original strata were maintained within the Young RLPB district; with some adjustment made to their boundaries.

Using transect counts of eastern grey kangaroos obtained from previous surveys (Cairns 2004, 2007; Cairns *et al.* 2010), the boundaries of the strata within six RLPB districts were redrafted with the aim of improving the design stratification. Reviewing these stratum boundaries in relation to the outcome of the surveys conducted in 2009 (Cairns *et al.* 2010) resulted in no changes being made to them in any of the RLPB districts except Cooma, where the boundary delineating the nominal high and medium density strata was removed, with the whole of the RLPB district forming a single survey area. The Bombala RLPB district was divided into a low and a medium density stratum. This division was based upon land capability criteria. The breakdown of the area of the management zone into its constituent strata is given in Table 1.

Table 1. Areas (km^2) of the Bombala RLPB district and of the six RLPB districts that comprise the current South East NSW kangaroo management zone. These areas do not include reserved lands such as National Parks (NPs) or State Forests (SFs). These areas are subdivided into the areas of high relief outside reserve lands that are unsuitable for aerial survey and three strata representing habitat associated with, in relative terms, likely high, medium and low kangaroo densities (adapted from Pople *et al.* 2003, Cairns 2004, 2007 and Cairns *et al.* 2010).

RLPB	*Bombala*	*Braidwood*	*Cooma*	*Goulburn*	*Gundagai*	*Yass*	*Young*	*TOTAL*
RLPB Area	6,722	8,824	11,375	6,426	9,507	6,305	8,884	58,043
High relief outside NPs and SFs		261	431	35	174	146	–	1,047
High density		–	–	–	–	–	3,185	9,203
Medium density	2,719	3,987	7,202	4,608	5,562	4,518	2,303	24,881
Low density	4,003	301	–	1,783	959	1,097	3,396	11,536
Survey area	2,719	3,987	7,202	4,608	5,562	4,522	5,488	34,158

Only the high and medium density strata were 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 RLPB districts (Cairns 2007). With the exclusion of national parks, reserves and miscellaneous areas of high relief, 76% of the combined area of the original six RLPB districts remained available to be surveyed. With the exclusion of the combined low density strata of each RLPB district, the final survey area represented 61% of the management zone. For the Bombala RLPB district, only 40% of the total area comprised the final survey area. For visual representation of the stratification of the zones, see Figs. 3-9.

3.2 Survey Effort

In line transect (distance) sampling, survey effort is defined as the total transect length. Although ultimately constrained by cost, survey effort is generally determined in relation to some desired level of precision (the ratio of standard error to mean). In the conduct of surveys such as those reported upon here, setting the level precision at 20% would appear to be realistic and cost-effective (Pople *et al.* 2003). For the present survey, the allocation of survey effort was made in relation to the determination of population estimates for each of the seven RLPB districts listed in Table 1.

To determine the effort required to attain the target levels of precision, the following equation from Buckland *et al.* (2001) was used:

$$L = \frac{L_0\{cv_0(\hat{D})\}^2}{\{cv_t(\hat{D})\}^2} \qquad (1)$$

where, L is the required survey effort for a target level of precision of $cv_t(D)$, and L_0 and $cv\ (D)$ are the survey effort and attained level of precision, respectively, from a previous or pilot survey. The values of L_0 and $cv\ (D)$ used here were those obtained from the surveys conducted in six RLPB districts (Bombala excluded) three years previously (Cairns *et al.* 2010). For the Braidwood RLPB district, L_0 = 163 km, $cv_0(\hat{D})$ = 27.6%. For the Cooma RLPB district, L_0 = 352 km, $cv_0(\hat{D})$ = 25.6%. For the Goulburn RLPB district, L_0 = 232 km, $cv_0(\hat{D})$ = 25.6%. For the Gundagai RLPB district, L_0 = 359 km, $cv_0(\hat{D})$ = 22.4%. For the Yass RLPB district, L_0 = 540 km, $cv_0(\hat{D})$ = 18.9%. For the Young high density stratum, L_0 = 183 km, $cv_0(\hat{D})$ = 21.1%. For the Young medium density stratum, L_0 = 185 km, $cv_0(\hat{D})$ = 23.1%. For those RLPB districts for which two sets of L_0 and $cv\ (D)$ values have not been given, a survey was designed only for the medium density stratum. No effort was allocated to any of the low density strata. The nominal survey efforts derived using equation (1) are given in Table 2.

In the first survey conducted in the SE NSW management zone (Cairns 2004), total effort across the then five RLPB districts was 735 km. With the inclusion of the low density strata in the second survey (Cairns 2007), the total survey effort was increased to 1,155 km. This was increased to a nominal total effort of 2,067 km for the third survey (Cairns *et al.* 2010). For the present survey which includes the

Table 2. Areas of the proportion of each RLPB district surveyed, the nominal survey effort determined using equation (1) (see text) and the actual survey effort applied during the survey. Note that the survey areas of the Young RLPB districts comprised high and medium kangaroo density strata. All the other survey areas were classed as medium density strata. The survey effort for the Bombala RLPB district was estimated in relation to the precision determined form the Cooma RLPB district.

RLPB	Survey area (km^2)	Nominal survey effort (km)	Actual survey effort (km)
Bombala	2,719	250	240
Braidwood	3,987	390	380
Cooma	7,202	600	570
Goulburn	4,608	405	405
Gundagai	5,562	460	460
Yass	4,518	470	470
Young (high)	3,185	200	200
Young (medium)	2,303	230	220

Bombala RLPB district, the nominal total effort was determined as 3,005 km (Table 2). It was anticipated that with this increased nominal survey effort and using the automated design procedure in DISTANCE 6.0, a level of precision better than 20% would be achieved at the level of the individual RLPB district.

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 (Strindberg *et al.* 2004). Achieving this is not straightforward, particularly when designing a survey by hand. However, taking advantage of GIS and using automated design algorithms such as those offered by DISTANCE 6.0 (Thomas *et al.* 2009) increases the likelihood that an optimal design will be achieved (Strindberg *et al.* 2004).

DISTANCE 6.0 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.* 2009). According to Buckland *et al.* (2001) and Strindberg *et al.* (2004), systematic designs give smaller variation in density estimation from one realisation to the next and avoid any problems associated with overlapping samplers (transects). Hence, a survey design incorporating systematic segmented trackline sampling with a buffer zone around the boundary of each survey stratum was selected as the most likely design option for the present surveys. It was tested for survey coverage against a systematic segmented gridline sampling option. As well as this, the option of maintaining the integrity of individual samplers (transects) was tested against the option of using split samplers.

Systematic segmented trackline sampling randomly superimposes a systematic set of segmented parallel lines onto the survey region (Thomas *et al.* 2009). 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 *et al.* 2004). Inclusion of a buffer of unspecified size (determined by the algorithm) results in what is termed minus sampling (Thomas *et al.* 2009). The buffers in adjacent strata do not overlap.

Surveys were designed separately for the high and medium density strata of each of RLPB district zones using the nominal survey efforts given in Table 2. 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 various survey designs selected for comparison (Strindberg *et al.* 2004; Thomas *et al.* 2009). Following this, once it had been confirmed that the systematic segmented trackline sampling design with fixed samplers provided a more than adequate even coverage of the survey area, a single realisation of that selected design was generated for each survey stratum within RLPB district.

For the Bombala RLPB district, the selected survey design allocated 25 transects of a length of 10 km to the medium density stratum (Fig. 3). For the Braidwood RLPB district, the selected survey design allocated 52 transects of a length of 7.5 km to the medium density stratum (Fig. 4). For the Cooma RLPB district, the survey design allocated 60 transects of a length of 10 km to the medium density stratum (Fig. 5). For the Goulburn RLPB district, the selected survey design allocated 54 transects of a length of 7.5 km to the medium density stratum (Fig. 6). For the Gundagai RLPB district, the selected survey design allocated 46 transects of a length of 10 km to the medium density stratum (Fig. 7). For the Yass RLPB district, the selected survey design allocated 63 transects of a length of 7.5 km to the medium density stratum (Fig. 8). For the Young RLPB district, the survey design allocated 23 transects of a length of 10 km to the medium density stratum and 20 transects of a length of 10 km to the high density stratum (Fig. 9).

The nominal total survey efforts used in the design process along with the total survey efforts of the realised survey designs are given in Table 2.

4. Survey Methods

The aerial survey of the seven RLPB districts was conducted as a helicopter survey during two sampling periods; the first during the period 25 August to 5 September 2012 and the second on 20 October 2012. The reason for this was that an extended period of windy weather in early September prevented the completion of the surveys of the Goulburn and Yass RLPB districts. These were completed on the second occasion.

The surveys were conducted in accordance with the survey plans developed above (see Section 3.3), with each RLPB district being considered a separate entity and subdivided into two to three strata; one to 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 343 transects to be flown across the seven LPB districts. For various logistical reasons, the completed surveys comprised a total of 337 transects (Table 2).

All surveys were conducted within either the two to three-hour period following sunrise or the two to three-hour period before sunset. Three observers were used: David Bearup, Scott Seymour and Mike Saunders (all from NPWS). Observers were rotated into active roles for each survey session. Paul Caristo was the pilots for the surveys. The seating of the observers in relation to the left-hand and the right-hand side of the aircraft was allocated randomly before each survey session.

Fig. 3. The Bombala RLPB district adjacent to the South East NSW kangaroo management zone. Shown are the two survey strata, the population centres (towns) and the placement of the survey transects within the medium (grey) kangaroo density strata. Note that no survey transects were placed into the low density (light grey) stratum.

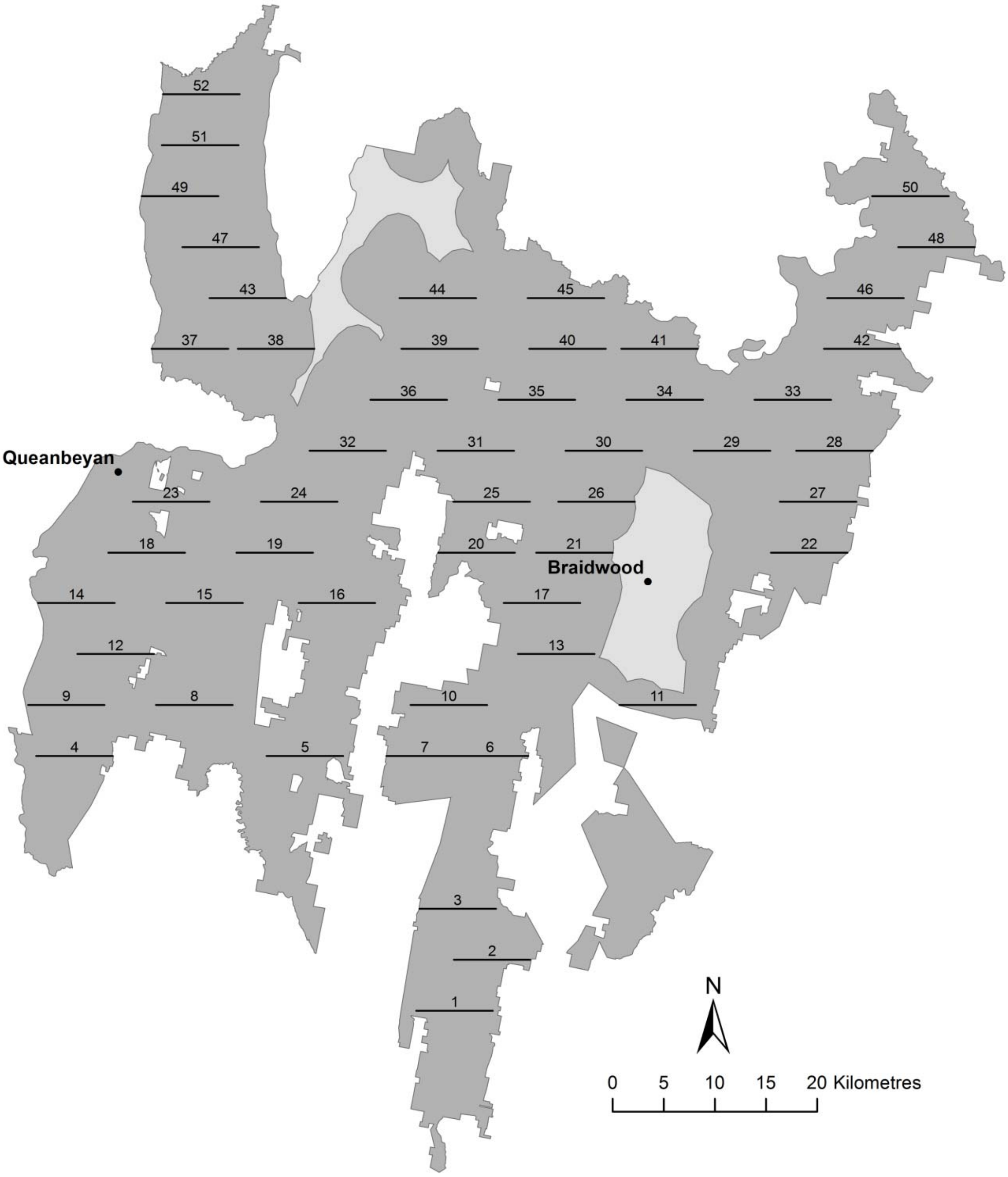


Fig. 4. The Braidwood RLPB district section of the South East NSW kangaroo management zone. Shown are the two survey strata, the population centres (towns) and the placement of the survey transects within the medium (grey) kangaroo density strata. Note that no survey transects were placed into the low density (light grey) stratum.

