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'.

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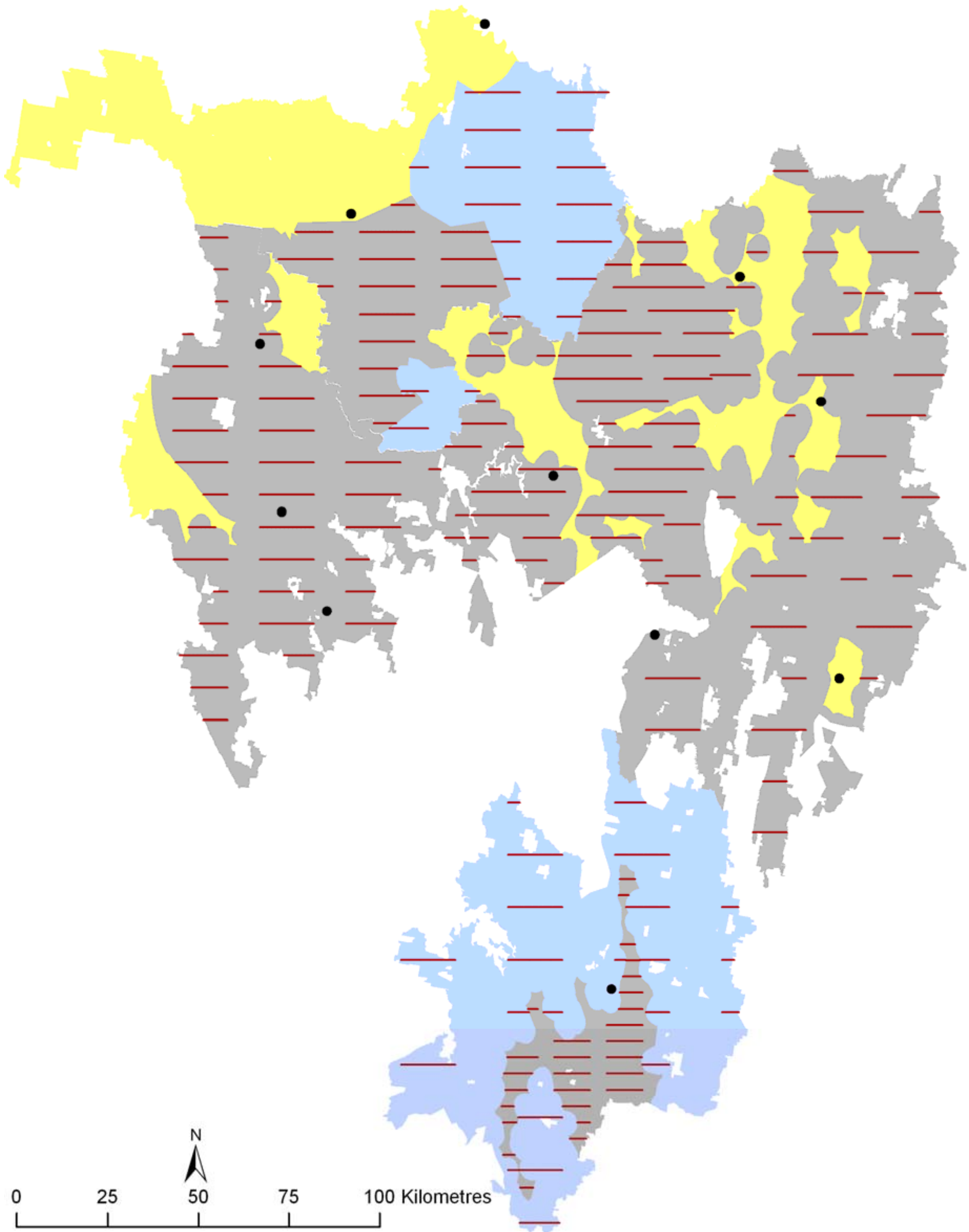

The sampling design used for the helicopter line transect survey of the six RLPB districts comprising the South East NSW kangaroo management zone. The survey area is restricted to areas outside National Parks and State Forests and to areas without high relief, which are shown in Fig. 1. The survey area is divided into high (blue), medium (grey) and low (yellow) kangaroo density strata.

Summary

1. A helicopter survey was conducted using the method of line transect sampling of the kangaroo populations in the South East NSW kangaroo management zone. The population estimates derived from this survey were intended to be used to set quotas for the commercial harvesting of eastern grey kangaroos (*Macropus giganteus*) from within this zone for the period 2010-2012.

2. The South East NSW kangaroo management zone comprises six Rural Lands Protection Board (RLPB) districts. In conducting the survey, each of these RLPB districts 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 medium to high densities of kangaroos were surveyed. The low density stratum was not. The surveys were designed using an automated survey design algorithm (Strindberg *et al.* 2004).

3. The survey was 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 varied considerably, being in the range 23-39%.

4. The estimated density of eastern grey kangaroos for the management zone was 17.09 km^{-2}. This density corresponded to a population estimate of 656,504 kangaroos.

5. Between the time that the most recent previous survey was conducted of the kangaroo populations in this management zone in 2006 and the time of the present survey, the eastern grey kangaroo has increased by 38%. This increase was based upon estimates determined for the five of the RLPB districts surveyed on both occasions.

1. Introduction

An integral part of the kangaroo management programs in operation in four of the five mainland states of Australia is the commercial harvesting of all or some of the four large species of kangaroo that are variously widespread and abundant throughout much of the continent (Pople & Grigg 1998). All harvesting is undertaken in relation to 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 harvest quotas with the intention of ensuring sustainability, it is necessary to obtain reasonably precise and accurate estimates of the sizes of the kangaroo populations proposed to be harvested. Quotas are set as proportions of these population estimates.

In New South Wales (NSW), some or all four of these species, 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 (Anon. 2006). Eight of these kangaroo management zones are located on the western plains. Estimates of the kangaroo populations from within these zones are obtained from broad-scale aerial surveys conducted annually using fixed-wing aircraft and strip transect sampling (Payne 2007). The other five management zones are based along the Great Dividing Range and its western slopes (see Fig. 1). Because of the general relief of the landscape of these management zones, the kangaroo populations there cannot be monitored using fixed-wing aircraft surveys. Hence, alternative methods of estimating kangaroo population densities have had to be considered. Estimates of the kangaroo populations from within 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 five management zones 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. It has now been expanded with the addition of another RLPB district (see Section 2). These RLPB districts no longer exist as administrative/management units. 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 four-year trial period (2004-2007). 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 2007a). The second survey was redesigned in relation to the density distributions of eastern grey kangaroos reported as a result of the first survey.

With this kangaroo management zone now established operationally, a third survey was conducted in early spring 2009. This third survey was redesigned in relation to the density distributions of eastern grey kangaroos reported as a result of the first and second surveys. This report outlines the methods used to conduct the survey and its results.

2. Study Area: the South East NSW Kangaroo Management Zone

In its present configuration, the South East NSW kangaroo management zone (Fig. 1) comprises six Rural Lands Protection Board (RLPB) districts, those of Goulburn, Braidwood, Cooma, Gundagai, Yass and Young. The Goulburn, Braidwood and Cooma RLPB districts make up part of the South Eastern Highlands Biogeographic Region (IBRA) (Sahukar *et al.* 2003). The Gundagai and Yass RLPB districts lie substantially within the South Eastern Highlands Biogeographic Region (IBRA) with their western edges extended into the South Western Slopes Biogeographic Region (IBRA) (Sahukar *et al.* 2003). The Young RLPB district is entirely within the South Western Slopes

Biogeographic Region (IBRA) (Sahukar *et al.* 2003). Further descriptions of the first five of these RLPB districts listed are given in Pople *et al.* (2003). The Goulburn and Yass RLPB districts now comprise part of the Tablelands LHPA district. The 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 suitability of the terrain for aerial survey and potential 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

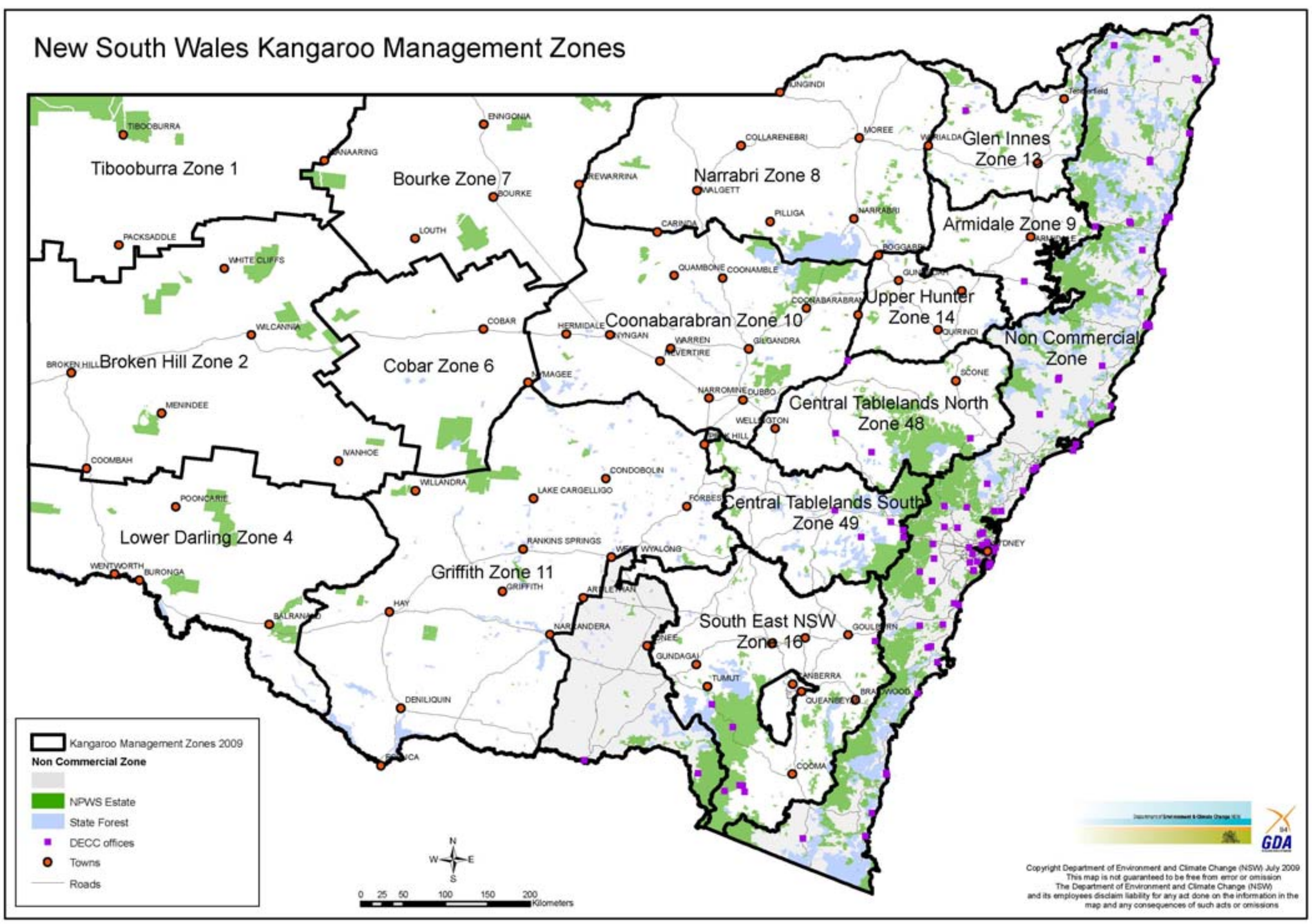

Fig. 1. The 14 kangaroo management zones administered by NSW DECC.

Cairns *et al.* 2008) and the outcome of an initial helicopter kangaroo survey conducted in this kangaroo management zone in August 2003 (Cairns 2003; Pople *et al.* 2006; Cairns *et al*. 2008). High relief areas were excluded from the survey protocol. The estimated total area of the management zone was 51,321 km^2; the estimated total area of the survey strata was 31,429 km^2 (see Table 1).

3. Survey Design

As has been the case with the previous aerial surveys conducted in the South East NSW kangaroo management zone (Cairns 2007a) and those conducted in the Northern Tablelands kangaroo management zones (Cairns 2007b) and the new Hunter and Central Tablelands management zone (Cairns 2009), the surveys reported on here were designed using the automated design capabilities of the most recent version of the DISTANCE software package (Thomas *et al.* 2009); in this case DISTANCE 6.0 Release 2.

To design a survey using DISTANCE, GIS shape files of the survey area are required and the nominal survey effort needs to be determined. The shape files used here were stratified and nominal survey effort was determined in relation to the precision of previously conducted surveys (see below). For each new survey, the boundaries of density strata were redefined in relation to density and survey count information obtained previously. This 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 management zone comprises the whole or part of six RLPB districts which represent a form of stratification; each being surveyed as a separate entity. To increase both the efficiency and the precision of the aerial survey a second level of stratification was applied within each of these six RLPB districts. To do this required GIS shape files for the six RLPB districts. These were obtained from NSW DECCW.

For the design of previous surveys (Cairns 2004, 2007a; Cairns *et al.* 2009), 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 adjust 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 Young 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 Young (Cairns 2004; Pople *et al.* 2006), a major restratification 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, 2007a; Cairns *et al.* 2009), the boundaries of the strata within six RLPB districts were redrafted with the aim of improving the design stratification. The breakdown of the area of the management zone into its constituent strata is given in Table 1. 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 been confirmed for the original five RLPB districts with the previous survey (Cairns 2007a). Excluding national parks, reserves and miscellaneous

Table 1. Areas (km^2) of the six RLPB districts that comprise the South East NSW kangaroo management zone. These areas do not include reserve 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 two strata representing habitat associated with likely medium and low kangaroo densities (adapted from Pople *et al.* 2003, Cairns 2004 and Cairns *et al.* 2009).

