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 zones”.

S. C. Cairns[1] and D. Bearup[2]

March, 2012

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

[2]New South Wales National Parks & 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)

Fax: (02) 67733814

email: scairns@.une.edu.au

DISCLAIMER
This report was prepared by Dr Stuart Cairns in good faith exercising all due care and attention, but no representation or warranty, express or implied, is made as to the relevance, accuracy, completeness or fitness for purpose of this document in respect of any particular user's circumstances. Users of this document should satisfy themselves concerning its application to, and where necessary seek expert advice in respect of, their situation. The views expressed within are not necessarily the views of the Office of Environment and Heritage (OEH) and may not represent OEH policy.

© Copyright State of NSW and the Office of Environment and Heritage

Table of Contents

Summary

1. Helicopter surveys for kangaroos were conducted using line transect sampling in the Central Tablelands North and Central Tablelands South kangaroo management zones. These surveys were the second conducted in these zones for the purpose of providing estimates of kangaroo numbers for the management of the commercial kangaroo harvest. Previous (initial) surveys were conducted in 2008.

2. Each management zone was subdivided into three strata of increasing kangaroo density in order to facilitate the process of designing the surveys. The two strata identified as probably supporting the highest numbers of kangaroos were surveyed. The third, low kangaroo density stratum was not surveyed. The surveys were designed using an automated survey design algorithm (Strindberg *et al.* 2004).

3. These surveys provided enough data to estimate the densities of eastern grey kangaroos, common wallaroos and swamp wallabies; although only eastern grey kangaroos are subject to commercial harvest in the two zones.

4. These surveys were designed with the aim of obtaining eastern grey kangaroo population estimates with coefficients of variation of 15-20%. The coefficients of variation of the population estimates obtained for eastern grey kangaroos were in the range 13-19 % in the Central Tablelands North zone. However, they were in the range 28-36 % in the Central Tablelands South zone.

5. Eastern grey kangaroo densities were estimated as being 24.19 km^{-2} in the Central Tablelands North zone and 15.37 km^{-2} in the Central Tablelands South zone. These densities correspond to population estimates of 612,509 and 347,830 kangaroos, respectively.

6. The densities of wallaroos were 1.96 km^{-2} in the Central Tablelands North zone and 0.42 km^{-2} Central Tablelands South zone. The densities of swamp wallabies were 2.04 km^{-2} and 1.10 km^{-2}, respectively.

1. Introduction

In mainland Australia, the management for commercial harvesting of all or some of the four large species of kangaroo that are variously widespread and abundant throughout much of the continent forms the basis of the kangaroo management programs of four of the mainland states (Pople & Grigg 1998). In New South Wales (NSW), all four species of large kangaroo, i.e. 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 harvested from at least some of the 14 designated kangaroo management zones (Anon. 2006).

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 accurate estimates of the sizes of the kangaroo populations proposed to be harvested. Eight of the kangaroo management zones in NSW are on the western plains of the state. Estimates of the kangaroo populations 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 kangaroo management zones are situated on the Great Dividing Range and its western slopes (see Figure 1). Because of the general relief of the landscape in these management zones, the kangaroo populations there cannot be monitored using fixed-wing aircraft surveys. Instead, an alternative method of estimating kangaroo population densities is used. This method is helicopter line transect sampling. The suitability and effectiveness of this method has been demonstrated by Clancy *et al.* (1997), Clancy (1999) and Southwell and Sheppard (2000).

Eastern grey kangaroo and the eastern subspecies of the common wallaroo (*M. robustus robustus*) are harvested commercially from the three kangaroo management zones in the Northern Tablelands region of northern NSW (NSW National Parks & Wildlife Service 2001). Eastern grey kangaroos are harvested from the South East NSW management zone and the two Central Tablelands zones (see Figure 1). The kangaroo populations in these five management zones are monitored using helicopter line transect surveys. These surveys are conducted on a triennial basis, a survey frequency option considered to be safe to use to monitor kangaroo populations in mesic as opposed to semi-arid rangeland environments (Pople 2003; Payne 2007). Further, according to Pople (2008), conducting kangaroo surveys on such a basis in areas defined as having a mesic environment is of relatively low risk with regard to quasi-extinctions resulting from the implementation of a specified harvesting program.