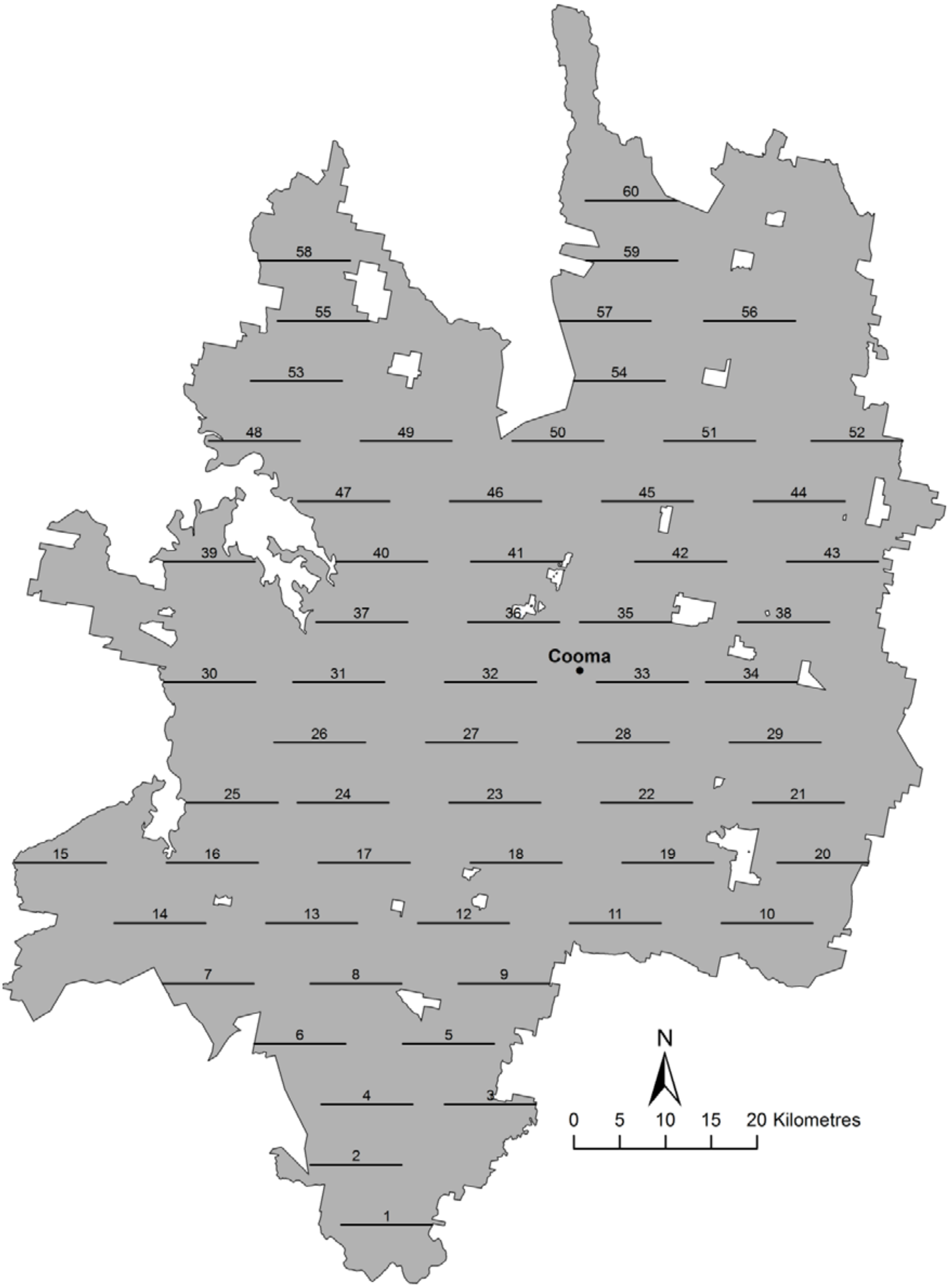


Fig. 5. The Cooma RLPB district section of the South East NSW kangaroo management zone. There is no stratification of this district. The whole area is considered to be equivalent to a medium kangaroo density stratum.

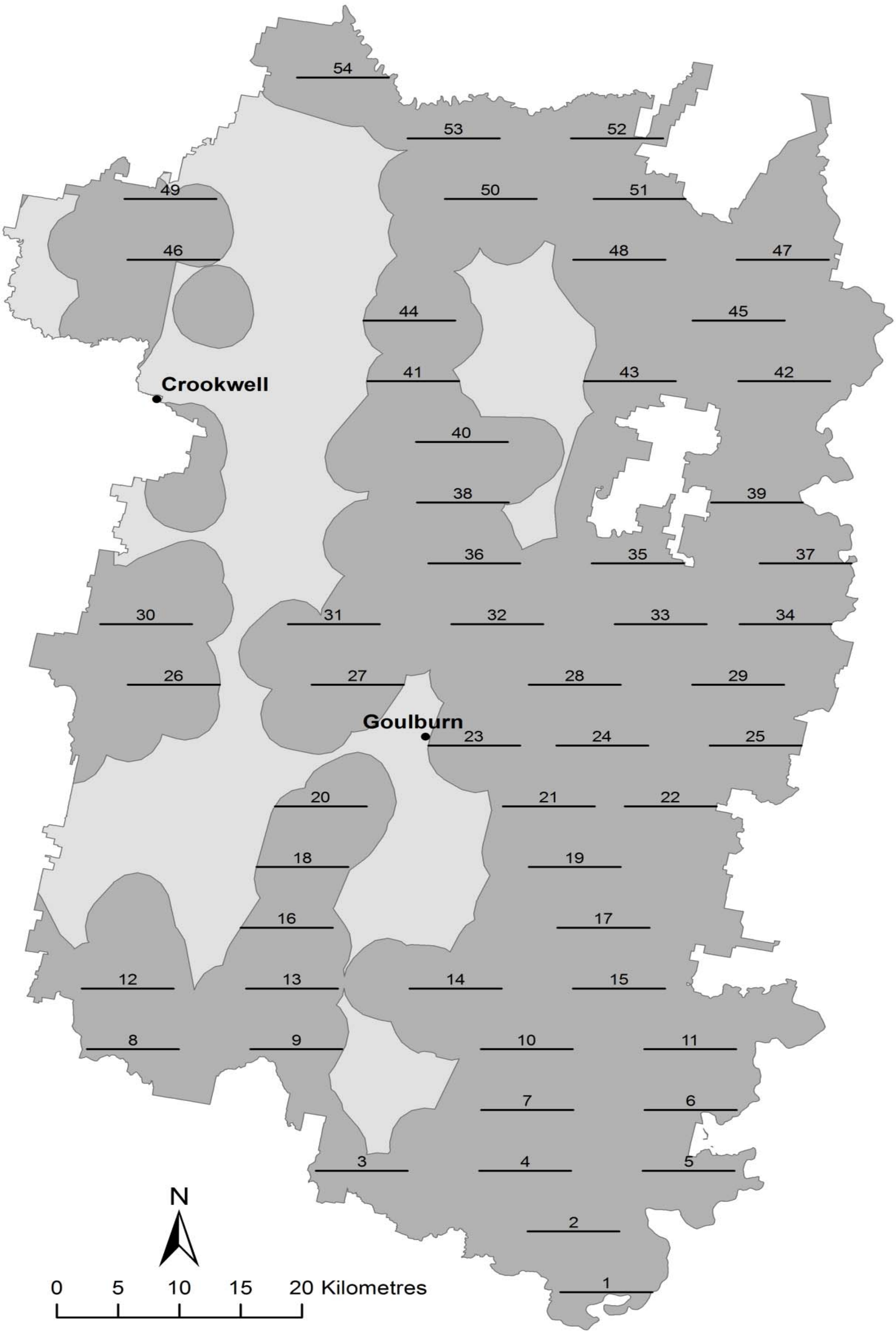


Fig. 6. The Goulburn RLPB district section of the South East NSW kangaroo management zone. Shown are the two survey strata, the population centres (towns) and the placement of the survey transects within the medium (grey) kangaroo density strata. Note that no survey transects were placed into the low density (light grey) stratum.

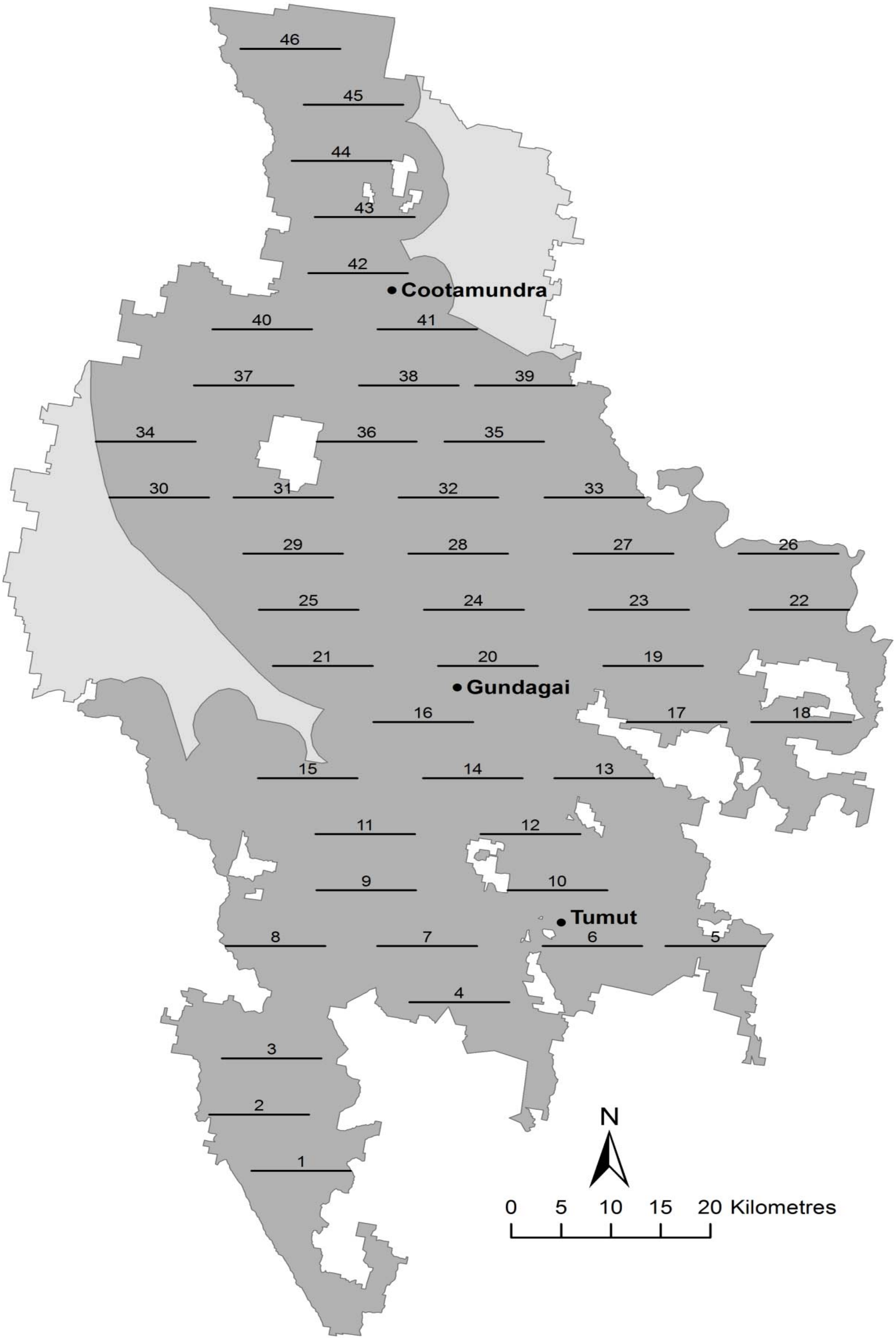


Fig. 7. The Gundagai RLPB district section of the South East NSW kangaroo management zone. Shown are the two survey strata, the population centres (towns) and the placement of the survey transects within the medium (grey) kangaroo density strata. Note that no survey transects were placed into the low density (light grey) stratum.