RLPB	*Goulburn*	*Braidwood*	*Cooma*	*Gundagai*	*Yass*	*Young*	*TOTAL*
RLPB Area	6,426	8,824	11,375	9,507	6,305	8,884	51,321
High relief outside NPs and SFs	35	261	431	174	146	–	1,047
High density	–	–	6,018	–	–	3,185	9,203
Medium density	4,608	3,987	1,184	5,562	4,518	2,303	22,162
Low density	1,783	301	–	959	1,097	3,396	7,533
Survey area	4,608	3,987	7,272	5,562	4,522	5,488	31,439

areas of high relief, 76% of the combined areas of the six RLPB districts comprised the area available to be surveyed. With the exclusion of the combined low density strata of each RLPB district, the survey area represented 61% of the management zone. For visual representation of the stratification of the zones, see Figs. 3-8.

3.2 Survey Effort

In line transect sampling, survey effort is defined as the total length of transect surveyed. Although ultimately constrained by cost, survey effort is generally determined in relation to some desired level of precision (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; Cairns *et al.* 2008). For the present survey, the allocation of survey effort was made in relation to the determination of population estimates for each of the RLPB districts comprising the management zone.

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

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

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 first five of the RLPB districts listed below three years previously (Cairns 2007a) and from the survey conducted in the Young district last year (Cairns *et al.* 2009). For the Goulburn RLPB district, L_0 = 200 km, $cv_0(\hat{D})$ = 21.9%. For the Braidwood RLPB district, L_0 = 170 km, $cv_0(\hat{D})$ = 18.4%. For the Cooma high density stratum, L_0 = 145 km, $cv_0(\hat{D})$ = 22.0%. For the Cooma medium density stratum, L_0 = 55 km, $cv_0(\hat{D})$ = 45.1%. For the Gundagai RLPB district, L_0 = 285 km, $cv_0(\hat{D})$ = 22.8%. For the Yass RLPB district, L_0 = 160 km, $cv_0(\hat{D})$ = 37.0%. For the Young high density stratum, L_0 = 155 km, $cv_0(\hat{D})$ = 21.5%. For the Young medium density stratum, L_0 = 97 km, $cv_0(\hat{D})$ = 35.0%. The value of L_0 for the Young medium density stratum has been scaled down from the original value in relation to the transfer of 30% of the medium density stratum to the low density stratum. 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 2007a), the total survey effort was increased to 1,155 km. For the present survey, the nominal total effort was increased further to 2,067 km. Much of this increased was directed towards the Cooma, Gundagai and

Table 2. Areas of the proportion of each RLPB district surveyed, the nominal survey effort determined using equation (1) and the actual survey effort applied during the survey. Note that the survey areas of the Cooma and Young RLPB districts comprised high and medium kangaroo density strata. All the other survey areas were classed as medium density strata.

RLPB	Survey area (km^2)	Nominal survey effort (km)	Actual survey effort (km)
Goulburn	4,608	240	232
Braidwood	3,987	150	163
Cooma (high)	6,018	175	174
Cooma (medium)	1,184	175*	177
Gundagai	5,562	370	359
Yass	4,518	550	540
Young (high)	3,185	180	183
Young (medium)	2,303	227	185

*This value was determined in relation to a $cv_t(D)$ of 25% rather than 20%.

Yass RLPB districts. Also, the Young RLPB district has now been included in the management zone.

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. The final design was expected to result in not all this effort being allocated to on-transect flying.

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 grid 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 random 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 grid 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 grid sampling design with split samplers provided the most even coverage of the survey area, a single realisation of that selected design was generated for each survey stratum within each management zone.

For the Goulburn RLPB district, the selected survey design allocated 26 transects with nominal lengths in the range of 5-15 km to the medium density stratum (Fig.3). For the Braidwood RLPB district, the selected survey design allocated 15 transects with nominal lengths in the range of 3-15 km to the medium density stratum (Fig. 4). For the Cooma RLPB district, the survey design allocated 27 transects with nominal lengths in the range of 3-10 km to the medium density stratum and 20 transects with nominal lengths in the range of 3-15 km to the high density stratum (Fig. 5). For the Gundagai RLPB district, the selected survey design allocated 35 transects with nominal lengths in the range of 3-15 km to the medium density stratum (Fig.6). For the Yass RLPB district, the selected survey design allocated 44 transects with nominal lengths in the range of 3-25 km to the medium density stratum (Fig.6). For the Young RLPB district, the survey design allocated 15 transects with nominal lengths in the range of 4-15 km to the medium density stratum and 17 transects with nominal lengths in the range of 4-15 km to the high density stratum (Fig. 7). 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 six RLPB districts comprising the South East NSW kangaroo management zone was conducted as a helicopter survey during the period 6-16 September, 2009. The survey was conducted in accordance with the survey plan devised 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) was used. In the original design for this survey, there was a total of 199 transects to be flown across the three proposed management zones. All of these transects were flown in this survey. .

All surveys were conducted within either the two to three-hour period following sunrise or the two to three-hour period before sunset. David Bearup and Peter Morris were the observers. Both personnel are trained and experienced observers. The helicopter was chartered from EPS Helicopters, Yagoona NSW. Paul Caristo and

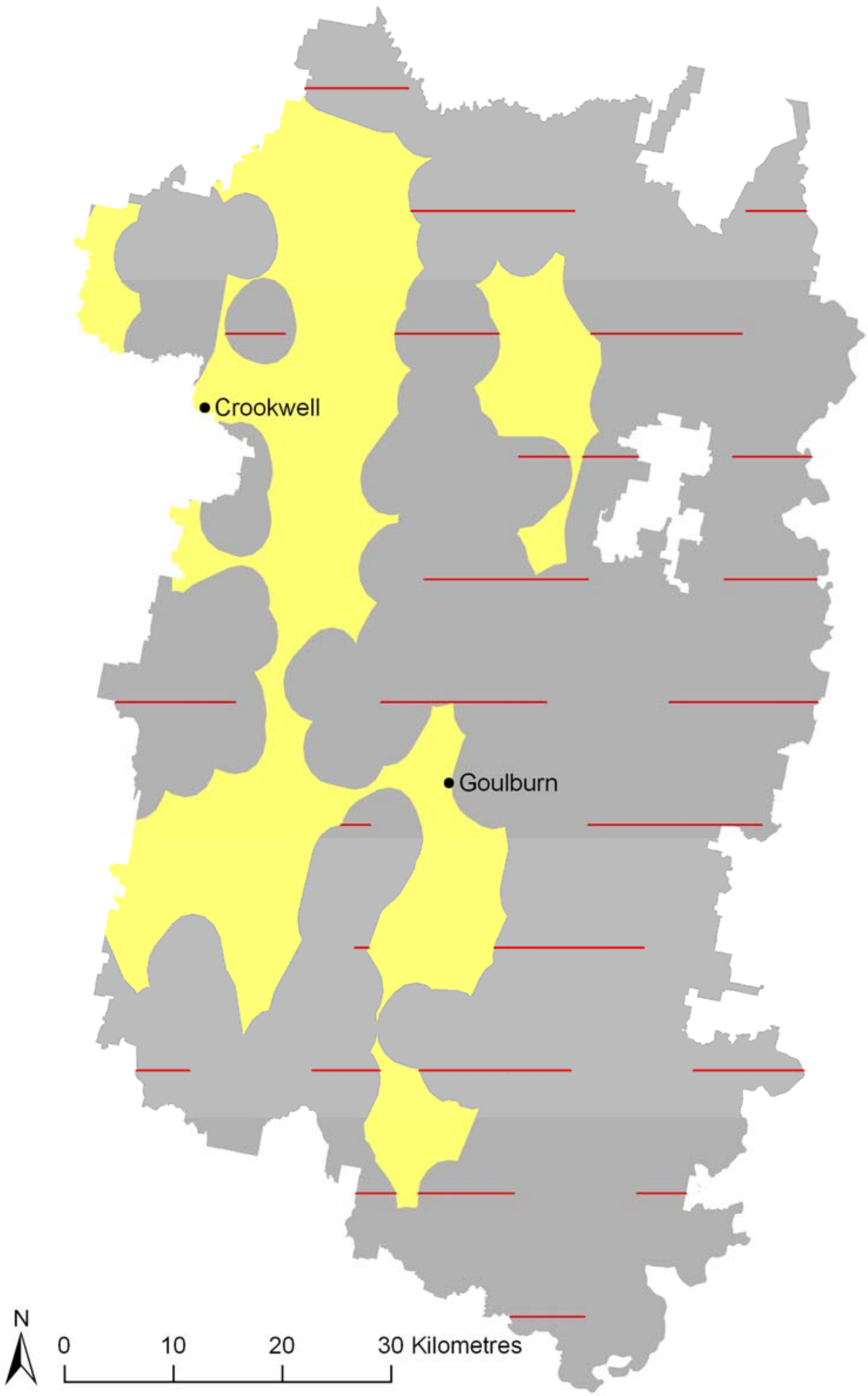

Fig. 3. The Goulburn RLPB district section of the South East NSW kangaroo management zone. Shown are the two survey strata, the population centres (towns) and the placement of the survey transects within the medium (grey) kangaroo density strata. Note that no survey transects were placed into the low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

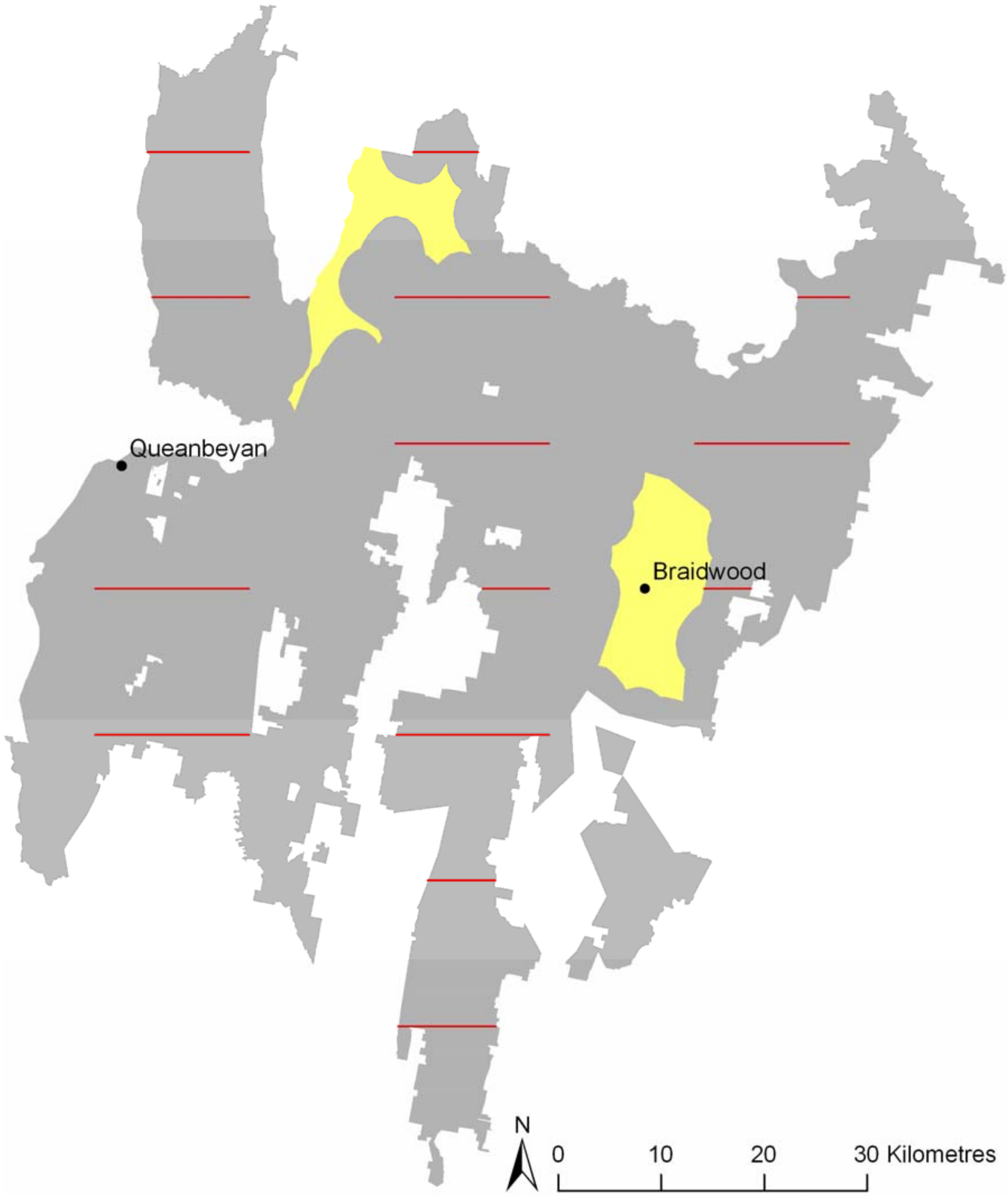

Fig. 4. The Braidwood RLPB district section of the South East NSW kangaroo management zone. Shown are the two survey strata, the population centres (towns) and the placement of the survey transects within the medium (grey) kangaroo density strata. Note that no survey transects were placed into the low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