The first helicopter line transect surveys used to monitor kangaroo populations in NSW were conducted in the Northern Tablelands management zones in 2001 (Cairns 2003). Subsequent surveys of these three management zones have been conducted in 2004 (Cairns 2004a), 2007 (Cairns 2007a) and 2010 (Cairns *et al.* 2011). The designs of the 2007 and 2010 surveys were improved over the design of the initial survey conducted over 2003 and 2004 through the use of area stratification and the automated design capabilities of the DISTANCE analysis program (Thomas *et al.* 2009). This design capability is GIS based and incorporates a range of algorithms that can be used to design line transect surveys (Strindberg *et al.* 2004; Thomas *et al.* 2009).

Following the first helicopter survey of the Northern Tablelands kangaroo management zones (Cairns 2003), a feasibility study was undertaken by Pople *et al.* (2003) into conducting a similar survey in southeastern NSW as a precursor to the establishment of a sustainable kangaroo harvesting program there. The outcome of this feasibility study led to an initial survey of what became the South East NSW kangaroo management zone (Cairns 2004b). Subsequent surveys of the South East NSW kangaroo management zone were conducted in 2006 (Cairns 2007b) and in 2009 (Cairns *et al.* 2010).

With the continued successful management of the harvest in the Northern Tablelands and South East NSW kangaroo management zones, an initial survey was undertaken in the Central Tablelands and near central western slopes as part of the process of establishing two more kangaroo management zones along the Great Dividing Range and its western slopes. This survey was undertaken in 2008 (Cairns *et al.* 2009) and led to the establishment of the Central Tablelands North and Central Tablelands South kangaroo management zones (see Fig 1). A mandatory second survey was scheduled for 2011. Reported here are the design, the survey and data analysis methods used, and the results of this second survey conducted in the two Central Tablelands management zones in September 2011.

2. Survey Areas

The two kangaroo management zones (KMZ) in the Central Tablelands region of NSW are shown as Zone 48 (Central Tablelands North) and Zone 49 (Central Tablelands South) in Figure 1. These zones lie between the Upper Hunter management zone (Zone 14) to the north and the South East NSW management zone to the south (Zone 16) (Figure 1).

The Central Tablelands North zone extends south from Liverpool Range that marks its boundary with the Upper Hunter zone to its boundary with the Central Tablelands South zone which lies in a line immediately south of the town of Kandos (32o 51’ 00” S, 149o 58’ 00” E). Its eastern boundary lies east of Singleton(32o 32’ 27” S, 151o 9’ 42” E) and just west of Branxton (32o 39’ 22” S, 151o 21’ 15” E) in the Hunter Valley. It is bounded in the west by the Coonabarabran kangaroo management zone (Zone 10), with its western boundary southwest of the township of Wellington (32o 33’ 20” S, 148o 56’ 35” E).