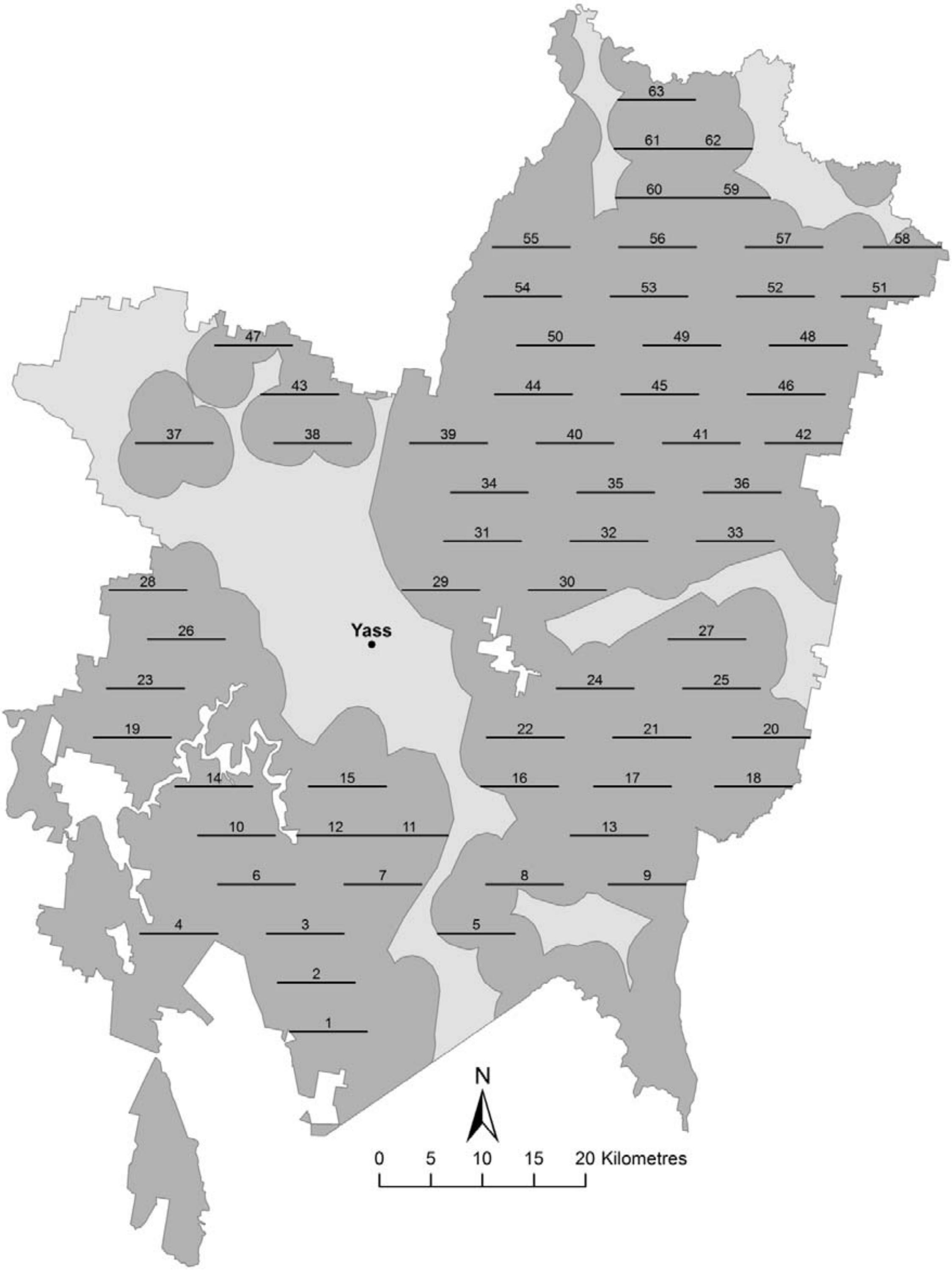


Fig. 8. The Yass RLPB district section of the South East NSW kangaroo management zone. Shown are the two survey strata, the population centres (towns) and the placement of the survey transects within the medium (grey) kangaroo density strata. Note that no survey transects were placed into the low density (light grey) stratum

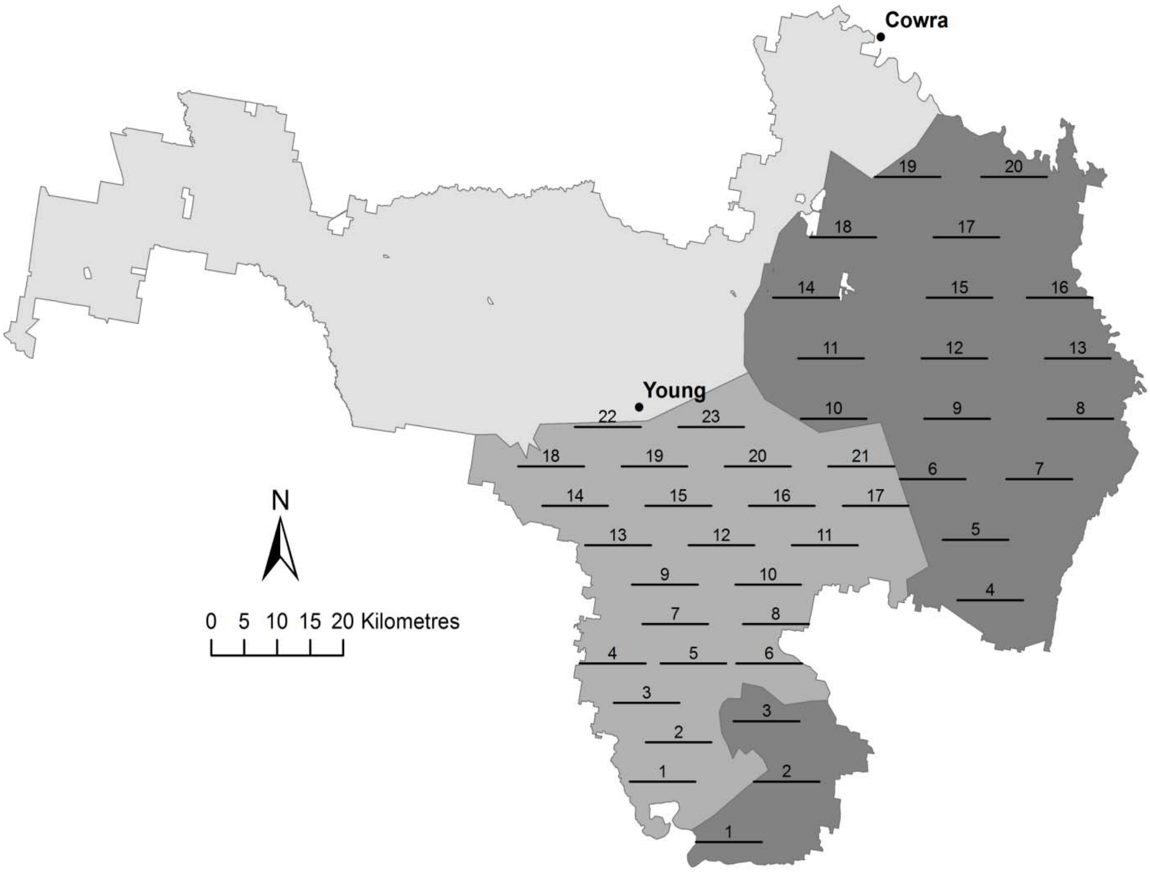


Fig. 9. The Young RLPB district section of the South East NSW kangaroo management zone. Shown are the three survey strata, the population centres (towns) and the placement of the survey transects within the high (dark grey) and medium (grey) kangaroo density strata. Note that no survey transects were placed into the low density (light grey) stratum.

4.1 Helicopter Line Transect Surveys

In conducting the survey, the helicopter, a Bell LongRanger, with the two rear doors removed 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 the ground. Navigation was by a global positioning system (GPS) receiver (Garmin GPSMAP 275c©). Observers occupied the two rear seats of the helicopter and counted the kangaroos seen on either side of the aircraft. 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 line. The distance classes were delineated on metal booms extending from either side of the helicopter.

Data in the form of the numbers of clusters (groups of one or more) of eastern grey kangaroos (*M. giganteus*), common wallaroos (*M. robustus*), red-necked wallabies (*M. rufogriseus*) and swamp wallabies (*Wallabia bicolor*) seen within the different delineated distance classes from the helicopter were recorded into digital voice recorders. The presence of other, non-target species was noted. Tapes were transcribed at the end of each survey session. For the purpose of data analysis, the exact transect lengths were equal to the nominal survey lengths of the original survey designs.

4.2 Data Analysis

The analysis of distance sampling data such as those collected here first involves the estimation of the detection probability of clusters of animals within the covered region (the designated survey strip), then the estimation of the density of animals within the covered region 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 region (Borchers and Burnham 2004). Survey results were recorded as the sightings of clusters of kangaroos and their broad perpendicular distances from the transect line. In order to estimate the probability (P_a) that a cluster of animals within the covered area of width w (the width of the nominal survey strip) will be observed, the detection function $g(x)$ representing the probability that a cluster at perpendicular distance *x* from the survey transect is detected (where 0≤ *x* ≤*w* and *g(0)* = 1) needs to be modelled and evaluated at *x* = 0 (Thomas *et al.* 2002). To do this, the data from the helicopter line transect surveys were analysed using DISTANCE 6.0 (Thomas *et al.* 2009; Thomas *et al.* 2010). Despite the problems that can occur with small sample sizes (which was not really a problem here), the use of cluster sightings in preference to individual sightings ensures against overestimation of the true variance of density and abundance estimations (Southwell and Weaver 1993).

DISTANCE 6.0 has three different analysis engines that can be used to estimate the detection function (Thomas *et al.* 2010). Of these, the conventional distance sampling (CDS) analysis engine was used here. The data from each stratum surveyed within each RLPB district were analysed separately. The results of the analyses conducted using the ranges of detection function model options available within the CDS analysis engine were compared serially in order to determine the most of the parsimonious model and hence the most likely and accurate estimates of population density and abundance. The model with the lowest value for a penalised log-likelihood in the form of Akaike's Information Criterion (*AIC= -2 x log-likelihood + 2[p +1]*; where *p* is the number of parameters in the model) was generally selected as the detection function. In selecting the most parsimonious model, along with comparing AIC values, some consideration was also given to goodness-of-fit and the shape criterion of the detection function; 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.

Following the recommendations of Buckland *et al.* (2001), six detection function models were considered in the analyses. Each model comprised a key function that, if required, could be adjusted by a cosine or polynomial series expansion containing one or more parameters. The different models considered were: a Uniform key function with an optional Cosine or Simple Polynomial series expansion; a Half-normal key function with an optional Cosine or Hermite Polynomial series expansion; and a Hazard-rate key function with an optional Cosine or Simple Polynomial series expansion. The number of adjustment terms incorporated into the model was determined through the sequential addition of up to three terms. As part of the analysis process, post-stratification was undertaken on the basis of observer difference and survey aspect difference. There were two observers and, with all survey transect having been flown from east to west (or vice versa), the observers would have either a north-facing or a south-facing aspect with regard to the transect line.

The method of determination of the density estimates of clusters of kangaroos, the density estimates of individual kangaroos and the estimates of population abundance in relation to the most parsimonious detection function model using the CDS analysis engine is given in Buckland *et al.* (2001). In determining kangaroo densities using this analysis engine, if the observed sizes of detected clusters (s) are independent of distance from the survey line (i.e. if *g(x)* does not depend upon *s*), then the sample mean cluster size ($\bar{s}$) is taken as an unbiased estimator of the mean size of the *n* clusters in the study area. If, however, the observed sizes of detected clusters are found to be dependent upon the perpendicular distance from the survey line, then, $\bar{s}$ is replaced by an expected value determined from a linear 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_{boot} %) were also determined by bootstrapping the data. The data were bootstrapped 999 times in relation to all model options in the analysis engine and not just the model selected to determine the empirical estimates of density and abundance. This was expected to improve the robustness of variance estimation (Buckland *et al.* 2001). The 95% confidence limits presented were determined as the 2.5% and 97.5% quantiles of the respective bootstrap estimates.

The data were analysed to determine separate density and population estimates for each kangaroo density stratum. These estimates were combined to produce density and abundance estimates for each RLPB district, and combined further to produce density and abundance estimates for the whole of the management zone.

5. Results and Discussion

Five of the seven RLPB districts listed in Table 1 were subdivided into two strata based on land capability and prior knowledge of eastern grey kangaroo densities (see Section 3.1). The Young RLPB district was subdivided into three strata. Only those strata identified as supporting medium and high kangaroo densities were surveyed. The Cooma RLPB district was not stratified; the whole area being surveyed as supporting medium to high densities of kangaroos.

The Bombala RLPB district was divided into a low density and a medium density stratum (Fig. 2). Twenty-four transects were flown in the medium density stratum on which 410 sightings of clusters of macropods were recorded. The Braidwood RLPB district was also divided into a low density and a medium density stratum (Fig. 3). Fifty-one transects were flown in the medium density stratum on which 433 sightings of clusters of macropods were recorded. The Cooma RLPB district was surveyed as a single stratum (Fig. 4). Fifty-seven transects were flown across it on which 722 sightings of clusters of macropods were recorded. The Goulburn RLPB district was divided into a low density and a medium density stratum (Fig. 5). Fifty-four transects were flown in the medium density stratum on which 371 sightings of clusters of macropods were recorded. The Gundagai RLPB district was divided into a low density and a medium density stratum (Fig. 6). Forty-six transects were flown in the medium density stratum on which 364 sightings of clusters of macropods were recorded. The Yass RLPB district was also divided into a low density and a medium density stratum (Fig. 7). Sixty-three transects were flown in the medium density stratum on which 404 sightings of clusters of macropods were recorded. The Young RLPB district was divided into a low, a medium and a high density stratum (Fig. 8). Twenty transects were flown in the high density stratum on which 422 sightings of clusters of macropods were recorded. Twenty-three transects were flown in the medium density stratum on which 101 sightings of clusters of macropods were recorded.