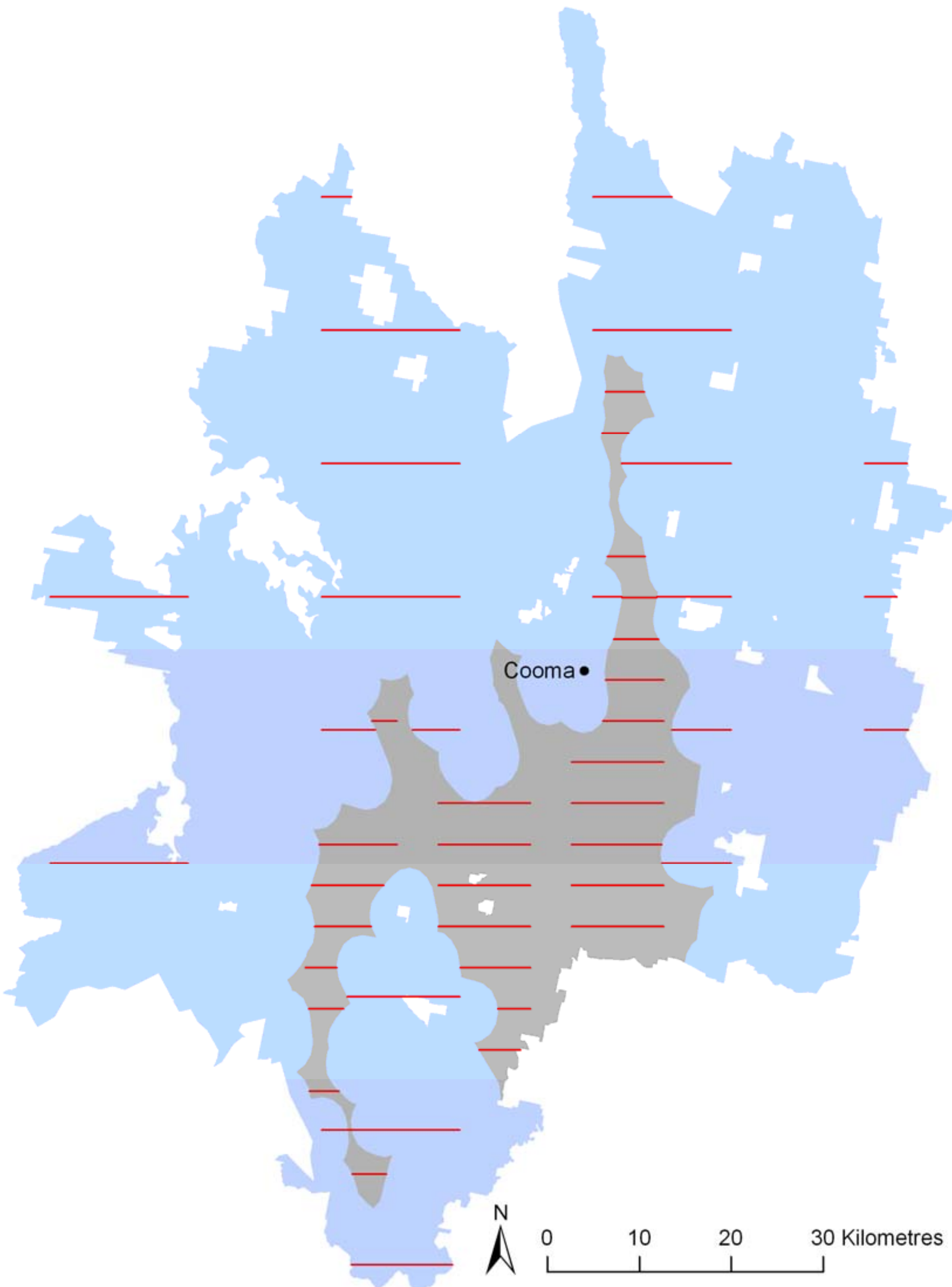

Fig. 5. The Cooma RLPB district section of the South East NSW kangaroo management zone. Shown are the three survey strata, the population centres (towns) and the placement of the survey transects within the high (blue) and medium (grey) kangaroo density strata. Note that there is no low density stratum in this district.

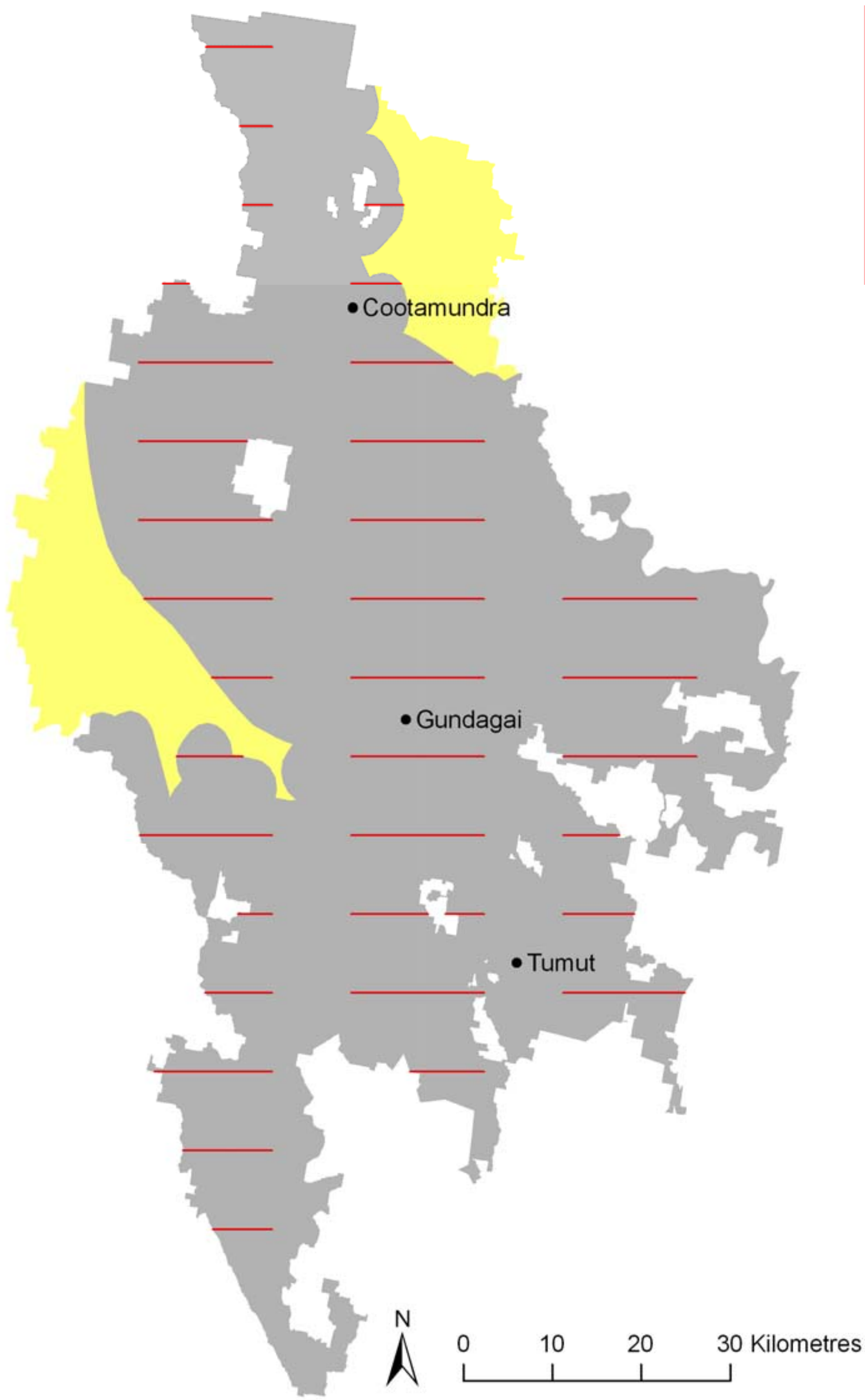

Fig. 6. The Gundagai RLPB district section of the South East NSW kangaroo management zone. Shown are the two survey strata, the population centres (towns) and the placement of the survey transects within the medium (grey) kangaroo density strata. Note that no survey transects were placed into the low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

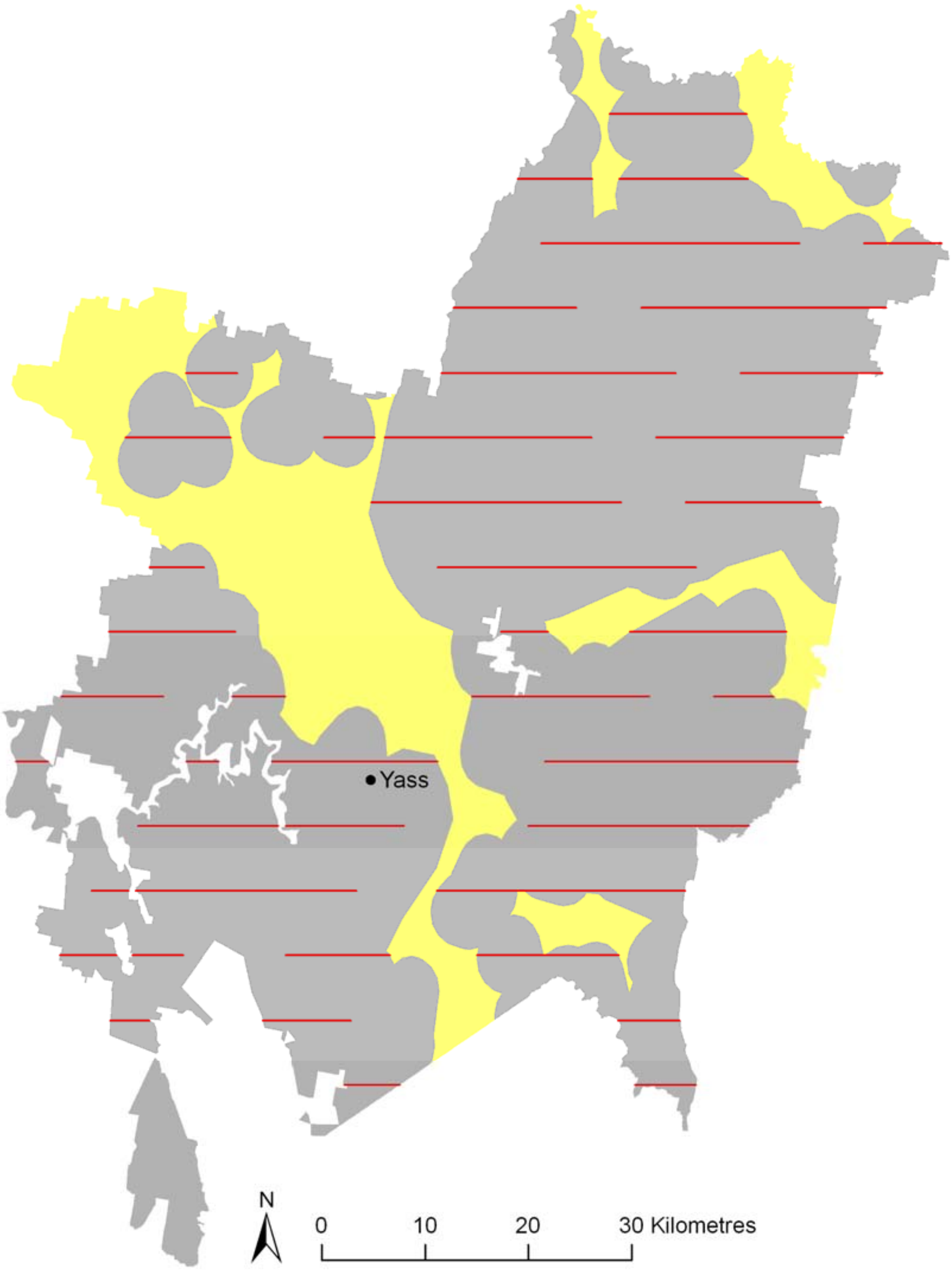

Fig. 7. The Yass RLPB district section of the South East NSW kangaroo management zone. Shown are the two survey strata, the population centres (towns) and the placement of the survey transects within the medium (grey) kangaroo density strata. Note that no survey transects were placed into the low density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

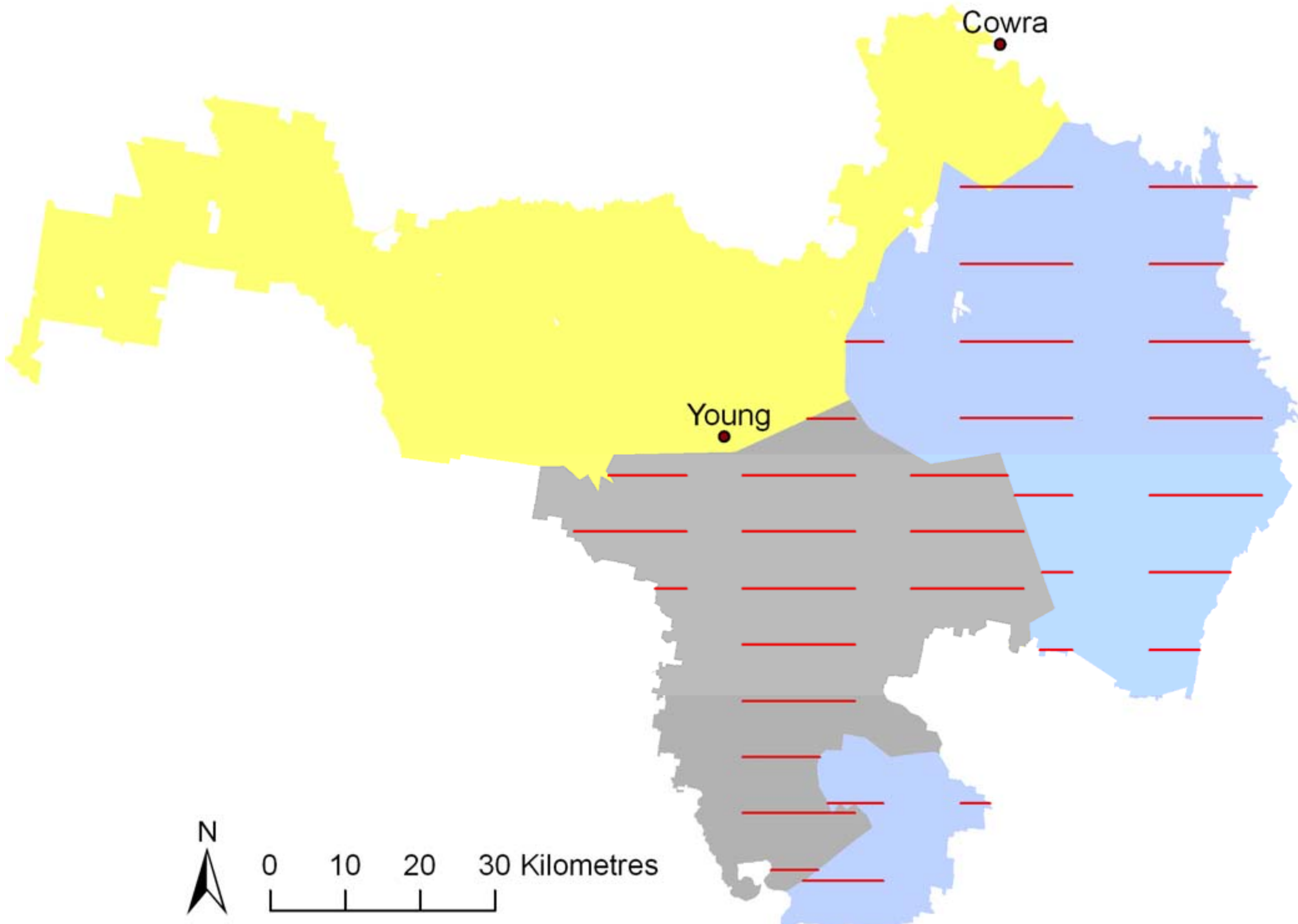

Fig. 8. The Young RLPB district section of the South East NSW kangaroo management zone. Shown are the three survey strata, the population centres (towns) and the placement of the survey transects within the high (blue) and medium (grey) kangaroo density strata. Note that no survey transects were placed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

Jo Murphy were the pilots. The seating of the observers (left or right-hand side) was allocated randomly for each survey session.

4.1 Helicopter Line Transect Surveys

In conducting the survey, the helicopter, a Bell JetRanger, 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©). The two 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, common wallaroos *M. robustus*), red-necked wallabies (*M. rufogriseus*) and swamp wallabies (*Wallabia bicolor*) seen in the different delineated distance classes from the helicopter were recorded into micro-cassette tape recorders. The presence of other, non-target species was noted. Tapes were transcribed at the end of each survey session. The survey transects varied in nominal length from 3-25 km. No rest breaks were taken by the observers on any transect during the survey sessions. Hence, for the purpose of data analysis, the exact transect lengths were equal to the nominal survey lengths of the original survey designs (see Table 3).

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 & Burnham 2004). Survey results were recorded as the sightings of clusters of kangaroos and their perpendicular distances from the survey platform. In order to estimate the probability (P_a) that a cluster of animals within the covered area of width w (the survey strip) is detected, the detection function $g(x)$ representing the probability that a cluster at perpendicular distance x from the survey transect is detected (where $0 \leq x \leq w$ and $g(0) = 1$) needs to be modelled and evaluated at $x = 0$ (Thomas *et al.* 2002). To do this, the data from the helicopter line transect surveys were analysed using DISTANCE 6.0 (Thomas *et al.* 2009a, b).

DISTANCE 6.0 has three different analysis engines for estimating the detection function (Thomas *et al.* 2009a). Two of these, the conventional distance sampling (CDS) analysis engine and the multiple-covariate distance sampling (MCDS) analysis engine were 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 both the CDS and MCDS analysis engines were compared serially in order to determine the most parsimonious detection function model and hence the most likely estimates of population density and abundance. The model with the lowest value for a penalised log-likelihood in the form of Akaike's Information Criterion ($AIC = -2 \times log\text{-}likelihood + 2[p + 1]$; 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 for this purpose.

Following the recommendations of Buckland *et al.* (2001), six detection function models were considered in the analyses using the CDS analysis engine. Each model comprised a key function that, if required, can be adjusted by a cosine or polynomial series expansion containing one or more parameters. The different models considered were: a 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 adjustment terms. As part of the analysis process using the CDS analysis engine, 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 nominal survey strip.

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.* 2009a). These covariates can be either factor (qualitative or categorical) or non-factor (continuous) and have effect of altering the scale but not the shape of the detection function. The covariates affect the rate at which detectability decreases with distance from the transect line, but not the overall shape of the detection curve (Thomas *et al.* 2009b). Covariates used in these analyses were related to individual detections of clusters of kangaroos and were identified as observer and survey aspect (both categorical), and cluster size (continuous). These were included in the analyses separately and in pairs, with cluster size being paired with either observer or survey aspect. Because they were to degree correlated, the two categorical covariates were not included in the same model. Only two key functions are available with the MCDS analysis engine: the Half-normal and the Hazard-rate functions. The Cosine, Simple Polynomial and Hermite Polynomial series expansions were available be used in relation to these two key functions.

The density estimates of clusters of kangaroos ($\hat{D}_s$) were determined as:

$$\hat{D}_s = \frac{n.f(0)}{2L} = \frac{n}{2wL\hat{P}_a} \qquad (1)$$

where, n is the number of sightings, $f(0)$ is the probability density function (the detection function rescaled to integrate to unity) of the perpendicular density data at zero distance from the survey transect, *L* is the total length of the survey transect, *w* is the truncation point (or half width of the survey strip) and is the probability that a randomly selected object (in this case a cluster of kangaroos) in the survey strip is detected (Buckland *et al.* 2001). The area surveyed is 2wL.

If the observed sizes of detected clusters are independent of distance from the survey line (i.e. if *g(x)* does not depend upon *s*), then the estimation of the density of individuals ( ) is simply determined as:

$$\hat{D} = \hat{D}_s x \bar{s} \qquad (2)$$

where, the sample mean ‾ is taken as an unbiased estimator of the mean size (*E(s)*) of the *n* clusters in the study area. If the observed sizes of detected clusters are dependent upon distance from the survey line, then, in analyses undertaken using the CDS analysis engine, $\bar{s}$ and $cv(\bar{s})$ are replaced by regression estimators designated as $\hat{E}(s)$ and $cv(\hat{E}(s))$ (Buckland *et al.* 2001). In analyses undertaken using the MCDS analysis engine, $\hat{E}(s)$ is determined as the ratio of the estimates of the density of individuals and density of clusters.

Variance estimates for the cluster densities were determined empirically as:

$$var(\hat{D}_s) = \hat{D}_s^2\{[CV(n)]^2 + [CV\{f(0)\}]^2\} \qquad (3)$$

where, *CV(n)* is the coefficient of variation for the number of sightings across the replicate survey lines and *C{(f(0)}* is the coefficient of variation of the probability density function of the perpendicular density data at zero distance (Buckland *et al.* 2001). Variance of the population density estimates were determined as:

$$var(\hat{D}) = \hat{D}_s^2\{[CV(n)]^2 + [CV\{f(0)\}]^2 + [cv(\bar{s})]^2\} \qquad (4)$$

where, $cv(\bar{s})$ is the coefficient of variation of $\bar{s}$, an unbiased estimator of the mean size (*E(s)*) of the *n* clusters in the study area. Recall that if the sizes of detected clusters are dependent upon distance from the line, then $\bar{s}$ and $cv(\bar{s})$ are replaced by regression estimators designated as $E(s)$ and $cv(E(s))$ (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. This is expected to improve the robustness of the estimation of these statistics (Buckland *et al.* 2001). In most instances, the 95% confidence limits presented were the 2.5% and 97.5% quantiles of the respective bootstrap estimates.

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 (Southwell & Weaver 1993). The data were analysed to produce separate density and population estimates for the high and medium kangaroo density strata of each RLPB district, for the whole of each RLPB district, with density being determined across all strata, and for the whole of the South East NSW kangaroo management zone.

5. Results and Discussion

Five of six RLPB districts were subdivided into two strata based on land capability and prior knowledge of eastern grey kangaroo densities (see Section 3.1). The sixth district, Young, was subdivided into three strata. Only those strata identified as supporting medium and high kangaroo densities were surveyed. The numbers of sightings of the four species of macropods found in the six RLPB districts are given in Table 3 in relation to survey stratum and transect. The total survey efforts flown in the strata surveyed within each RLPB district are given in Table 2.

The Goulburn RLPB district was divided into a low density and a medium density stratum (Fig. 3). Twenty-six transects were flown in the medium density stratum on which 93 sightings of clusters of kangaroos were made. These sightings comprised

Table 3. 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 six RLPB districts comprising the South East NSW kangaroo management zone. The transect lengths given are the actual lengths and are each identified in relation to the survey stratum to which they belong within a RLPB districts by the second letter of their identification code (M = medium, H = high).

	Length	No. of	***Raw counts***			
Transect	*(km)*	sightings	*EGK*	*CW*	*RNW*	*SW*
Goulburn						
GbM01	9.5	15	27	2	–	–
GbM02	15.0	1	1	–	–	–
GbM03	5.5	–	–	–	–	–
GbM04	5.4	1	2	–	–	–
GbM05	9.6	5	14	–	–	–
GbM06	13.8	4	18	–	–	–
GbM07	4.6	–	–	–	–	–
GbM08	5.1	5	14	–	–	–
GbM09	7.2	2	2	–	–	–
GbM10	15.0	19	55	1	–	1
GbM11	8.5	8	62	–	–	–
GbM12	11.0	6	11	–	4	–
GbM13	15.2	1	4	–	–	–
GbM14	13.6	4	5	–	–	1
GbM15	2.7	–	–	–	–	–
GbM16	16.0	2	2	–	–	1
GbM17	1.3	–	–	–	–	–
GbM18	13.7	2	2	–	–	–
GbM19	4.9	6	19	–	–	–
GbM20	6.2	–	–	–	–	–
GbM21	13.9	3	8	–	2	–
GbM22	10.1	–	–	–	–	–
GbM23	3.7	–	–	–	–	–
GbM24	8.8	6	48	–	2	–
GbM25	4.5	–	–	–	–	–
GbM26	6.8	3	3	–	–	–

Transect	Length (km)	No. of sightings	***Raw counts*** *EGK*	*CW*	*RNW*	*SW*
Braidwood						
BM01	9.9	19	81	–	–	–
BM02	6.3	1	–	–	4	–
BM03	9.5	27	106	–	–	–
BM04	15.0	12	36	–	1	–
BM05	5.0	3	3	–	1	–
BM06	15.0	4	19	–	–	–
BM07	15.0	13	32	–	1	1
BM08	15.0	2	5	–	–	–
BM09	15.0	3	5	–	–	–
BM10	6.5	11	53	–	4	–
BM11	4.6	2	11	–	–	–
BM12	15.0	5	11	–	–	–
BM13	14.9	14	42	–	2	–
BM14	6.6	3	10	–	–	–
BM15	9.5	14	35	–	3	–
Cooma						
CM01	4.2	2	4	–	–	–
CM02	2.9	3	11	–	–	–
CM03	4.1	–	–	–	–	–
CM04	3.8	–	–	–	–	–
CM05	4.9	–	–	–	–	–
CM06	6.3	2	10	–	–	–
CM07	2.8	3	17	–	–	–
CM08	6.6	3	13	–	–	–
CM09	10.0	2	4	–	–	–
CM10	10.0	15	91	–	–	–
CM11	10.0	13	46	–	–	–
CM12	8.5	–	–	–	–	–
CM13	10.0	3	11	–	–	–
CM14	9.8	12	95	–	–	–

Transect	Length (km)	No. of sightings	Raw counts			
			EGK	*CW*	*RNW*	*SW*
CM15	7.9	8	25	–	–	–
CM16	10.0	11	52	–	–	–
CM17	10.0	20	96	–	–	–
CM18	6.1	4	8	–	–	–
CM19	10.0	3	9	–	–	–
CM20	10.0	13	58	–	–	–
CM21	3.4	–	–	–	–	–
CM22	7.6	10	105	–	–	–
CM23	3.8	2	15	–	–	–
CM25	4.5	–	–	–	–	–
CM26	3.2	–	–	–	–	–
CM27	3.8	–	–	–	–	–
CH01	3.3	13	34	–	–	–
CH02	8.6	1	10	–	–	–
CH03	15.0	20	59	–	–	–
CH04	15.0	1	2	–	–	–
CH05	15.0	12	50	–	–	–
CH06	11.9	2	8	–	–	–
CH07	4.6	3	5	–	–	–
CH08	15.0	18	51	1	2	–
CH09	3.1	3	44	–	–	–
CH10	8.1	7	46	–	–	–
CH11	3.5	6	26	–	–	–
CH12	5.9	3	6	1	–	–
CH13	6.5	–	–	–	–	–
CH14	5.2	–	–	–	–	–
CH15	4.8	14	45	–	–	1
CH16	5.3	1	1	–	–	–
CH17	7.5	15	132	–	–	–
CH18	10.0	5	53	–	–	–
CH19	15.0	3	15	–	–	–

Transect	Length (km)	No. of sightings	Raw counts			
			EGK	*CW*	*RNW*	*SW*
CH20	11.0	6	11	–	–	–
Gundagai						
GuM01	7.4	–	–	–	–	–
GuM02	3.6	–	–	–	–	–
GuM03	3.3	–	–	–	–	–
GuM04	4.3	–	–	–	–	–
GuM05	3.0	2	6	–	–	–
GuM06	5.6	–	–	–	–	–
GuM07	15.0	3	5	–	–	1
GuM08	5.1	–	–	–	–	–
GuM09	12.2	4	6	–	–	–
GuM10	15.0	1	5	–	–	–
GuM11	15.0	1	2	–	–	–
GuM12	15.0	–	–	–	–	–
GuM13	14.4	–	–	–	–	–
GuM14	15.0	2	5	–	–	–
GuM15	15.0	1	7	–	–	–
GuM16	6.8	–	–	–	–	–
GuM17	15.0	3	25	–	–	–
GuM18	15.0	–	–	–	–	–
GuM19	7.4	4	13	–	–	–
GuM20	15.0	6	20	–	–	–
GuM21	15.0	9	23	–	–	–
GuM22	14.9	6	21	–	–	–
GuM23	15.0	20	49	–	–	1
GuM24	6.4	–	–	–	–	–
GuM25	3.8	15	41	–	–	–
GuM26	8.7	1	2	–	–	–
GuM27	4.3	4	8	–	–	2
GuM28	8.0	3	5	–	–	–

Transect	Length (km)	No. of sightings	***Raw counts***			
			EGK	*CW*	*RNW*	*SW*
GuM29	7.6	13	26	–	–	–
GuM30	15.0	6	8	–	–	1
GuM31	13.7	2	3	–	–	–
GuM32	13.2	8	16	–	–	–
GuM33	8.4	7	9	–	–	–
GuM34	10.0	10	25	–	–	–
GuM35	6.6	6	13	–	–	–
Yass						
YM01	13.3	20	53	3	–	3
YM02	7.2	4	4	–	–	2
YM03	12.5	4	11	–	–	–
YM04	25.0	8	2	–	1	1
YM05	7.5	–	–	–	–	–
YM06	11.9	11	17	–	1	1
YM07	23.7	4	6	1	–	–
YM08	5.0	1	6	–	–	–
YM09	22.7	8	38	–	–	–
YM10	13.8	2	4	–	–	–
YM11	10.2	–	–	–	–	–
YM12	4.9	5	20	–	–	–
YM13	20.1	36	65	1	3	3
YM14	18.1	14	39	–	–	1
YM15	24.2	5	11	–	–	–
YM16	13.1	8	20	–	–	–
YM17	5.3	2	4	–	–	–
YM18	25.0	3	3	3	–	–
YM19	12.3	–	–	–	–	–
YM20	4.6	1	4	–	–	–
YM21	15.2	22	147	–	–	–
YM22	9.9	3	18	–	–	–
YM23	5.1	3	5	–	–	–