A summary of the raw counts of the four species of macropods inhabiting the survey regions is given in Table 3. The numbers of macropod sightings for each transect and the raw counts of each species comprising these sightings are given in Table A.1. The total survey efforts flown in the strata surveyed within each RLPB district are also given in Table 3.

The CDS analysis engine of DISTANCE 6.0 (Thomas *et al.* 2010) was used to analyse the survey results. The distance categories used in these analyses were those set on the survey booms: 0-20 m, 20-40 m, 40-70 m, 70-100 m and 100-150 m. Eastern grey kangaroo density and abundance estimates were

Table 3. Number of transects, survey effort and raw counts of macropods for each of the seven RLPB districts.

			Raw counts			
RLPB district	No. of transects	Effort (km)	Eastern grey kangaroos	Common wallaroos	Red-necked wallabies	Swamp wallabies
Bombala	24	240.0	1,541	2	8	17
Braidwood	51	382.5	1,503	1	9	4
Cooma	57	570.0	2,541	5	9	24
Goulburn	54	405.0	1,181	5	3	6
Gundagai	46	460.0	1,207	2	1	9
Yass	63	472.5	1,489	7	4	21
Young						
High	20	200.0	1,382	15	3	16
Medium	23	220.0	364	-	2	8

determined separately for each RLPB district. The estimates for all districts except Bombala were combined to provide density and abundance estimates for the current South East NSW kangaroo management zone. Because of a general paucity of data, 16 sightings overall of common wallaroos and 28 of red-necked wallabies, no attempts were made to determine density and abundance estimates for these two species, for which there are no commercial quotas set in this kangaroo management zone. However, with 99 sighting of swamp wallabies, a density and an abundance estimate for this species could be determined on the basis of the total area surveyed.

The most parsimonious detection function models fitted to the results of the surveys of eastern grey kangaroos in the seven RLPB districts are given in Table 4. Single models were fitted to the results for Braidwood, Goulburn and Gundagai, and the two strata surveyed in the Young RLPB district. Two models, derived in relation to post-stratification on the basis of survey aspect (side of aircraft), were fitted to the results for Bombala, Cooma and Yass. In each instance, the most parsimonious

Table 4. The number of sightings of clusters kangaroos (n), the detection function model, the probability that a randomly-selected cluster of kangaroos in the nominal survey strip is detected (P_a) and the effective strip width (μ) for the survey of the eastern grey kangaroo populations in the seven RLPB districts. In some instances, post-stratification on the basis of survey aspect (N = north, S = south) was used to determine the most parsimonious detection function models.

RLPB District	n	Model	P_a	μ (m)
Bombala		Post-stratification by survey aspect:		
	174	Hazard-rate/Cosine (N)	0.54	81.5
	182	Half-normal/Hermite (S)	0.42	62.9
Braidwood	405	Half-normal/Cosine	0.32	48.3
Cooma		Post-stratification by survey aspect:		
	318	Half-normal/Cosine (N)	0.40	59.4
	351	Half-normal/Cosine (S)	0.33	48.8
Goulburn	310	Half-normal/Cosine	0.31	46.5
Gundagai	329	Half-normal/Cosine	0.34	51.7
Yass		Post-stratification by survey aspect:		
	185	Half-normal/Hermite (N)	0.43	64.5
	189	Half-normal/Cosine (S)	0.35	53.0
Young				
High	406	Half-normal/Cosine	0.41	62.2
Medium	93	Half-normal/Cosine	0.38	57.5

(specific) model was selected principally on the basis of it being the one that yielded the smallest value of the AIC statistic (see Section 4.2). The forms of the detection functions are shown in Figs. A2.1-A2.7.

In relation to each of the detection function models in Table 4, estimates are also given of the probability that a randomly selected cluster of kangaroos in the nominal survey strip will be detected (P_a) and the associated effective strip (half-) widths (μ). The probability that a randomly selected cluster of eastern grey kangaroos in the survey strip will be detected (P_a) showed substantial variation across survey strata, ranging from 0.31 to 0.54. The extent of the variation in this statistic appears to be similar to that determined from the previous surveys conducted in this kangaroo management zone (Cairns *et al.* 2010) and in the other eastern kangaroo management zones surveyed using helicopter line transect sampling (Cairns *et al.* 2011: Cairns and Bearup 2012).

By virtue of the way it is determined ($\mu = W \times P_a$; where W is the nominal strip width of the survey transect), the higher the value of P_a, the wider will be the effective strip width. The effective strip widths determined in relation to the results of these surveys ranged from 47 m to 82 m. According to Buckland *et al.* (2001), the effective strip width is defined by the perpendicular distance from the transect line beyond which as many objects are detected as are missed within that distance. In relation to this, a line transect survey can be thought of as effectively covering survey strips of a total area of $2L\mu$, for some $\mu \leq W$ and length L (Borchers and Burnham 2004).

Although the variation in these statistics probably reflects the extent of the variation in the general sightability of eastern grey kangaroos in relation to the differing broad landscapes of the constituent parts of the survey areas, it also reflects the possible influence of general weather conditions and light on sightability. Separating the influence of these factors would be difficult. In relation to this, however, the values of these statistics were somewhat higher than those determined from the previous surveys conducted in these RLPB districts (Cairns *et al*. 2010). The overall relatively low values of P_a and narrow estimate of the effective strip width in relation to the nominal survey half-width of 150 m are indicative of the effectiveness of the use of line transect sampling as opposed to strip transect sampling for estimating the abundance of macropods under the conditions of these surveys.

The initial density estimates obtained from of the analyses of the eastern grey kangaroo survey data are given in Table 5. These are results determined at the level of survey stratum. Note that in three instances the analysis has involved post-stratification. Given are the densities of clusters of eastern grey kangaroos and the corresponding population densities. As would be expected, cluster density is strongly correlated with population density (r_9 = 0.98; P<< 0.001). Average cluster density remains fairly consistent across the RLPB strata of the management zone.

Bootstrap confidence intervals and coefficients of variation were determined for these densities. These proved acceptable in all cases except in relation to the two post-stratified estimates for the Yass district (Table 5).

Population estimates derived using the eastern grey kangaroo densities determined for the surveyed strata of each RLPB district are given in Table 6. Density estimates determined in relation to the total area (including all strata) of each RLPB district are given in Table 7.

In relation to the determination of the estimates of population density and abundance, it should be noted that for the conduct the current surveys, the boundaries of the strata of each of the RLPB districts were subjected to some minor adjustments carried out in relation to the results of previous surveys (see Section 3.1). On the whole, the adjustments were minor; They would not have created any problems from the point of view of being able to compare the results of the current survey with those of the survey conducted in 2009 (Cairns *et al.* 2010). The integrity of the boundaries of each of the RLPB districts has been maintained.

Overall, the total number of eastern grey kangaroos in the South East NSW kangaroo management zone was estimated to be 936,040 (Table 7). An additional 76,700 kangaroos were estimated to be in the Bombala RLPD district. Within the current management zone, the highest density of eastern grey kangaroos was found in the Cooma RLPB district (Table 7).

The previous surveys conducted in this management zone resulted in total estimates of eastern grey kangaroo numbers of 656,600 in 2009 (Cairns *et al.* 2010) and of 415,270 in 2006 for, in this latter instance, an area excluding the Young RLPB district (Cairns *et al.* 2007). The increase in numbers over the three year period between 2006 and 2009 (Young RLPB district excluded from the calculation) was 38%. The increase in numbers over the three year period between 2006 and 2009 (Young RLPB district included in the calculation) was 42.5%. These increases translate into an annual exponential rate of increase in kangaroo numbers of 11% over the six year period since the conduct of the 2006 survey.

Table 6. The areas of the survey strata in the seven RLPB districts and the eastern grey kangaroo densities (D) and abundances (N) in these strata. Given also are the bootstrap coefficients for each of the estimates.

RLPB District	Area (km^2)	D (km^{-2})	95% bootstrap confidence interval	N	95% bootstrap confidence interval	CV_{boot} (%)
Bombala	2,719	28.21	15.19 – 38.06	76,700	41,300 – 103,470	18.7
Braidwood	3,987	27.07	19.22 – 35.35	107,940	76,630 – 140,940	14.8
Cooma	7,202	34.48	27.34 – 42.25	248,330	196,310 – 304,310	11.1
Goulburn	4,608	23.47	13.20 – 37.25	108,170	60,630 – 173,970	27.6
Gundagai	5,562	21.00	13.82 – 27.83	116,780	76,860 – 154,780	17.7
Yass	4,518	23.58	15.70 – 37.02	106,520	79,950 – 167,260	31.3
Young						
High	3,185	43.40	27.25 – 65.58	138,220	86,780 – 208,860	22.2
Medium	2,303	14.49	6.22 – 24.68	33,380	14,330 – 56,840	34.6
Pooled	5,488	31.27	20.90 – 43.84	171,600	114,640 – 240,590	19.1

Table 7. The total area, total number (N) and density (D) of eastern grey kangaroos for each of the RLPB districts and the whole SE NSW kangaroo management zone.

RLPB District	Area (km^2)	N	D (km^{-2})
Bombala	6,722	76,700	11.41
Braidwood	4,284	107,940	25.20
Cooma	7,271	248,330	34.15
Goulburn	6,028	108,170	17.94
Gundagai	6,342	116,780	18.41
Yass	5,615	106,520	18.97
Young	8,884	171,600	19.32
SE NSW zone*	38,424	936,040	24.36

*The zone total and density have been determined for the original six RLPB districts comprising the SE NSW zone; Bombala not included.

An assessment of numbers within the individual RLPB districts provides some insight into the overall change in the eastern grey kangaroo population within the management zone. Although numbers increased across the whole of management zone between 2006 and 2009, the only RLPB district where this increase was found to be significant ($p < 0.001$) was the Cooma RLPB district. There, the number of eastern grey kangaroos was found to have increased by some 140% over the numbers estimated by the 2006 survey. This substantial increase in numbers in the Cooma RLPB district was matched by a decrease in numbers in the Goulburn RLPB district, and smaller, but not significant, increases in the Braidwood, Yass and Gundagai RLPB districts. In relation to this the Young RLPB district, which was to be incorporated into the South East NSW management zone, was surveyed in 2008 (Cairns *et al.* 2009). Compared with the result of that survey, there was also a non-significant increase in eastern grey kangaroo density from 11.22 km^{-2} in 2008 to 15.14 km^{-2} in 2009.

A breakdown of the similar overall proportional increase in kangaroo numbers that occurred between 2009 and 2012 reveals that there was a very slight decline

(2%) in numbers in the Cooma RLPB district, indicating a consolidation of the increase that had been recorded for the previous three years. With a proportional increase of 6%, numbers also remained essentially unchanged in the Yass RLPB district. Relatively high increases in numbers were recorded in the Braidwood (36%), Goulburn (51%) and Gundagai (69%) RLPB districts. As substantial as some of these increases appear, none were statistically significant ($P > 0.05$). The only district to record a significant ($P < 0.05$) increase in numbers was the Young RLPB district, which registered a doubling of the size of the kangaroo population.

As has been the case with the design of previous surveys (Cairns 2004; Cairns *et al.* 2007, 2010), the aim with designing the current survey was to determine eastern grey kangaroo population estimates with coefficients of variation <20% for each of the RLPB districts. This target was achieved for the surveys conducted in five of the seven RLPB districts (Table 6). For the Goulburn and Yass districts, the bootstrap coefficients of variation were 27.65 and 31.3%, respectively. This could be interpreted in relation to the patchiness of the distributions of the kangaroos throughout the survey strata in these two districts, particularly in the medium density stratum of the Young RLPB district (Fig. 9). In terms of overall precision, the outcome of these surveys represents a considerable improvement on those of the last surveys conducted in this kangaroo management zone (Cairns *et al.* 2010).

A footnote to the estimation of eastern grey kangaroo numbers from these surveys is that with enough sightings having been made across the whole seven RLPB districts, an estimate could be made of the swamp wallabies present. This analysis was based upon 99 sightings of swamp wallabies made on a total of 337 survey transects comprising 2,950 km of survey effort. The most parsimonious detection function was the Half-normal/Cosine model (Fig. A2.8). The results of the analysis are given in Table 8.

Table 8. Estimates of the density of clusters (D_s), density of individuals (D) and abundance (N) of swamp wallabies in the seven RLPB districts surveyed. Given with these estimates are the empirical coefficients of variation (CV), 95% bootstrap confidence intervals and the bootstrap coefficients of variation (CV_{boot}).