Transect	Length (km)	No. of sightings	*Raw counts*			
			EGK	*CW*	*RNW*	*SW*
YM24	17.2	9	29	–	2	1
YM25	5.8	1	2	–	–	–
YM26	3.1	2	5	–	–	–
YM27	3.1	2	6	–	–	1
YM28	16.1	6	49	–	–	–
YM29	24.5	40	150	–	–	–
YM30	13.6	2	3	–	–	–
YM31	11.4	10	28	–	–	–
YM32	21.4	20	161	–	–	–
YM33	3.6	4	13	–	–	1
YM34	21.4	23	83	–	–	1
YM35	24.1	20	107	–	–	–
YM36	5.5	4	10	–	–	–
YM37	5.0	6	8	1	–	1
YM38	10.1	4	10	–	–	–
YM39	13.7	6	50	–	–	–
YM40	3.8	3	–	–	–	3
YM41	8.5	3	5	–	1	–
YM42	6.0	14	117	–	–	–
YM43	5.4	3	4	–	–	–
YM44	5.9	7	29	–	–	–
Young						
YoM01	6.3	–	–	–	–	–
YoM02	10.4	–	–	–	–	–
YoM03	15.0	6	9	–	–	–
YoM04	12.9	4	6	–	–	–
YoM05	15.0	1	4	–	–	–
YoM06	15.0	2	5	–	–	–
YoM07	15.0	3	8	–	–	–
YoM08	4.1	–	–	–	–	–
YoM09	15.0	3	5	–	–	–

Transect	Length (km)	No. of sightings	*Raw counts*			
			EGK	*CW*	*RNW*	*SW*
YoM10	15.0	2	2	–	–	–
YoM11	15.0	2	9	–	–	–
YoM12	15.0	2	12	–	–	–
YoM13	10.3	3	9	–	–	–
YoM14	15.0	3	5	–	–	1
YoM15	6.3	3	3	–	–	–
YoH01	15.0	–	–	–	–	–
YoH02	14.3	26	65	1	–	2
YoH03	15.0	16	68	–	–	2
YoH04	9.9	9	41	–	–	1
YoH05	15.0	14	49	–	–	–
YoH06	13.3	17	66	–	–	1
YoH07	15.0	3	2	2	–	–
YoH08	15.0	23	43	9	–	3
YoH09	7.7	–	–	–	–	–
YoH10	15.0	3	4	–	–	–
YoH11	4.1	–	–	–	–	–
YoH12	10.8	18	54	–	–	2
YoH13	4.4	16	54	–	–	2
YoH14	6.7	7	8	1	–	–
YoH15	7.4	15	34	–	–	–
YoH16	4.0	4	15	–	–	–
YoH17	10.7	8	41	–	–	–

297 eastern grey kangaroos, three common wallaroos, eight red-necked wallabies and three swamp wallabies.

The Braidwood RLPB district was also divided into a low density and a medium density stratum (Fig. 4). Fifteen transects were flown in the medium density stratum on which 133 sightings of clusters of kangaroos were made. These sightings comprised 429 eastern grey kangaroos, 16 red-necked wallabies and one swamp wallaby. No common wallaroos were sighted in this stratum.

The Cooma RLPB district was divided into a medium density and a high density stratum (Fig. 5), which meant that all of this district was surveyed. Twenty-seven transects were flown in the medium density stratum on which 126 sightings of clusters of kangaroos were made. These sightings comprised 670 eastern grey kangaroos. No common wallaroos, red-necked wallabies or swamp wallabies were sighted in this stratum. Twenty transects were flown in the high density stratum on which 167 sightings of clusters of kangaroos were made. These sightings comprised 598 eastern grey kangaroos, two common wallaroos, two red-necked wallabies and one swamp wallaby.

The Gundagai RLPB district was divided into a low density and a medium density stratum (Fig. 6). Thirty-five transects were flown in the medium density stratum on which 130 sightings of clusters of kangaroos were made. These sightings comprised 364 eastern grey kangaroos and five swamp wallabies. No common wallaroos or red-necked wallabies were sighted.

The Yass RLPB district was also divided into a low density and a medium density stratum (Fig. 7). Forty-four transects were flown in the medium density stratum on which 194 sightings of clusters of kangaroos were made. These sightings comprised 456 eastern grey kangaroos, nine common wallaroos, eight red-necked wallabies and 18 swamp wallabies.

The Young RLPB district was divided into a low, medium and high density stratum (Fig. 8). Fifteen transects were flown in the medium density stratum on which 34 sightings were made of clusters of kangaroos. These sightings comprised 670 eastern grey kangaroos. No common wallaroos, red-necked wallabies or swamp wallabies were sighted in this stratum. Seventeen transects were flown in the high density stratum on which 167 sightings of clusters of kangaroos were made. These sightings comprised 598 eastern grey kangaroos, two common wallaroos, two red-necked wallabies and one swamp wallaby.

Eastern grey kangaroo density and abundance estimates were determined separately for each RLPB district. These estimates were combined to provide density and abundance estimates for the whole South East NSW kangaroo management zone. Because of a general paucity of data, 13 sightings overall of common wallaroos, 16 of red-necked wallabies and 29 of swamp wallabies, no attempts were made at determining density and abundance estimates for these three species, for which there are, at present, no commercial quotas set anyway. Hence, discussion from this point onwards will be concerned only with eastern grey kangaroos.

In determining the eastern grey kangaroo density and abundance estimates for each RLPB district, a number of different approaches were adopted; all from within a generally well understood analysis framework for distance sampling data as presented in Buckland *et al.* (2001). In general, the data were analysed separately for the high and medium kangaroo density strata and the results combined to provide first RLPB district estimates.

The CDS and MCDS analysis engines of DISTANCE 6.0 (Thomas *et al.* 2010) were used to analyse the survey results. The analysis engines found to produce the most parsimonious detection function models for eastern grey kangaroos are given in Table 4. Given also are the specific models and the probability that a randomly selected cluster of kangaroos in the survey strip will be detected (P_a). In each instance, the most parsimonious model was selected principally on the basis of it being the model that yielded the smallest value of the AIC statistic (see Section 4.2). In the medium density strata of the Goulburn, Braidwood and Yass RLPB districts, the MCDS analysis engine produced the most parsimonious models of the detection function, each with a Half-normal key function and, except for Braidwood, a Cosine series expansion. Each of the three models also included the non-factor covariate of cluster size and the factor covariate of observer.

Table 4. The survey effort, number of sightings of clusters of eastern grey kangaroos (n), Distance analysis engine used for each analysis, detection function model and the probability that a randomly selected cluster of kangaroos in the survey strip is detected (P_a). Where the conventional distance sampling analysis engine (CDS) was used, post-stratification on the basis of either observer (DB and PM) or survey aspect (N and S) was used to determine the most parsimonious detection function model. Where the multiple-covariate distance sampling engine (MCDS) was used, cluster size and observer were incorporated into the detection function model as covariates.

RLPB District	Effort	n	Analysis engine	Model	Covariates	P_a
Goulburn	231.6	86	MCDS	Half-normal/Cosine	cluster + observer	0.29
Braidwood	162.8	120	MCDS	Half-normal	cluster + observer	0.36
Cooma						
High	174.3		CDS	Post-stratification by observer		
		76		Half-normal/Hermite (DB)	–	0.36
		53		Hazard-rate/Cosine (PM)	–	0.22
Medium	177.8		CDS	Post-stratification by observer		
		79		Half-normal/Cosine (DB)	–	0.51
		54		Uniform/Cosine (PM)	–	0.50
Gundagai	358.7		CDS	Post-stratification by aspect		
		60		Half-normal/Cosine (N)	–	0.49
		69		Hazard-rate/Cosine (S)	–	0.21
Yass	539.8	316	MCDS	Half-normal/Cosine	cluster + observer	0.34
Young						
High	183.3		CDS	Post-stratification by aspect		
		75		Hazard-rate/Cosine (N)	–	0.31
		53		Half-normal/Cosine (S)	–	0.36
Medium	185.3	32	CDS	Half-normal/Cosine*	–	0.41

*This model is a global model determined using all data pooled across both the high and medium density strata of the Young RLPB district.

These three multiple-covariate models were compared with alternatives derived using the CDS analysis engine; with the size of the difference in AIC values indicating the extent of the closeness in outcomes. Generally, if the difference in AIC values

(ΔAIC) is >2, then the models are considered not to be at all close in determination (Burnham and Anderson 2002). In the case of the Goulburn RLPB district, based upon this criterion, a possible alternative to the multiple-covariate model obtained using the CDS analysis engine could have been one post-stratified in relation to observer that resulted in the derivation of two separate Half-normal/Cosine detection function models (ΔAIC = 0.83). For the Braidwood data, the nearest alternative model produced using the CDS analysis engine to the multiple-covariate model was also one based upon post-stratification in relation to observer. However, the multiple-covariate model was far superior to this post-stratification model (ΔAIC = 6.06). This was also the case with the analysis of the Yass data, where the multiple-covariate model was far superior to the post-stratification model (ΔAIC = 10.97). Hence, for two of these three instances, using the MCDS analysis engine proved far superior to using the CDS analysis engine. In the third instance, the result was somewhat equivocal. The forms of the detection functions derived using the MCDS analysis engine are given separately for each of the two observers (averaged over cluster size) in Figs. A1.1, A1.2 and A1.6, respectively, of Appendix 1.

The CDS analysis engine produced the most parsimonious detection function models for two strata surveyed in the Cooma RLPB district, the single stratum surveyed in the Gundagai RLPD district and the two strata surveyed in the Young RLPB district. For both the high and medium density strata of the Cooma district, the most parsimonious detection function models were models based upon post-stratification in relation to observer (Table 4). In both instances, these post-stratification models proved to be superior to the multiple-covariate alternatives (high: ΔAIC = 2.09; medium: ΔAIC = 3.22). For the medium density stratum of the Gundagai district, the most parsimonious detection function models were models based upon post-stratification in relation to survey aspect (Table 4). These post-stratification models proved to be superior to the multiple-covariate alternative (ΔAIC = 6.58). For the high density stratum of the Young district, the most parsimonious detection function models were also models based upon post-stratification in relation to survey aspect (Table 4). These post-stratification models proved to be superior to the multiple-covariate alternative (ΔAIC = 6.50). For the medium density stratum of the Young district, the single most parsimonious detection function model was a model derived using data pooled across the high and medium density strata. No multiple-covariate alternative was compared to this model. The forms of the detection functions derived using the CDS analysis engine are given separately for each post-stratification, where appropriate, in Figs. A1.3, A1.4, A1.5, A1.7 and A1.8, respectively, of Appendix 1.

The probability that a randomly selected cluster of kangaroos in the survey strip will be detected (P_a) showed substantial variation across survey strata, ranging from 0.21 to 0.51 (Table 4). Although this variation is thought to reflect the extent of variation in the general sightability of eastern grey kangaroos in relation to the differing landscapes comprising the constituent parts of the South East NSW kangaroo management zone, it almost certainly also reflects the influence of weather conditions and light on sightability. The observers reported that a number of the surveys were conducted under somewhat overcast conditions. This outcome was consistent with those of the two previous surveys that have been conducted in this kangaroo management zone (Cairns 2004, 2007a); although the stratifications used were different.

The results of the analyses in terms of the density of clusters (D_s) of eastern grey kangaroos and population density (D) are given in Table 5. These density estimates were determined for the medium density strata of all six RLPB districts, plus the high density strata of the Cooma and Young districts. As would be expected, cluster density is strongly correlated with population density (r_{10} = 0.79; P <0.001) across the constituent parts of the survey. 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 for the whole of each RLPB district (including all strata) 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). In most

Table 5. Survey stratum area, form of post-stratification used with CDS analysis engine (observer: DB and PM; survey aspect: N and S), density of clusters of eastern grey kangaroos sighted (D_s) and kangaroo population density (D). Given also are the coefficients of variation and confidence intervals associated with these two density statistics.

			Cluster density (km^{-2})				Kangaroo density (km^{-2})			
RLPB District	Area (km^2)	Post-stratification	D_s	CV (%)	95% bootstrap confidence interval	CV_{boot} (%)	D	CV (%)	95% bootstrap confidence interval	CV_{boot} (%)
Goulburn	4,608	–	4.23	–	2.63 – 6.08	22.8	15.59	–	8.84 – 22.50	25.6
Braidwood	3,987	–	6.90	–	4.17 – 11.55	25.1	19.76	–	12.06 – 33.98	27.5
Cooma										
High	6,018	DB	3.99	23.3	2.69 – 28.15	92.8	20.91	25.3	10.28 – 144.33	95.7
		PM	4.59	32.0	2.51 – 17.22	49.5	16.18	33.8	5.57 – 56.13	71.5
Medium	1,184	DB	2.91	20.1	1.74 – 5.43	41.1	18.25	22.5	7.49 – 36.29	62.3
		PM	2.02	29.7	1.06 – 4.04	31.5	6.75	30.8	3.35 – 13.21	41.7
Gundagai	5,562	N	1.41	28.5	0.63 – 2.66	106.0	4.05	29.6	1.69 – 7.38	106.0
		S	3.06	28.3	1.73 – 5.09	45.1	8.38	29.9	4.17 – 16.02	41.1
Yass	4,518	–	5.79	–	4.14 – 7.57	18.6	22.17	–	15.40 – 30.80	18.9
Young										
High	3,185	N	4.42	38.0	2.29 – 7.19	31.0	8.75	39.0	4.75 – 18.85	38.4
		S	4.16	22.9	2.42 – 5.58	24.1	15.04	24.4	7.26 – 19.57	29.7
Medium	2,303	–	1.41	19.0	1.03 – 3.51	67.8	3.18	23.1	2.18 – 8.65	60.0

Table 6. The areas of the survey strata in the six RLPB districts, eastern grey kangaroo densities (D) and abundances (N).

RLPB District	Area (km^2)	D (km^{-2})	95% bootstrap confidence interval	N	95% bootstrap confidence interval
Goulburn	4,608	15.59	8.84 – 22.50	71,826	40,749 – 103,690
Braidwood	3,987	19.76	12.06 – 33.98	78,795	48,088 – 135,490
Cooma					
High	6,018	37.08	26.19 – 188.48	223,210	157,600 – 1,134,200
Medium	1,184	25.00	13.46 – 44.80	29,598	15,940 – 53,039
Pooled		35.10		252,808	
Gundagai	5,562	12.43	7.71 – 23.89	69,134	42,876 – 132,870
Yass	4,518	22.17	15.40 – 30.80	100,260	69,625 – 139,430
Young					
High	3,185	23.79	14.09 – 33.08	75,761	44,866 – 105,360
Medium	2,303	3.18	2.18 – 8.65	7,320	5,016 – 19,916
Pooled		15.14		83,081	

instances, the adjustments were minor; the exception being the Young RLPB district where the area of the medium kangaroo density stratum was reduced by about one-third; the excised portion being reallocated to the low density stratum. These adjustments would not have created any problems from the point of view of being able to compare the results of the current survey with the results of the one conducted in 2006 (Cairns 2007a). 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 656,504 (Table 7). Some 83,081 of these kangaroos were to be found in the Young RLPB district that has now incorporated into the zone. Subtracting this number from the zone total resulted in there being an estimated 573,423 eastern grey kangaroos in the five RLPB districts that comprised the management zone before the addition of the Young RLPB district to its total area. This

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

RLPB District	Area (km^2)	N	D (km^{-2})
Goulburn	6,028	71,826	11.92
Braidwood	4,284	78,795	18.39
Cooma	7,271	252,808	34.77
Gundagai	6,342	69,134	10.90
Yass	5,615	100,260	17.86
Young	8,884	83,081	9.35
SE NSW zone	38,424	656,504	17.09

number can be compared to the 415,271 eastern grey kangaroos estimated to be in this area at the time of the previous survey conducted in 2006 (Table A2.1; Cairns 2007a).

In terms of density, the population has increased from 14.07 km^{-2} eastern grey kangaroos to 19.43 km^{-2} between the 2006 and 2009 surveys; representing an increase of 38% over the past three years. This represents an annual exponential rate of increase of 11% for the period between last two successive surveys.

An assessment of numbers within the individual RLPB districts is more revealing with regard to the change in eastern grey kangaroo population within the management zone. The population estimates from the 2006 survey (Cairns 2007a) are given in Table A2.1 (Appendix 2). Although numbers increased across the whole of management zone, 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 240% 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. The Young RLPB district 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} to 15.14 km^{-2}.

The overall increase in eastern grey kangaroo numbers could be attributed to natural population increase. The substantial increase in the Cooma RLPB district, while obviously being, in part, the result of natural population increase, could also be seen as a concentration of eastern grey kangaroos within the southern district of the management zone. Had the existence of the RLPB district boundaries not been incorporated into the design of the survey, the concentration of kangaroos in the Cooma RLPB district would have been unlikely to have been detected.

As has been the case previously (Cairns 2004, 2007a), in designing this survey, the aim 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 the Yass RLPB districts (Table 5). For the other RLPB districts the coefficients of variation were all > 20%; in three instances being >30%. The bootstrap coefficients of variation were even high. This could be interpreted in relation to the patchiness of the distributions of the kangaroos throughout the various survey strata.

The present survey was designed in relation to the two previous surveys conducted in the South Eastern NSW kangaroo management zone (Pople *et al.* 2003; Cairns 2004; Cairns *et al.* 2007a) using the automated design algorithms currently available in DISTANCE 6.0 (Thomas *et al.* 2009). It is anticipated that a future survey conducted in this management zone will use information derived from the present survey and the automated design algorithms of, presumably, the next generation of DISTANCE. It would be expected that if a future survey design incorporated into it the division of the management zone into its constituent RLPB districts, then these would be stratified on the same basis they were for the present survey, but that survey effort would be reallocated in order to improve the precision of estimation. Based upon the eastern grey kangaroo densities determined for the two density strata of the Cooma RLPB district (Table 5), it would be expected that consideration would be given to either combining these strata or, alternatively, to making major changes to their dividing boundary.

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. Apart from filling the role of a very able observer during the conduct of the surveys, co-author David Bearup provided invaluable support with regard helping the flight crew plan each day's survey. Paul Caristo and Jo Murphy provided excellent and obliging service as the pilots. Their attention to OH&S issues was well appreciated. Peter Morris obliged by coming back from retirement to ably fill the role of the second observer.

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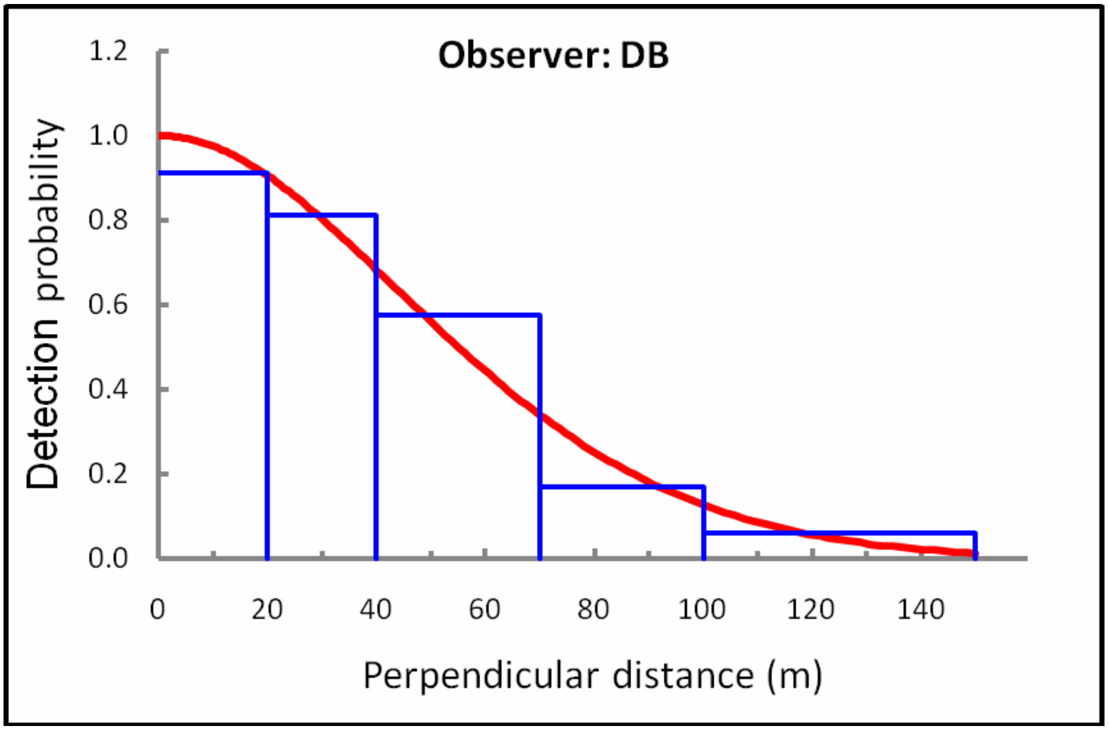
Appendix 1

The detection function models for eastern grey kangaroos (*M. giganteus*) in the strata surveyed within the six RLPB districts comprising the South East NSW kangaroo management zone.



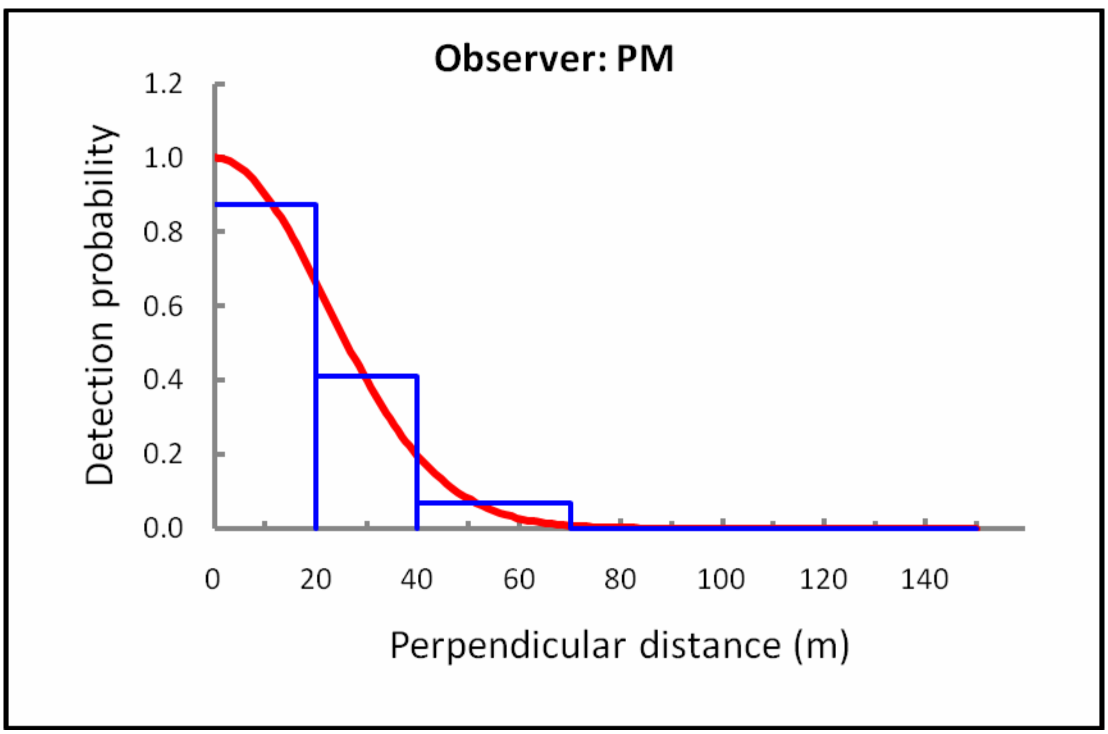


Fig. A1.1. The detection functions for eastern grey kangaroos in the medium density stratum of the Goulburn RLPB district. The two detection functions shown are pooled across cluster sizes. See Table 4 for further details of the models. DB and PM are the two different observers.

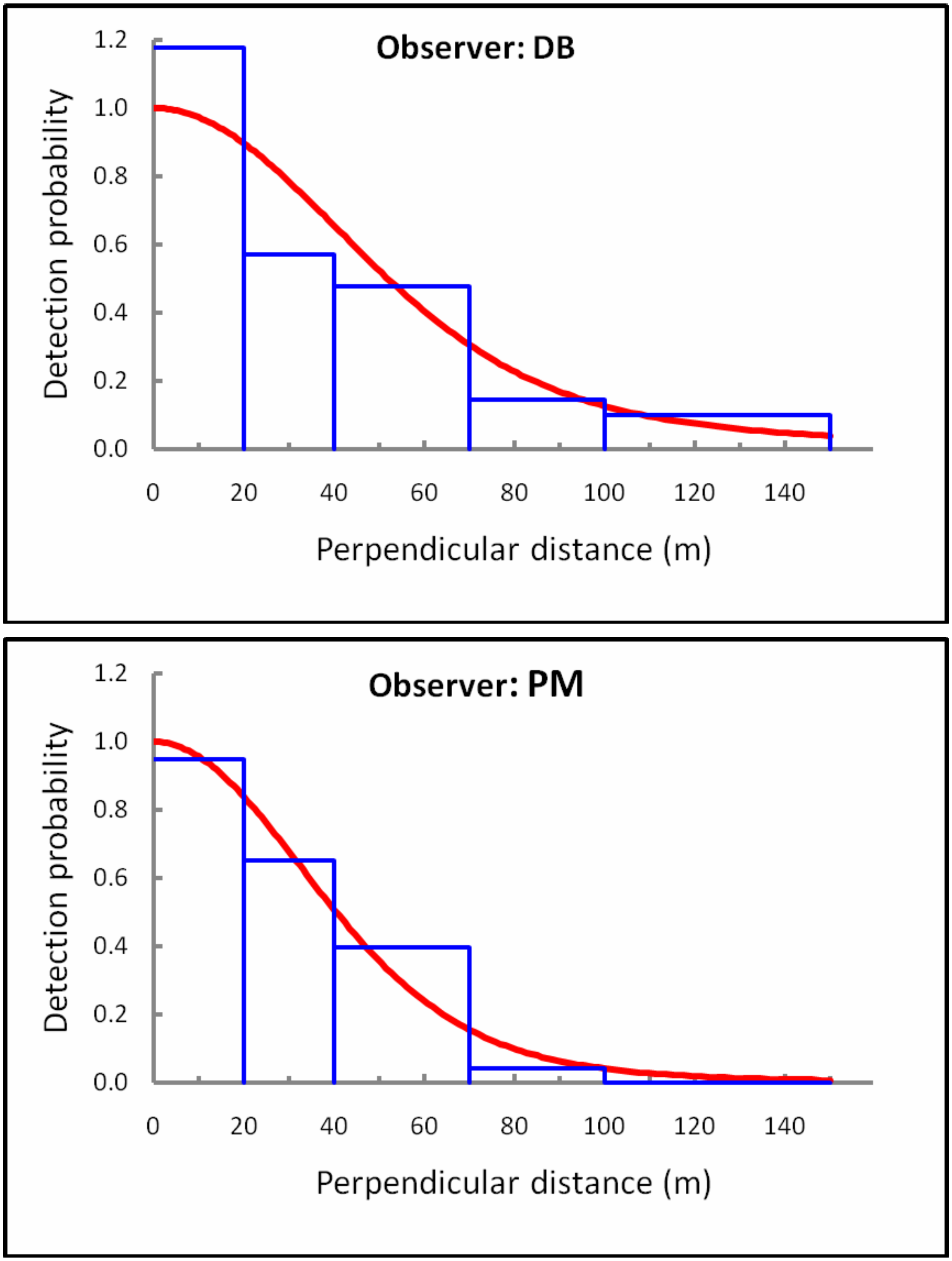


Fig. A1.2. The detection functions for eastern grey kangaroos in the medium density stratum of the Braidwood RLPB district. The two detection functions shown are pooled across cluster sizes. See Table 4 for further details of the models. DB and PM are the two different observers.