	Estimate	CV (%)	95% bootstrap confidence interval	CV_{boot} (%)
D_s (km^{-2})	0.58	14,3	0.43 – 0.78	15.5
D (km^{-2})	0.67	14.5	0.47 – 0.93	18.2
N	26,000	14.5	18,740 – 36,660	18.2

6. Acknowledgements

As with any project, the job is never completed without the support of others who are either wittingly or unwittingly drawn in to provide assistance. Co-author Greg Lollback provided invaluable GIS support, without which projects such as this would founder. As well as filling the role of a very able observer during the conduct of the surveys, co-author David Bearup provided invaluable support with regard to helping the flight crew plan each day's survey. Scott Seymour and Mike Saunders both more than ably filled seats as observers. Paul Caristo and his crew provided excellent and obliging service with the helicopter. Their attention to OH&S issues was well appreciated. The Southern Rivers Catchment Management Authority provided funding that allowed OEH to include the former Bombala Rural Lands Protection Board in the survey.

7. References

Borchers, D.L & Burnham, K. P. (2004). General formulation for distance sampling. In: *Advanced Distance Sampling* (eds. S. T. Buckland, D. A. Anderson, K. P. Burnham, J. L. Laake and L. Thomas). Pp. 6-30.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L. & Thomas, L. (2001). *Introduction to Distance Sampling: Estimating abundance of biological populations*. Oxford University Press, Oxford.

Cairns, S. C. (2004). *A report to the New South Wales National Parks & Wildlife Service on the consultancy: Kangaroo Monitoring – South East New South Wales Helicopter Survey.* Unpublished report to New South Wales National Parks and Wildlife Service, Dubbo, NSW. 19 pp.

Cairns, S. C. (2007). *A report to the New South Wales Department of Environment and Climate Change on the consultancy: Kangaroo Monitoring – South East New South Wales Helicopter Survey.* Unpublished report to New South Wales Department of Environment and Climate Change, Dubbo, NSW. 30 pp.

Cairns, S. C. and Bearup, D. (2012). *A report to the New South Wales Office of Environment and Heritage on the consultancy: Design and Analysis of Helicopter Surveys of Kangaroo Populations in the Central Tablelands North and South management zone.* An unpublished report to the New South Wales Office of Environment and Heritage. 44 pp.

Cairns, S. C., Lollback, G. W. and Bearup, D. (2009). *Kangaroo monitoring – design and analysis of the Central Tablelands Region helicopter survey.* Unpublished report to New South Wales Department of Environment, Climate Change and Water, Dubbo, NSW. 43pp.

Cairns, S. C., Lollback, G. W. and Bearup, D. (2010). *A report to the New South Wales Department of Environment, Climate Change and Water on the consultancy: Kangaroo Monitoring* – South East NSW Commercial Harvest Zone Redesign and Analysis of Helicopter Survey.' Unpublished report to New South Wales Department of Environment, Climate Change and Water, Dubbo, NSW. 55 pp.

Cairns, S. C., Lollback, G. W. and Bearup, D. (2011). A report to the New South Wales Office of Environment and Heritage on the consultancy: 'Kangaroo Monitoring: Northern Tablelands Harvest Zones – Redesign and Analysis of Helicopter Survey'. Unpublished report to New South Wales Department of Environment, Climate Change and Water, Dubbo, NSW. 49 pp.

Clancy, T. F. (1999). Choice of survey platforms and technique for broad-scale monitoring of kangaroo populations. *Australian Zoologist* **31**: 367-274.

Clancy, T. F., Pople, A. R. & Gibson, L. A. (1997). Comparison of helicopter line transects with walked line transects for estimating densities of kangaroos. *Wildlife Research* **24**: 397-409.

Office of Environment and Heritage (NSW). (2011). *New South Wales Commercial Kangaroo Harvest Management Plan 2012–2016*. Office of Environment and Heritage, Department of Premier and Cabinet (NSW), Sydney. 50 pp.

Payne, N. (2007). *Population Monitoring Methods for the NSW Kangaroo Management Program.* Department of Environment and Conservation, NSW. 17 pp.

Pople, A. R., Cairns, S. C. & Menke, N. (2003). 'Monitoring Kangaroo Populations in Southeastern New South Wales.' Unpublished report to New South Wales National Parks and Wildlife Service, Dubbo, NSW. 24 pp.

Pople, A. R., Cairns, S. C., Menke, N. & Payne, N. (2006). Estimating the abundance of eastern grey kangaroos (*Macropus giganteus*) in south-eastern New South Wales, Australia. *Wildlife Research* **33**: 93-102.

Pople, A. R. and Grigg, G. C. (1998). *Commercial harvesting of kangaroos in Australia.* Environment Australia, Canberra. Retrieved in April 2013 from http://www.ea.gov.au/biodiversity/trade-use/wild-harvest/kangaroo/harvesting/index.html

Sahukar, R., Gallery, C., Smart, J. and Mitchell, P. (2003). *The Bioregions of New South Wales: their biodiversity, conservation and history*. National Parks and Wildlife Service (NSW).

Southwell, C. J., and Sheppard, N. (2000). Assessing harvested populations of the euro (*Macropus robustus erubescens*) in the Barrier Ranges of western NSW. *Australian Mammalogy* **21**: 165-171.

Strindberg, S., Buckland, S. T. & Thomas, L. (2004). Design of distance sampling surveys and Geographic Information Systems. In: *Advanced Distance Sampling* (eds. S. T. Buckland, D. A. Anderson, K. P. Burnham, J. L. Laake and L. Thomas). Pp. 190-228.

Thomas, L., Buckland, S. T., Burnham, K. P., Anderson, D. R., Laake, J. L., Borchers, D. L. & Stringberg, S. (2002). Distance sampling. In: *Encyclopaedia of Environmentrics* (eds. A. H. El-Shaarawi and W. W. Piegorsch). Volume 1, pp. 544-552.

Thomas, L., Buckland, S. T., Rexstad, E. A., Laake, J. L., Strinberg, S., Hedley, S. L., Bishop, J. R. B., Marques, T. A. and Burnham, K. P. (2010). Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* **47**: 5-14.

Thomas, L., Laake, J.L., Rexstad, E., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Burt, M.L., Hedley, S.L., Pollard, J.H., Bishop, J.R.B. and Marques, T.A. 2009. Distance 6.0. Release “x”1. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. Retrieved in April 2013 from http://www.ruwpa.st-and.ac.uk/distance/

Appendix 1

The number of sightings and raw counts of macropods for the transects surveyed in the high and medium density strata of the seven RLPB districts

Table A.1. The total number of sightings of macropods and the raw counts of eastern grey kangaroos (*EGK*), common wallaroos (*CW*), red-necked wallabies (*RNW*) and swamp wallabies (*SW*) for each of the transects surveyed within the seven RLPB districts. For the Young RLPB district, the transects are each identified in relation to the survey stratum to which they belong by the second letter of their identification code (M = medium, H = high).

	No. of	***Raw counts***			
Transect	sightings	*EGK*	*CW*	*RNW*	*SW*
Bombala					
Bo01	6	21	-	-	-
Bo02	4	10	-	-	-
Bo03	15	40	-	-	-
Bo04	30	61	-	-	-
Bo05	19	36	-	-	2
Bo06	23	115	-	-	-
Bo07	11	30	-	2	2
Bo08	50	181	-	-	1
Bo09	30	89	-	1	2
Bo10	3	4	-	2	-
Bo11	22	85	-	-	1
Bo12	30	90	-	-	1
Bo13	31	109	1	-	-
Bo14	35	119	-	3	1
Bo15	18	42	-	-	1
Bo16	2	-	-	-	-
Bo17	8	19	-	-	-
Bo18	4	1	-	-	3
Bo19	6	17	-	-	-
Bo20	12	56	1	-	1
Bo21	6	12	-	-	1
Bo22	17	42	-	-	-
Bo24	28	272	-	-	-
Bo25	11	48	-	-	-

Transect	No. of sightings	***Raw counts***			
		EGK	*CW*	*RNW*	*SW*
<u>Braidwood</u>					
Br01	5	11	-	3	-
Br02	13	42	-	1	-
Br03	11	35	-	-	-
Br04	14	64	-	-	-
Br05	11	34	-	-	-
Br06	-	-	-	-	-
Br07	5	7	-	-	1
Br08	7	20	1	-	-
Br09	4	30	-	-	-
Br10	5	8	-	2	-
Br11	-	-	-	-	-
Br12	13	83	-	-	-
Br13	1	1	-	-	-
Br14	19	80	-	-	-
Br15	14	60	-	-	-
Br16	11	46	-	-	-
Br17	4	10	-	-	-
Br18	8	51	-	-	1
Br19	31	135	-	-	-
Br20	3	5	-	-	-
Br21	4	12	-	-	-
Br22	8	9	-	-	-
Br23	7	14	-	-	-
Br25	3	3	-	-	-
Br26	8	25	-	-	-
Br27	-	-	-	-	-
Br28	28	105	-	-	-
Br29	22	71	-	-	-
Br30	5	7	-	1	-
Br31	2	1	-	-	-
Br32	11	36	-	-	-

Transect	No. of sightings	***Raw counts*** *EGK*	*CW*	*RNW*	*SW*
Br33	7	23	-	-	-
Br34	2	1	-	-	-
Br35	10	37	-	-	-
Br36	9	41	-	-	-
Br37	7	18	-	-	-
Br38	4	24	-	-	-
Br39	4	14	-	-	-
Br40	20	79	-	-	-
Br41	3	16	-	-	-
Br42	9	19	-	-	1
Br43	4	18	-	-	-
Br44	22	73	-	-	-
Br45	2	1	-	-	-
Br46	15	23	-	-	1
Br47	14	30	-	1	-
Br48	10	30	-	-	-
Br49	6	12	-	-	-
Br50	2	-	-	1	-
Br51	4	19	-	-	-
Br52	5	20	-	-	-
Cooma					
Co01	12	31	-	-	-
Co02	1	3	-	-	-
Co03	31	93	-	-	-
Co04	7	20	-	-	-
Co05	17	52	-	-	-
Co06	5	12	-	-	-
Co07	2	3	-	-	-
Co08	18	95	-	-	2
Co09	4	16	-	-	-
Co10	17	55	-	-	-

Transect	No. of sightings	***Raw counts***			
		EGK	*CW*	*RNW*	*SW*
Co11	2	15	-	-	-
Co12	24	73	-	-	-
Co13	10	38	-	-	1
Co14	8	41	-	-	-
Co16	21	90	-	-	-
Co17	5	13	-	-	-
Co18	24	82	-	-	-
Co20	5	3	-	-	3
Co21	8	46	-	-	4
Co22	9	75	-	-	-
Co23	1	4	-	-	-
Co24	5	16	-	-	-
Co25	23	112	-	-	1
Co26	7	32	-	-	-
Co27	8	20	-	-	1
Co28	11	60	-	-	-
Co29	5	35	-	-	-
Co30	10	17	-	-	-
Co31	42	141	2	-	-
Co32	6	20	-	-	-
Co33	5	26	-	-	-
Co34	10	32	-	-	1
Co35	8	38	-	-	-
Co36	25	92	-	-	-
Co37	9	35	-	-	1
Co39	24	79	-	-	-
Co40	10	21	-	1	1
Co41	20	49	1	-	-
Co42	18	71	-	-	-
Co43	6	16	-	-	-
Co44	6	32	-	-	-
Co45	13	35	-	1	-

Transect	No. of sightings	*Raw counts*			
		EGK	*CW*	*RNW*	*SW*
Co46	9	20	1	-	1
Co47	3	11	-	-	-
Co48	7	18	-	1	1
Co49	43	142	-	3	-
Co50	16	48	1	1	2
Co51	5	9	-	-	-
Co52	3	3	-	-	1
Co53	39	223	-	-	-
Co54	18	38	-	2	1
Co55	22	69	-	4	1
Co56	3	2	-	2	1
Co57	26	56	-	3	1
Co58	10	21	-	-	-
Co59	9	19	-	-	-
Co60	5	25	-	-	-
Goulburn					
Gb01	13	23	-	-	2
Gb02	12	-	-	-	-
Gb03	19	173	-	-	-
Gb04	2	3	-	-	-
Gb05	4	7	-	-	-
Gb06	4	4	-	-	-
Gb07	3	20	-	-	-
Gb08	3	14	-	1	-
Gb09	12	67	-	-	-
Gb10	3	18	-	-	-
Gb11	2	20	-	-	-
Gb12	9	47	-	1	-
Gb13	2	10	-	-	-
Gb14	2	-	-	-	-
Gb15	3	7	-	-	-

Transect	No. of sightings	Raw counts			
		EGK	*CW*	*RNW*	*SW*
Gb16	2	-	-	-	-
Gb17	25	124	-	-	-
Gb18	8	43	-	-	-
Gb19	10	16	-	-	2
Gb20	5	12	-	-	-
Gb21	6	7	-	-	-
Gb22	2	-	-	-	-
Gb23	13	59	-	-	-
Gb24	8	9	-	-	1
Gb25	9	62	-	-	-
Gb26	5	20	-	-	-
Gb27	2	-	-	-	-
Gb28	5	4	-	-	-
Gb29	2	-	-	-	-
Gb30	2	2	-	-	-
Gb31	16	44	-	1	-
Gb32	4	2	-	-	-
Gb33	2	-	-	-	-
Gb34	5	2	-	-	-
Gb35	6	14	-	-	-
Gb36	22	48	-	-	-
Gb37	5	6	1	-	-
Gb38	2	-	-	-	-
Gb39	12	23	-	-	-
Gb40	7	24	-	-	-
Gb41	7	30	-	-	-
Gb42	5	16	-	-	-
Gb43	26	97	-	-	-
Gb44	12	26	-	-	1
Gb45	2	-	-	1	-
Gb46	2	-	-	-	-
Gb47	3	3	-	-	-

Transect	No. of sightings	Raw counts EGK	CW	RNW	SW
Gb48	8	19	-	-	-
Gb49	4	11	-	-	-
Gb50	2	-	-	-	-
Gb51	12	27	-	-	-
Gb52	2	-	-	-	-
Gb53	6	11	-	-	-
Gb54	2	3	-	-	-
Gundagai					
Gu01	26	97	-	-	1
Gu02	15	48	-	-	-
Gu03	3	6	-	-	-
Gu04	13	56	-	-	2
Gu05	7	14	-	-	1
Gu06	-	-	-	-	-
Gu07	2	6	-	-	-
Gu08	10	36	-	-	-
Gu09	6	13	-	-	1
Gu10	8	14	-	-	-
Gu11	12	25	-	-	-
Gu12	8	29	-	-	-
Gu13	-	-	-	-	-
Gu14	8	16	-	-	-
Gu15	4	8	-	-	-
Gu16	3	9	-	-	-
Gu17	33	119	-	-	1
Gu18	3	22	-	-	-
Gu19	11	38	-	-	-
Gu20	-	-	-	-	-
Gu21	10	29	-	-	-
Gu22	6	25	-	-	-
Gu23	8	38	-	-	-

Transect	No. of sightings	***Raw counts*** *EGK*	*CW*	*RNW*	*SW*
Gu24	-	-	-	-	-
Gu25	11	16	-	-	2
Gu26	10	26	1	-	1
Gu27	9	25	-	-	-
Gu28	6	24	-	-	-
Gu29	8	32	-	-	-
Gu30	-	-	-	-	-
Gu31	3	5	-	-	-
Gu32	-	-	-	-	-
Gu33	8	26	-	-	-
Gu34	-	-	-	-	-
Gu35	5	17	-	-	-
Gu36	38	117	-	-	-
Gu37	10	34	-	-	-
Gu38	3	26	-	-	-
Gu39	29	130	-	-	-
Gu40	11	26	-	1	-
Gu41	10	35	1	-	-
Gu42	-	-	-	-	-
Gu43	1	1	-	-	-
Gu44	-	-	-	-	-
Gu45	5	7	-	-	-
Gu46	3	10	-	-	-
Yass					
Ya01	-	-	-	-	-
Ya02	1	6	-	-	-
Ya03	8	23	-	-	-
Ya04	4	31	-	-	-
Ya05	2	3	-	-	-

Transect	No. of sightings	*Raw counts*			
		EGK	*CW*	*RNW*	*SW*
Ya06	16	72	-	-	-
Ya07	2	6	-	-	-
Ya08	2	5	-	-	-
Ya09	7	43	-	-	-
Ya10	9	117	-	-	-
Ya11	7	20	-	-	-
Ya12	1	3	-	-	-
Ya13	4	7	-	1	-
Ya14	19	47	-	-	-
Ya15	1	10	-	-	-
Ya16	4	18	-	-	-
Ya17	34	151	-	1	-
Ya18	5	15	-	-	-
Ya19	3	15	-	-	1
Ya20	11	39	-	-	-
Ya21	6	21	-	-	-
Ya22	5	16	-	-	-
Ya23	13	46	-	-	-
Ya24	6	14	-	-	1
Ya25	12	52	-	-	2
Ya26	-	-	-	-	-
Ya27	12	63	-	-	-
Ya28	30	157	-	-	1
Ya29	2	2	-	-	-
Ya30	3	3	-	-	2
Ya31	3	-	-	2	2
Ya32	5	9	-	-	-
Ya33	-	-	-	-	-
Ya34	6	5	-	-	3
Ya35	-	-	-	-	-
Ya36	-	-	-	-	-
Ya37	4	13	6	-	-

Transect	No.of sightings	Raw counts			
		EGK	*CW*	*RNW*	*SW*
Ya38	2	8	-	-	-
Ya39	9	19	-	-	-
Ya40	17	64	-	-	-
Ya41	4	4	-	-	2
Ya42	3	5	1	-	-
Ya43	2	4	-	-	-
Ya44	9	27	-	-	-
Ya45	16	34	-	-	1
Ya46	2	2	-	-	-
Ya47	7	10	-	-	-
Ya48	-	-	-	-	-
Ya49	-	-	-	-	-
Ya50	23	72	-	-	-
Ya51	1	3	-	-	-
Ya52	-	-	-	-	-
Ya53	14	41	-	-	-
Ya54	3	4	-	-	-
Ya55	36	116	-	-	5
Ya56	1	6	-	-	-
Ya57	-	-	-	-	-
Ya58	-	-	-	-	-
Ya59	5	19	-	-	1
Ya60	1	5	-	-	-
Ya61	-	-	-	-	-
Ya62	1	4	-	-	-
Ya63	-	-	-	-	-
	-	-	-	-	-
Young High					
YoH01	14	43	-	-	-
YoH02	-	-	-	-	-
YoH03	6	12	-	-	1
YoH04	11	37	3	-	2

Transect	No. of sightings	Raw counts			
		EGK	*CW*	*RNW*	*SW*
YoH05	2	3	-	-	-
YoH06	26	150	-	-	-
YoH07	12	26	-	-	1
YoH08	24	41	1	-	6
YoH09	13	24	-	-	-
YoH10	19	47	-	-	1
YoH11	54	244	1	1	-
YoH12	18	56	-	-	1
YoH13	31	105	-	1	2
YoH14	74	197	-	1	1
YoH15	5	21	-	-	-
YoH16	24	71	1	-	-
YoH17	36	155	-	-	-
YoH18	30	80	1	-	1
YoH19	7	22	-	-	-
YoH20	26	48	8	-	-
			-	-	-
Young Medium					
YoM01	-	-	-	-	-
YoM02	-	-	-	-	-
YoM03	1	8	-	-	-
YoM04	-	-	-	-	-
YoM05	-	-	-	-	-
YoM06	6	27	-	-	2
YoM07	4	5	-	-	2
YoM08	1	4	-	-	-
YoM09	-	-	-	-	-
YoM10	2	19	-	-	-
YoM11	2	6	-	-	-
YoM12	2	7	-	-	-
YoM13	7	16	-	-	-

Transect	No. of sightings	Raw counts			
		EGK	*CW*	*RNW*	*SW*
YoM14	4	15	-	-	-
YoM15	-	-	-	-	-
YoM16	13	40	-	-	1
YoM18	12	40	-	-	-
YoM19	3	24	-	-	-
YoM20	4	1	-	1	2
YoM21	23	107	-	-	-
YoM22	8	22	-	1	-
YoM23	9	23	-	-	1

Appendix 2

The detection function models for eastern grey kangaroos (*M. giganteus*) and swamp wallabies (*W. bicolour*) in the seven RLPB districts.

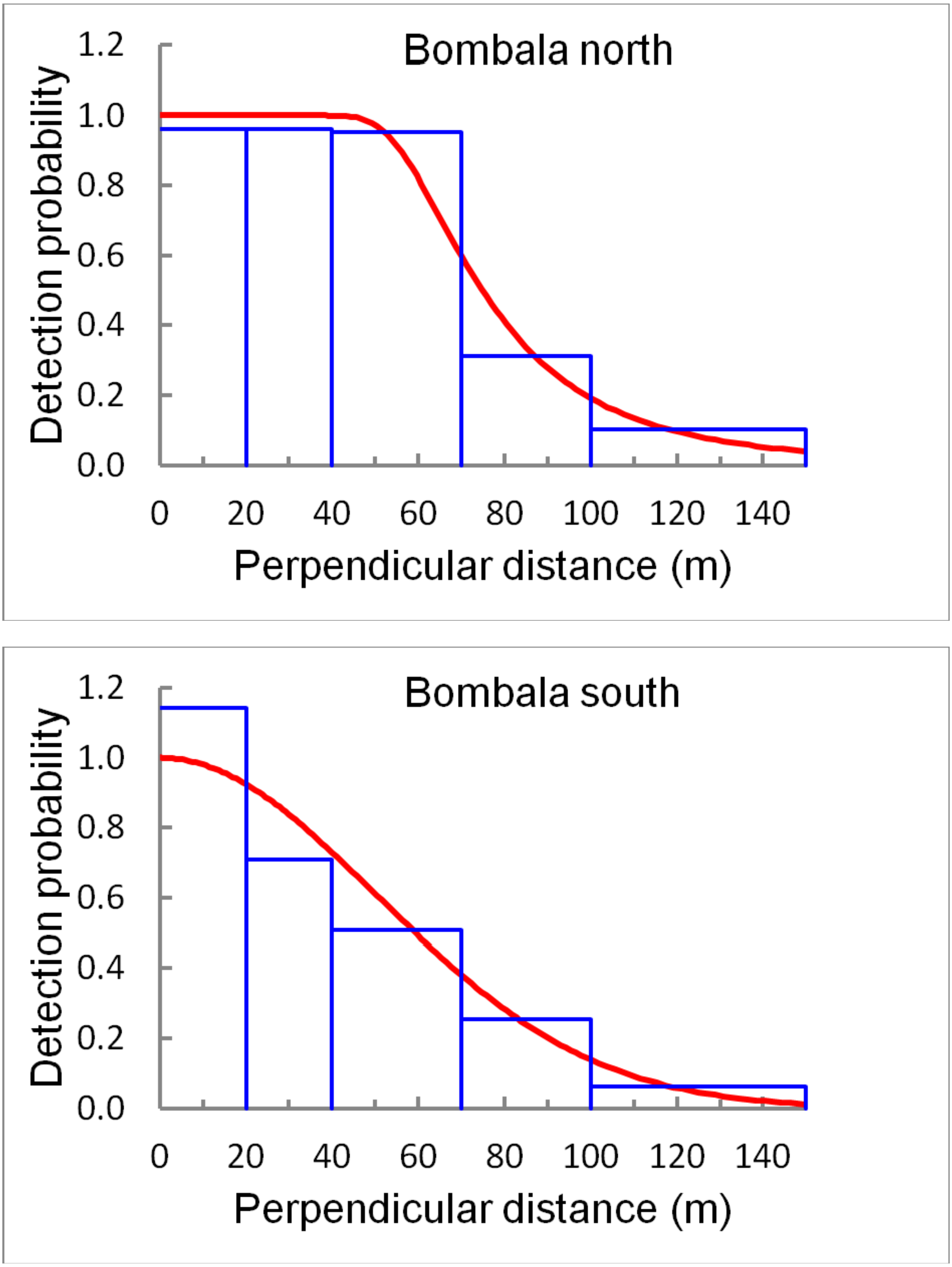


Fig. A2.1. The detection functions for eastern grey kangaroos in the Bombala RLPB district. These detection functions were derived using the CDS analysis engine of

DISTANCE 6.0 and post-stratification on basis of survey aspect (for further details, see Table 4).