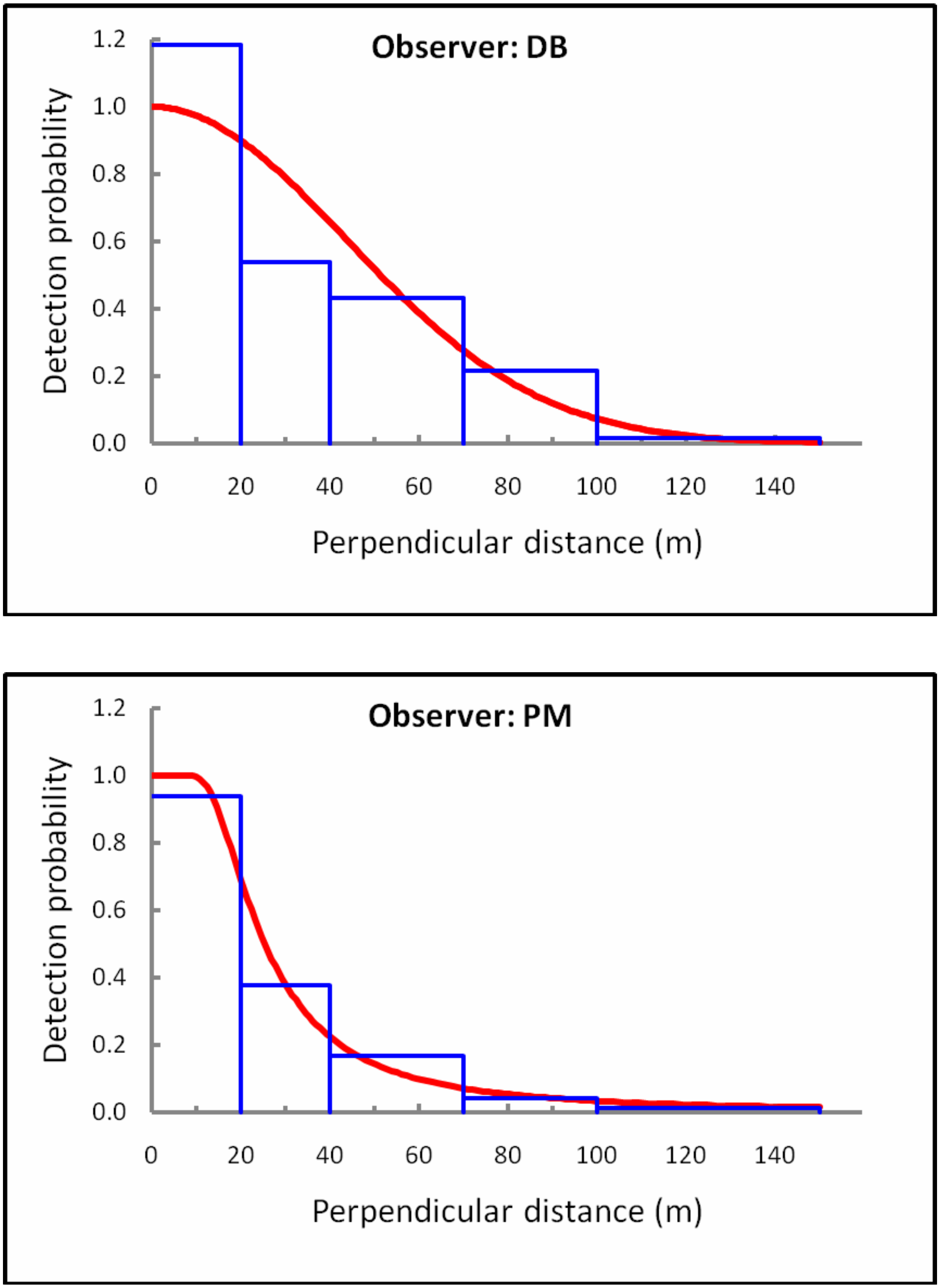
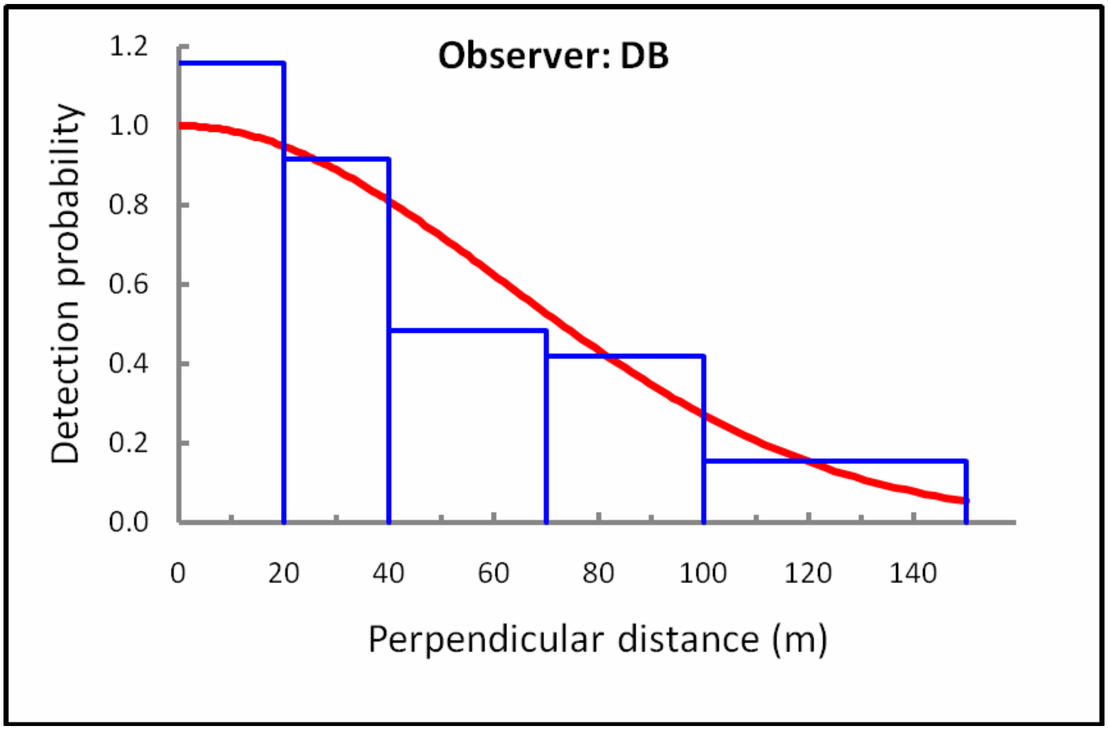


Fig. A1.3. The detection functions for eastern grey kangaroos in the high density stratum of the Cooma RLPB district. See Table 4 for further details of the models. DB and PM are the two different observers.



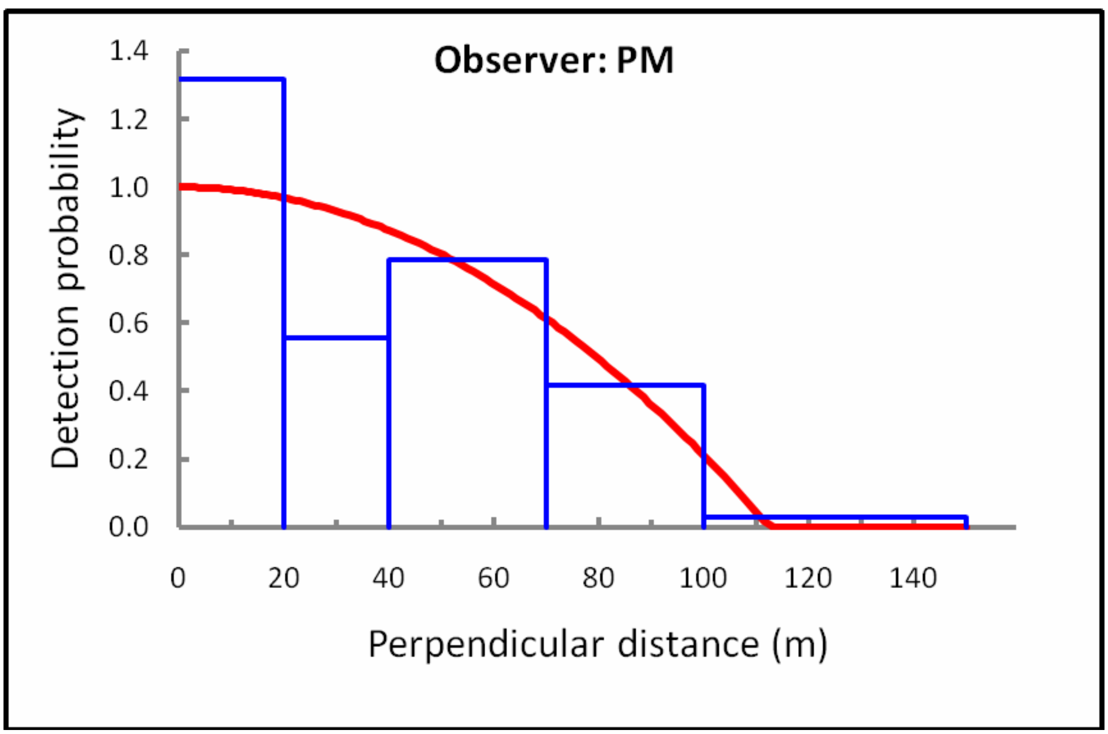
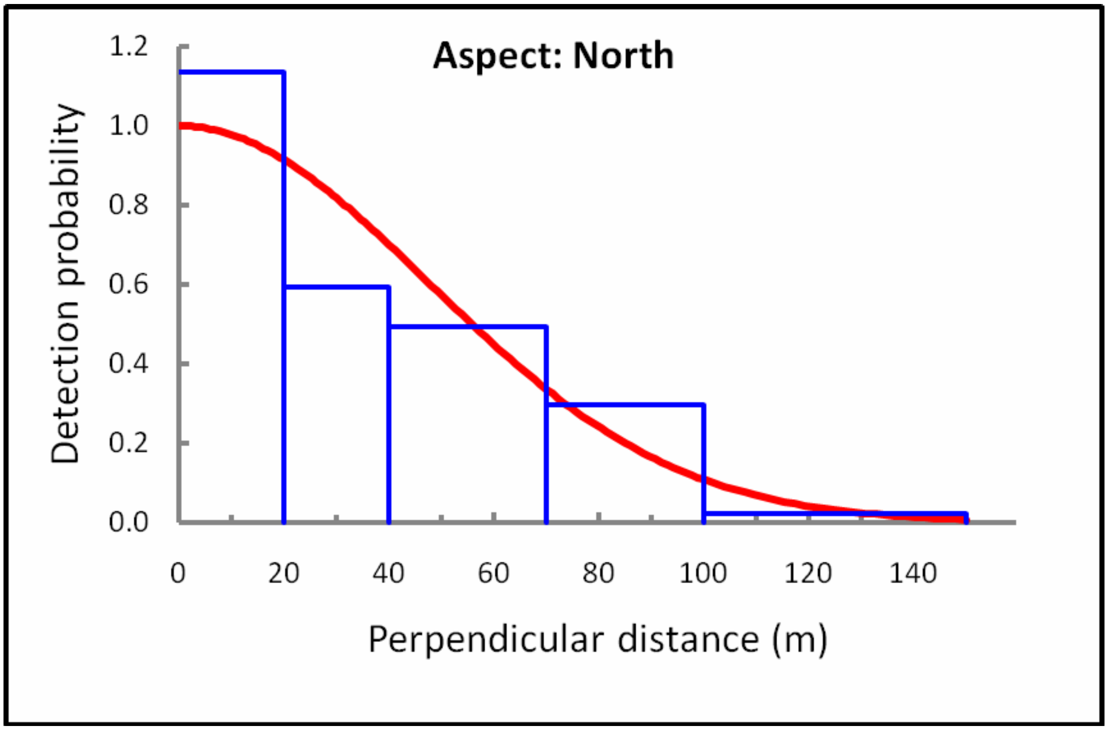


Fig. A1.4. The detection functions for eastern grey kangaroos in the medium density stratum of the Cooma RLPB district. See Table 4 for further details of the models. DB and PM are the two different observers.