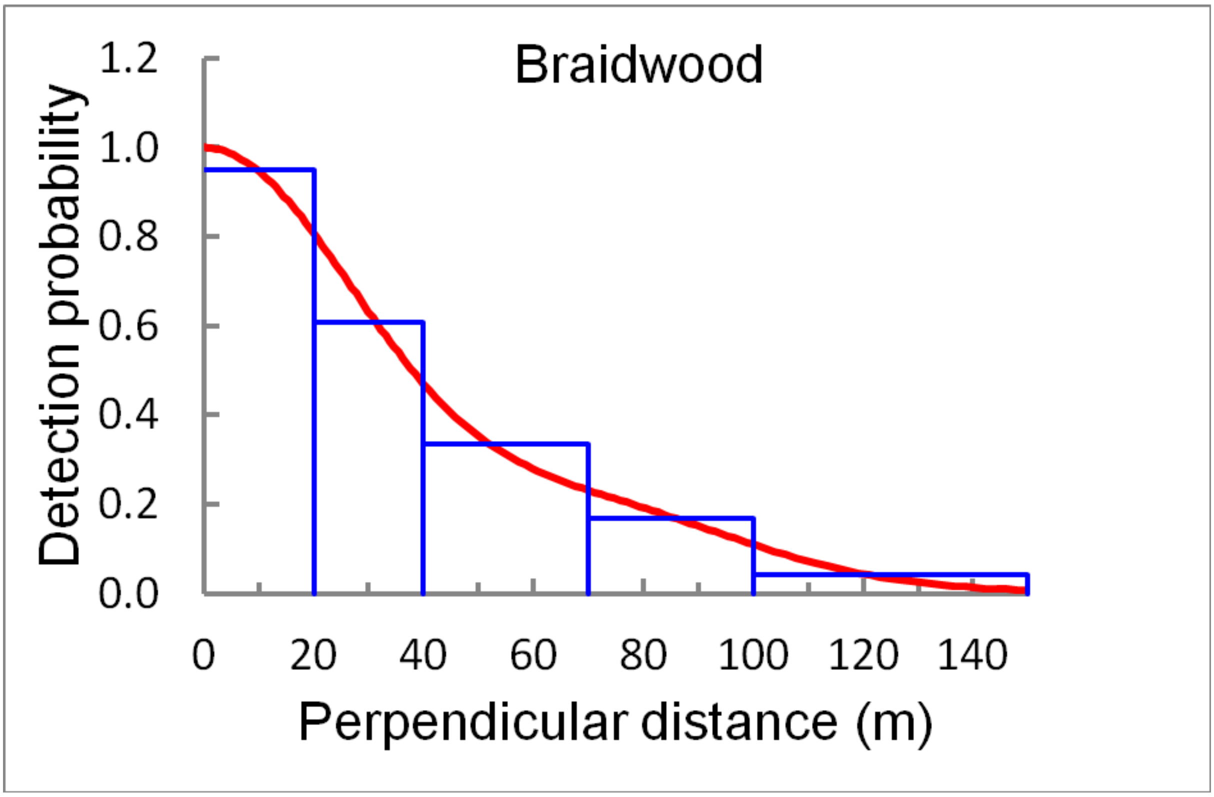


Fig. A2.2. The detection functions for eastern grey kangaroos in the Braidwood RLPB district. This detection function was derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see Table 4).

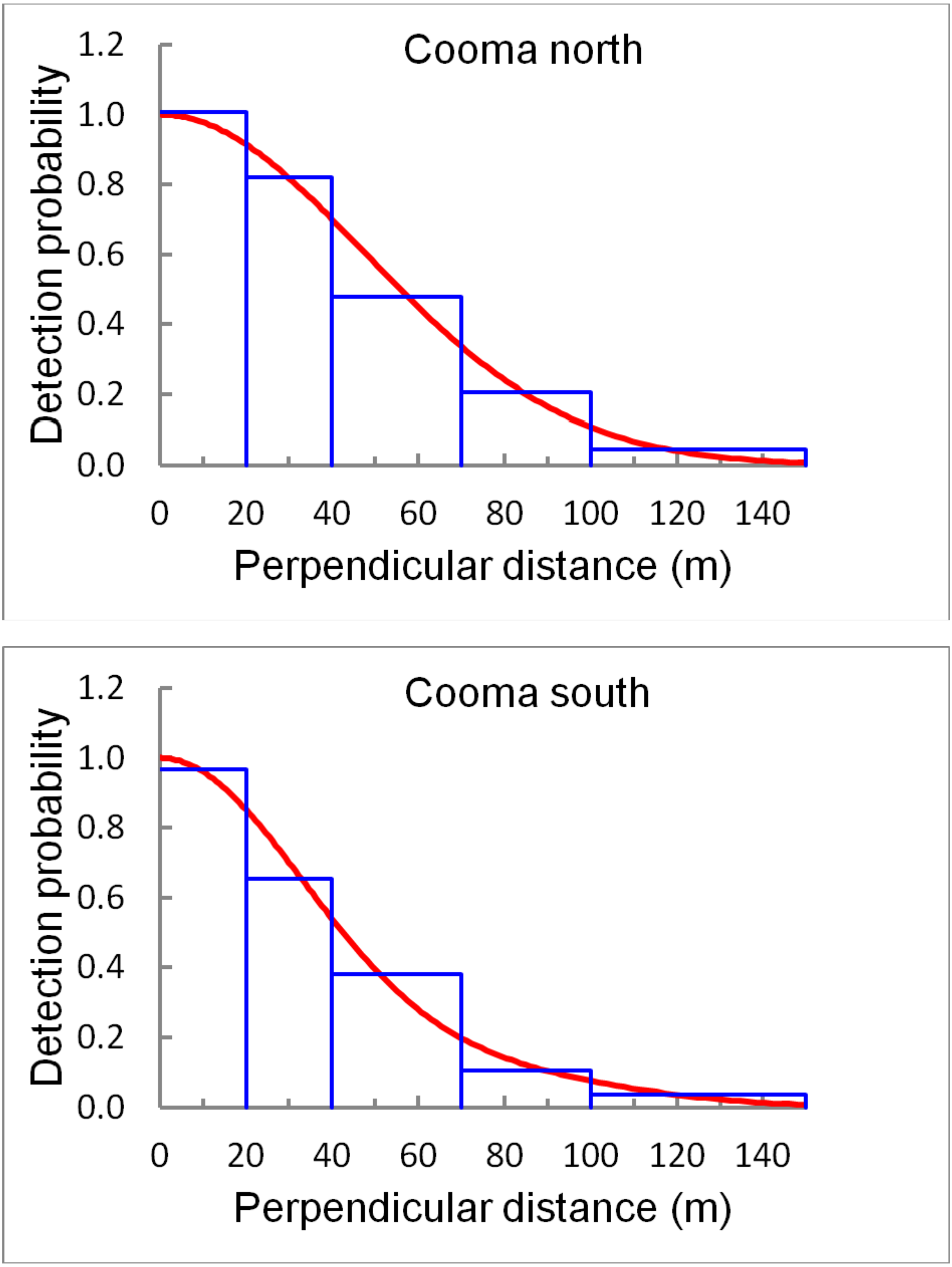


Fig. A2.3. The detection functions for eastern grey kangaroos in the Cooma RLPB district. These detection functions were derived using the CDS analysis engine of DISTANCE 6.0 and post-stratification on basis of survey aspect (for further details, see Table 4).

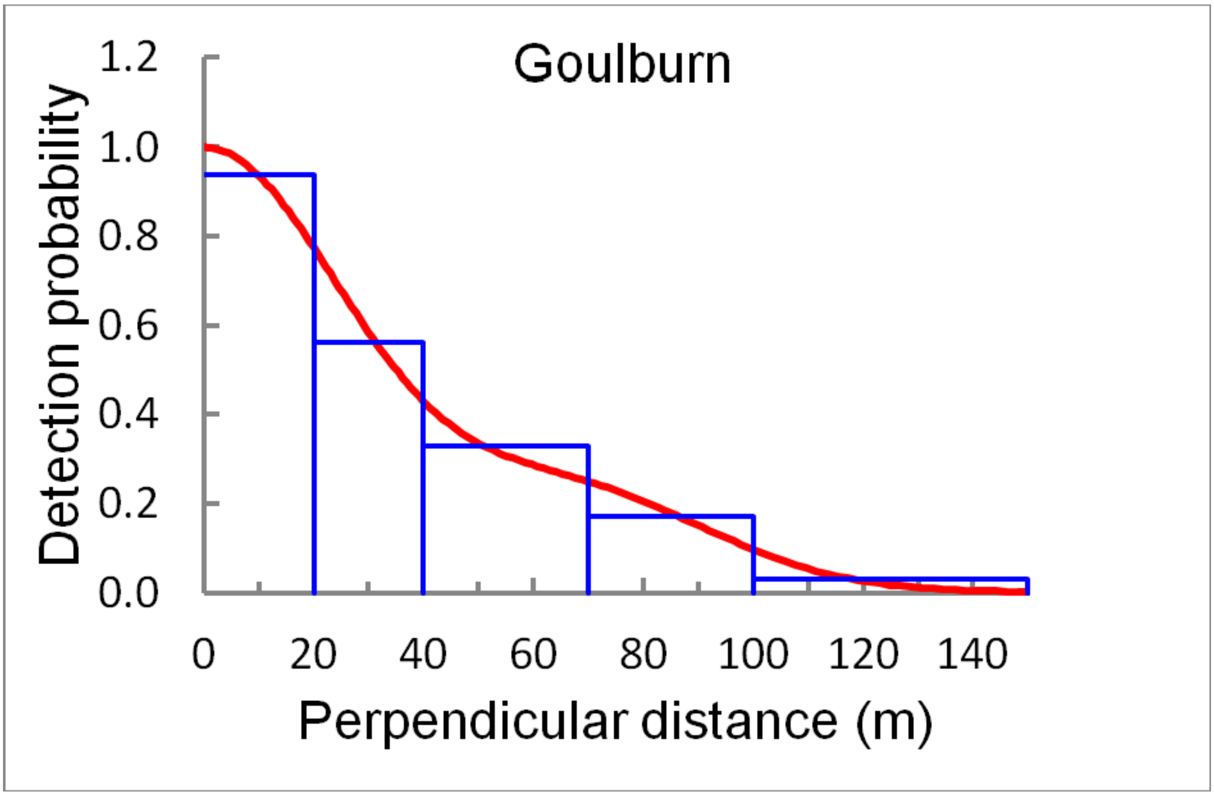


Fig. A2.4. The detection functions for eastern grey kangaroos in the Goulburn RLPB district. This detection function was derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see Table 4).

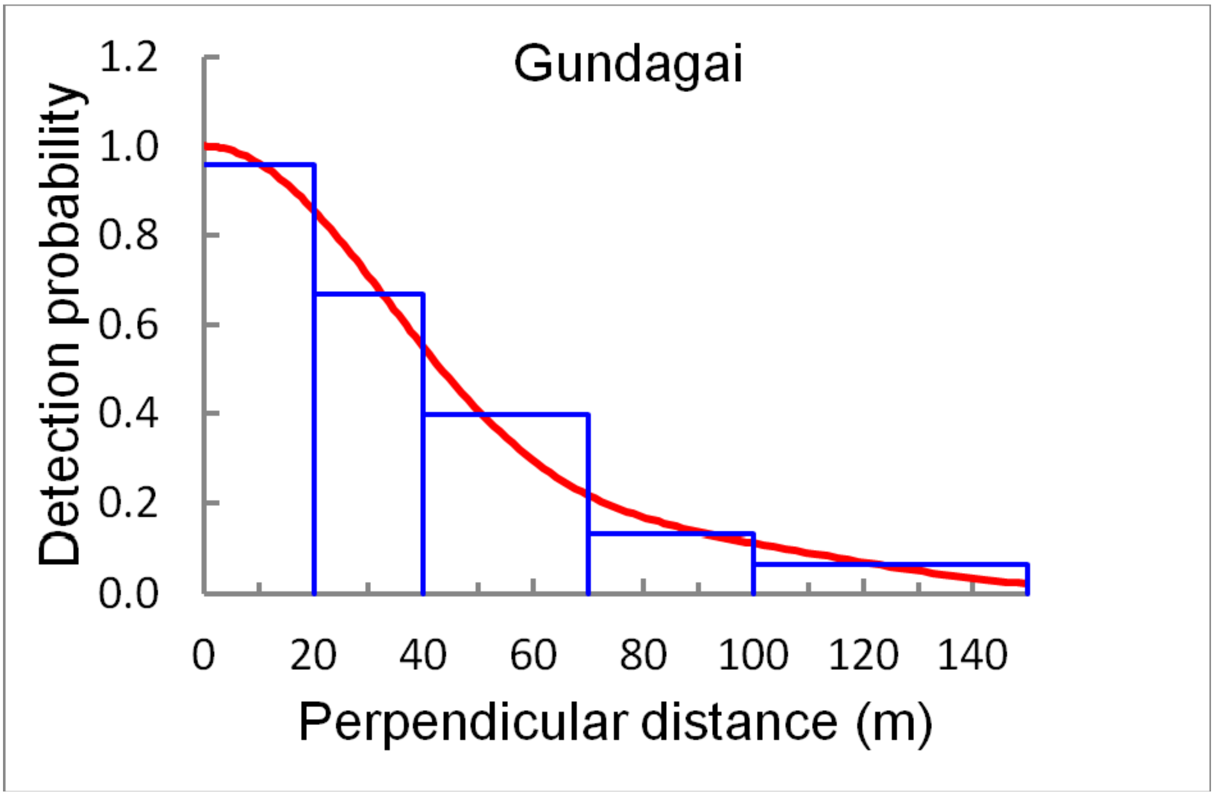
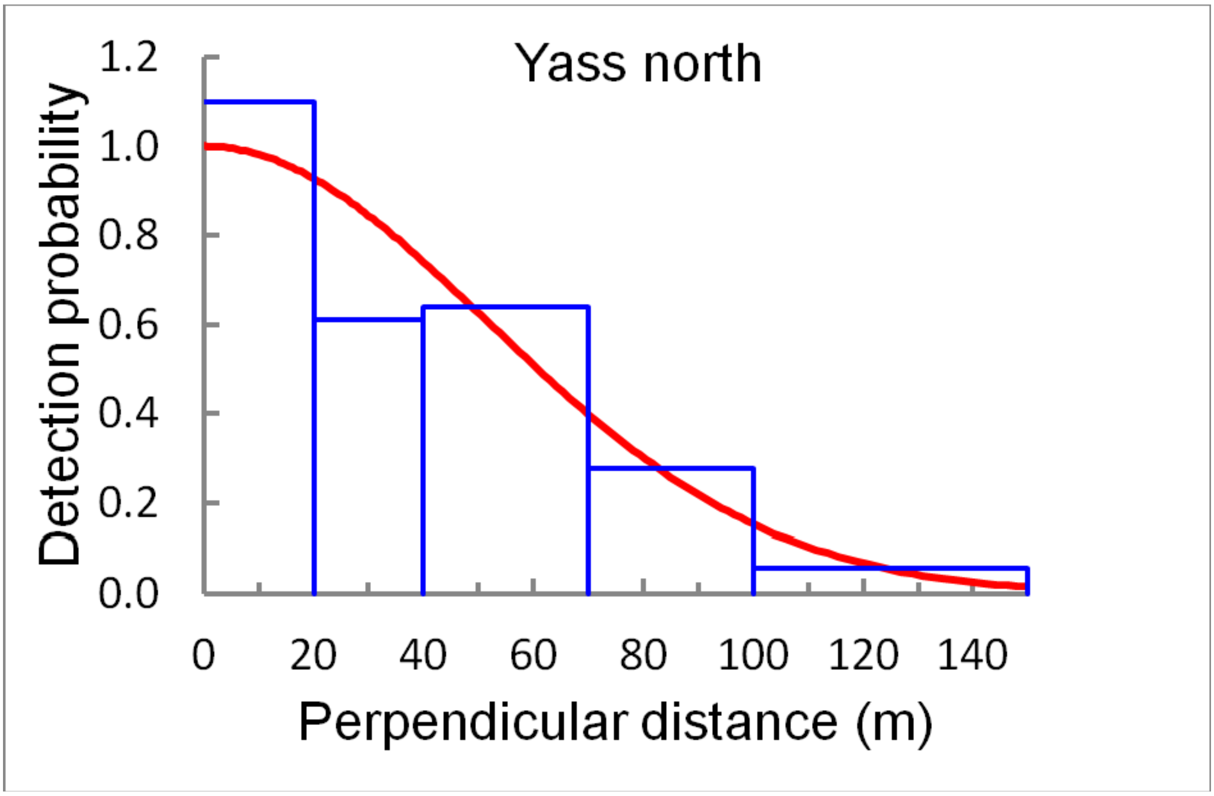