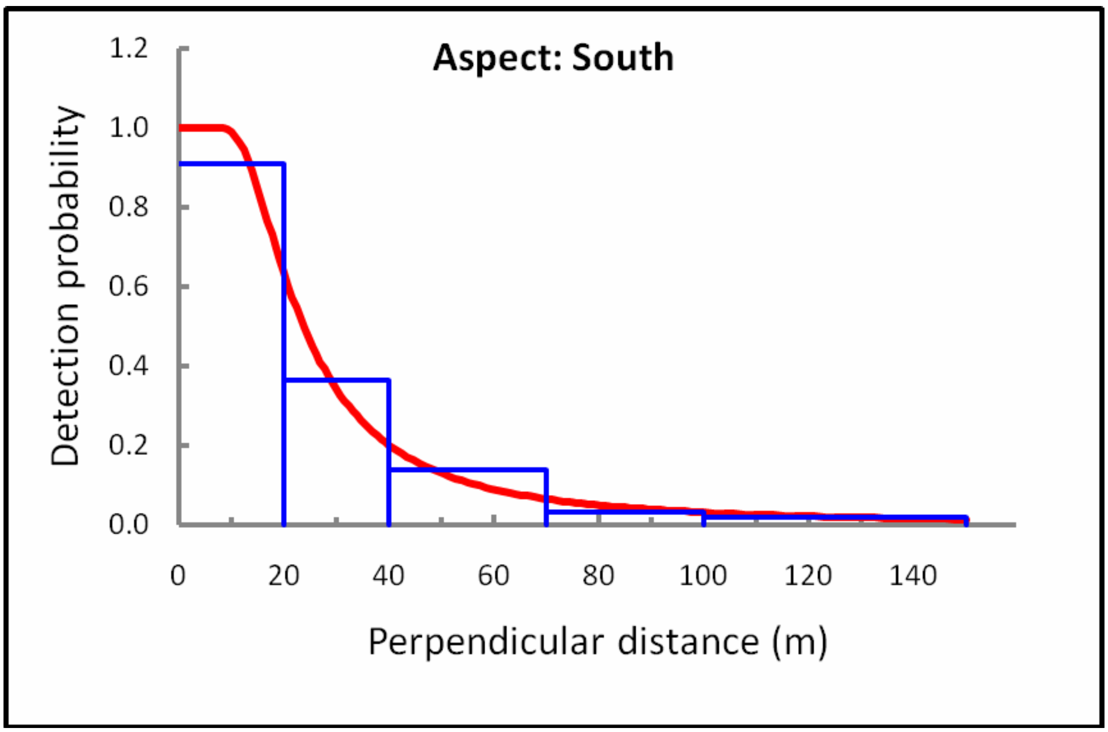
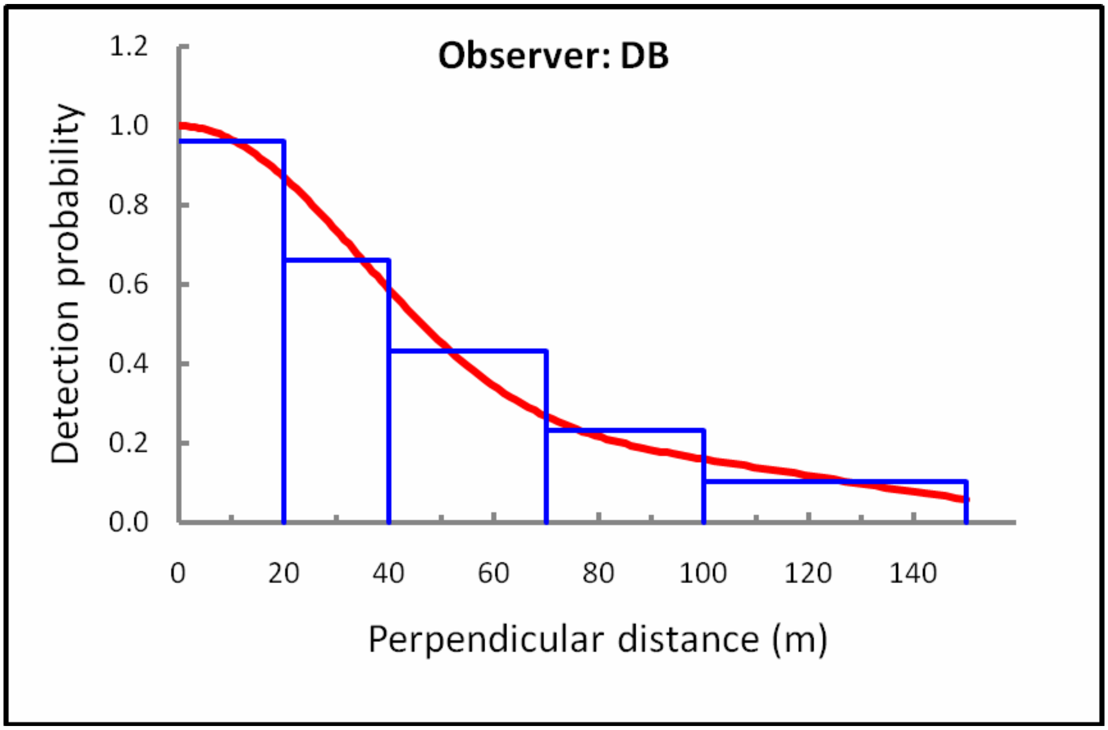


Fig. A1.5. The detection functions for eastern grey kangaroos in the medium density stratum of the Gundagai RLPB district. See Table 4 for further details of the models.



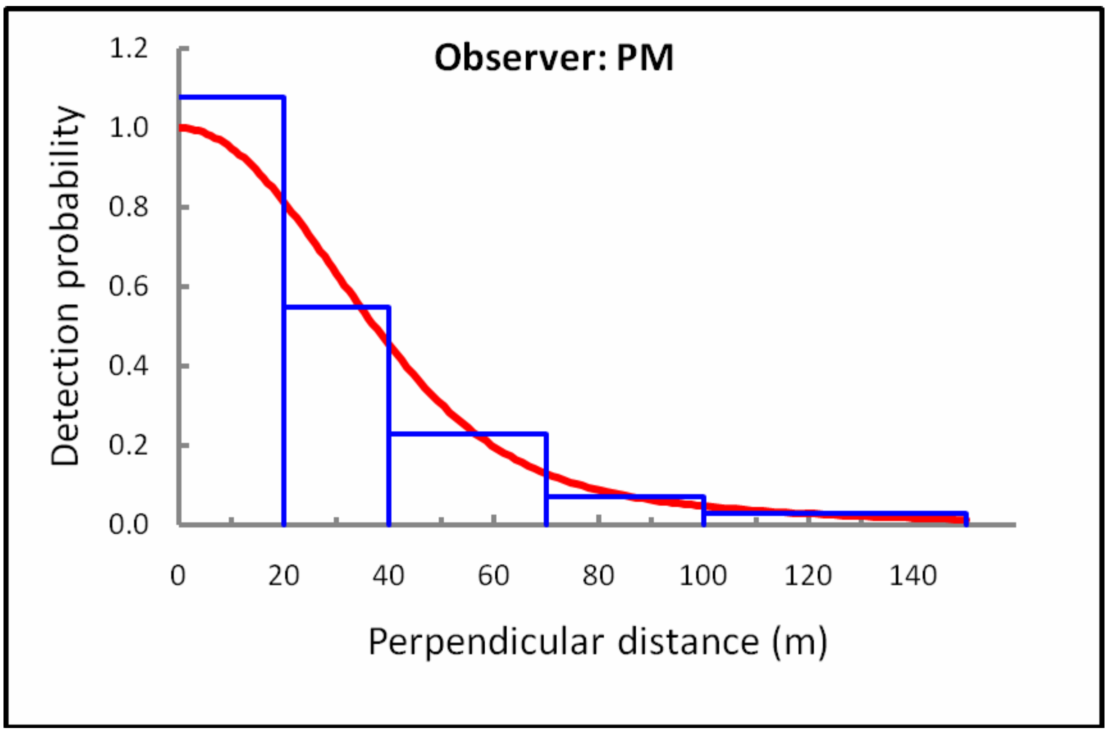


Fig. A1.6. The detection functions for eastern grey kangaroos in the medium density stratum of the Yass RLPB district. See Table 4 for further details of the models. DB and PM are the two different observers.

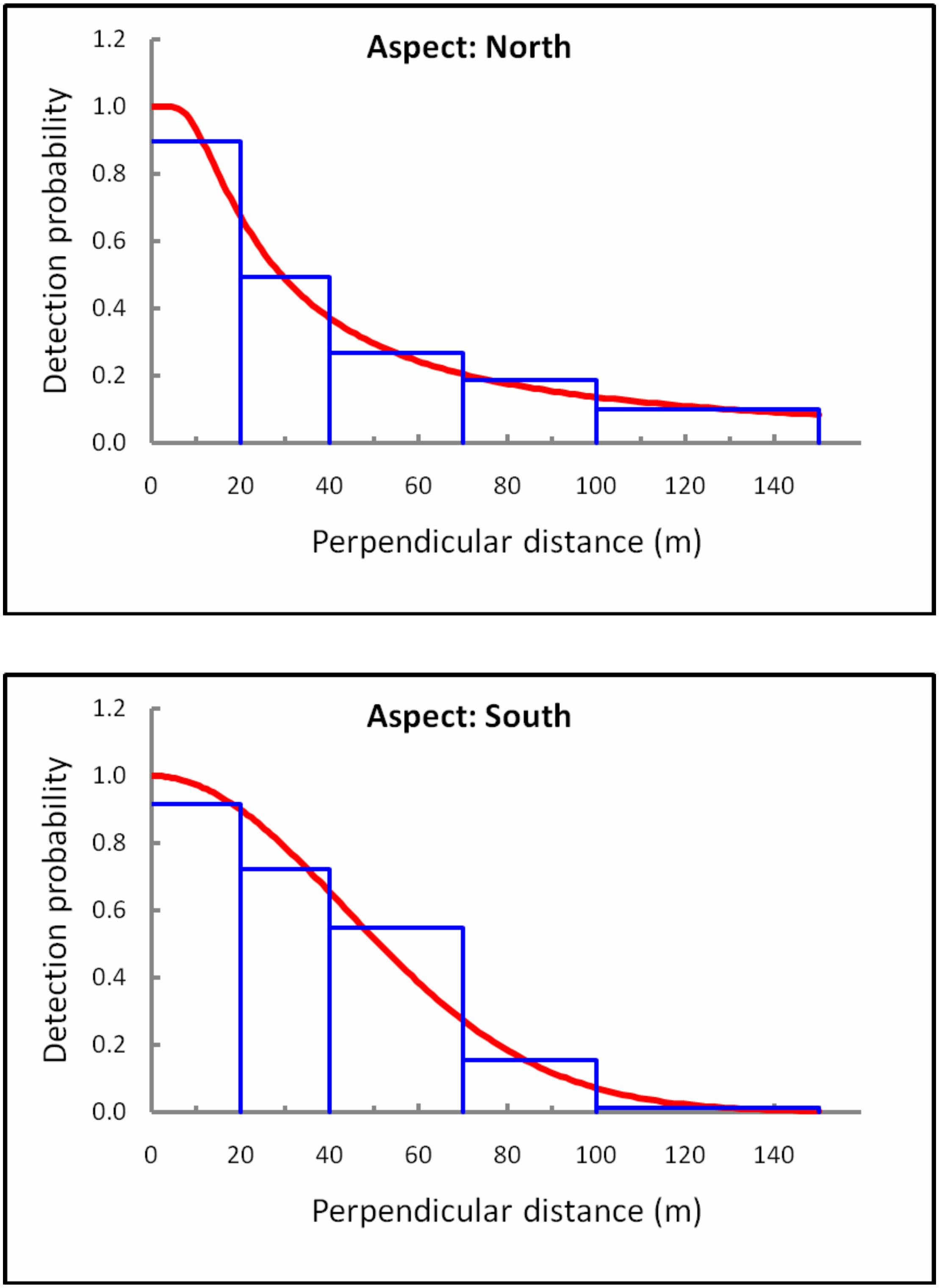


Fig. A1.7. The detection functions for eastern grey kangaroos in the high density stratum of the Young RLPB district. See Table 4 for further details of the models.

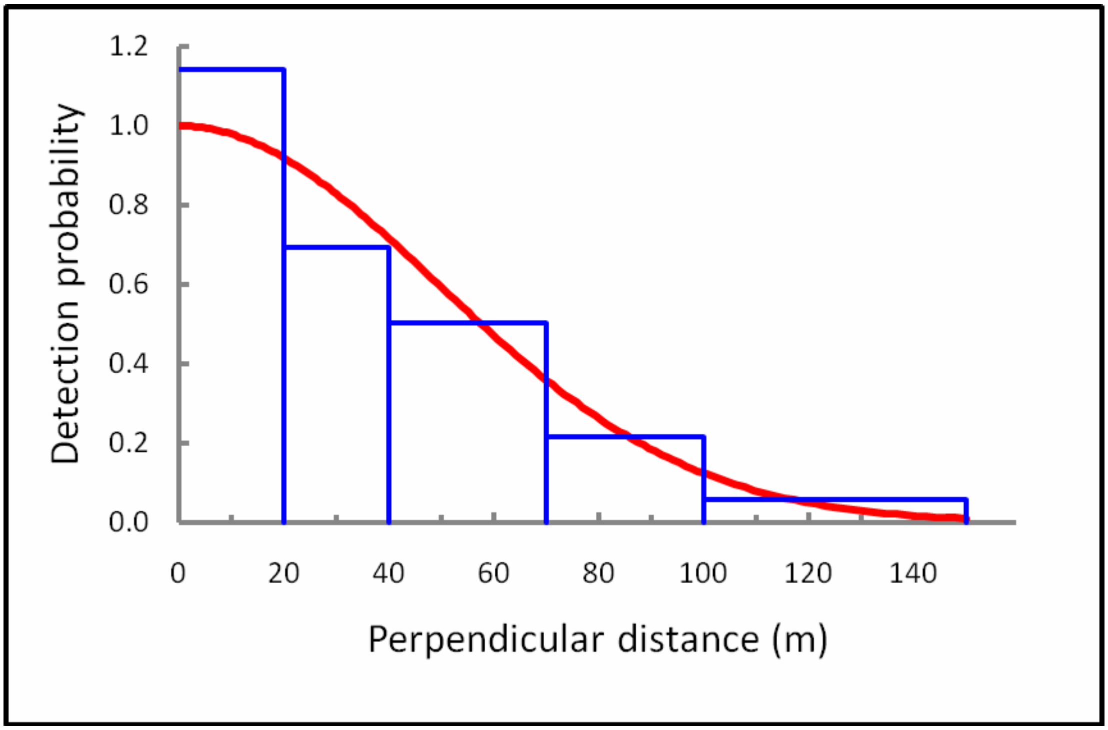


Fig. A1.8. The detection functions for eastern grey kangaroos in the medium density stratum of the Young RLPB district. See Table 4 for further details of the model.

Appendix 2

The population density and abundance estimates for eastern grey kangaroos (*M. giganteus*) in the strata surveyed within the five RLPB districts comprising the South Eastern NSW kangaroo management zone surveyed in September, 2006.

Table A2.1. Population and whole-district density estimates for eastern grey kangaroos in the five RLPB districts surveyed in September, 2006. Given along with each population and density estimate are the areas of the each district and the 95% bootstrap confidence intervals and coefficient of variation (*CV%*) for the estimates. The 95% bootstrap confidence intervals and coefficient of variation (*CV%*) given for the whole-zone estimates are based upon an estimate of the bootstrap variance determined from the bootstrap variances for each RLPB district.

RLPB District	*Area (km^2)*	*Population estimate*	*95% bootstrap confidence intervals*	*Density (km^{-2})*	*95% bootstrap confidence intervals*	*CV (%)*
Goulburn	5,973	114,430	76,570 – 173,120	19.16	12.82 – 28.98	21.9
Braidwood	4,284	64,461	45,153 – 96,661	15.05	10.54 – 22.56	18.4
Cooma	7,271	106,046	57,818 – 143,663	14.58	7.95 – 19.76	16.5
Yass	5,615	72,588	39,817 – 157,330	12.93	7.09 – 28.02	33.0
Gundagai	6,373	57,746	33,456 – 83,888	9.06	5.25 – 13.16	22.8
KMZ	29,516	415,271	329,579 – 500,963	14.07	11.17 – 16.97	10.3