Fig. A2.5. The detection functions for eastern grey kangaroos in the Gundagai RLPB district. This detection function was derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see Table 4).



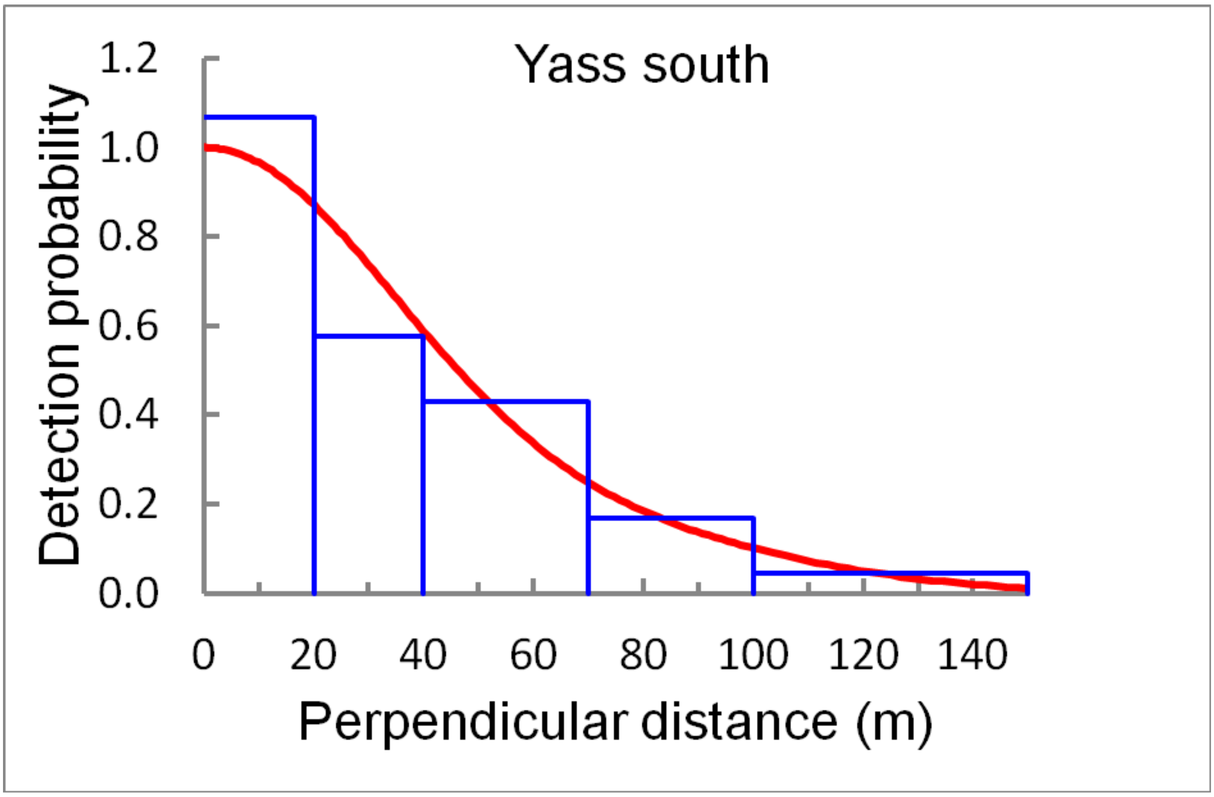


Fig. A2.6. The detection functions for eastern grey kangaroos in the Yass RLPB district. These detection functions were derived using the CDS analysis engine of DISTANCE 6.0 and post-stratification on basis of survey aspect (for further details, see Table 4).

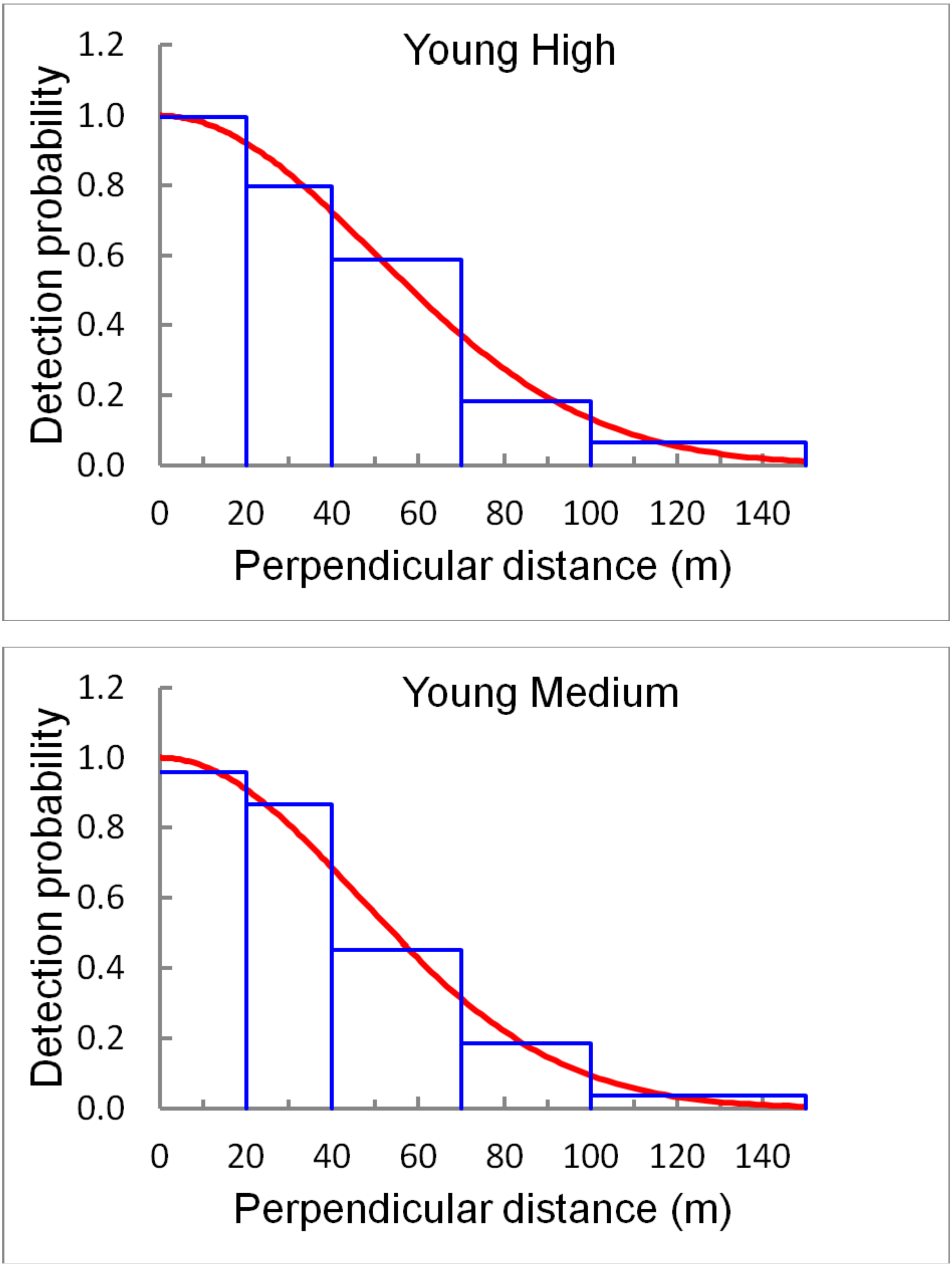


Fig. A2.7. The detection functions for eastern grey kangaroos in the Young RLPB district. These detection functions were derived using the CDS analysis engine of DISTANCE 6.0 and stratification of the area surveyed (for further details, see Table 4).

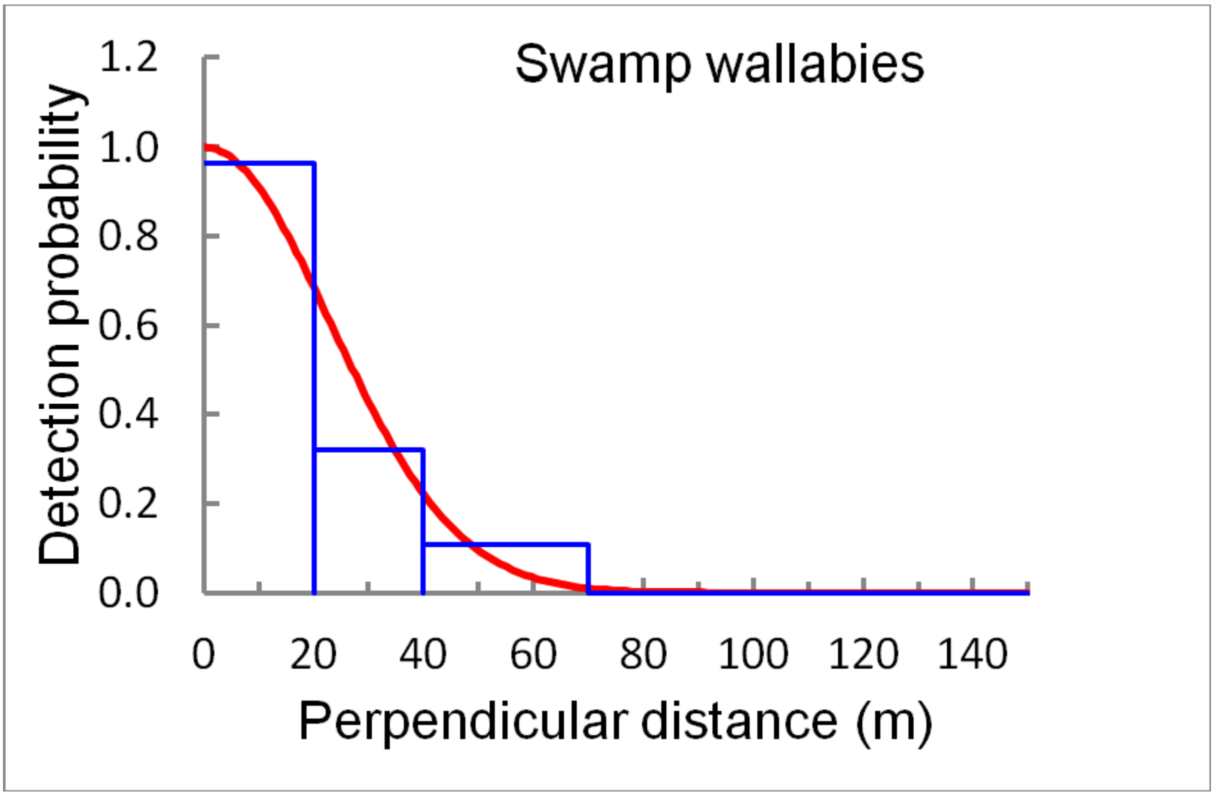


Fig. A2.5. The detection functions for Swamp wallabies in the seven RLPB districts surveyed. This detection function was derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see text).