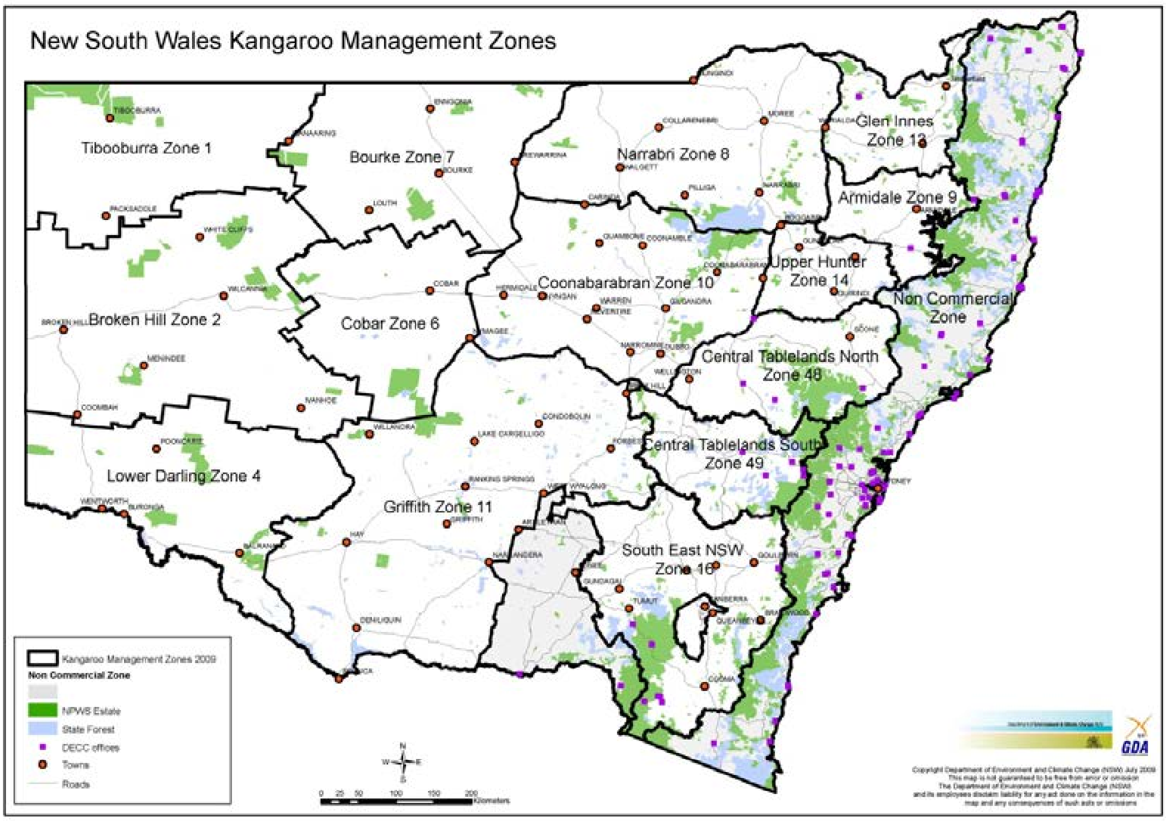


Figure 1. The 14 kangaroo management zones in NSW administered by the Office of Environment and Heritage. The two Central Tablelands kangaroo management zones are Zone 48 and Zone 49.

The Central Tablelands North zone takes in parts of four biogeographic regions. In the northeast, there is a small portion of the North Coast Biogeographic Region (IBRA), while the rest of the eastern part of the zone falls within the Hunter subregion of the Sydney Basin Biogeographic Region (IBRA) (Sahukar *et al.* 2003). In the west, the zone falls within the Brigalow Belt South Biogeographic Region (IBRA) towards the north and falls within the South Western Slopes Biogeographic Region (IBRA) towards the south (Sahukar *et al.* 2003). The characteristic landforms of this zone extend from steep, hilly and undulating ranges to rolling hills and wide valleys. There are no particularly prominent geodiversity features present such as those found in the Northern Tablelands management zones (Cairns, 2011).

The Central Tablelands South zone extends south from its boundary with the Central Tablelands North zone to its boundary with the South East NSW kangaroo management zone (Zone 16). Its eastern boundary is to the east of Bathurst (33^o 25' 00" S, 149^o 34' 00" E); in line with Wallerawang (33^o 24' 40" S, 150^o 03' 51" E). It is bounded in the west by the existing Griffith kangaroo management zone (KMZ 11), with its western boundary to the east of the townships of Parkes (33^o 08' 00" S, 148^o 10' 00" E) and Forbes (33^o 22' 00" S, 148^o 00' 00" E).

The Central Tablelands South zone takes in parts of two biogeographic regions. In the east, it falls within the South Eastern Highlands Biogeographic Region (IBRA), while in the west, it falls within the South Western Slopes Biogeographic Region (IBRA) (Sahukar *et al.* 2003). The topography of both the South Eastern Highlands and the South Western Slopes Biogeographic Regions comprise the western fall of the Great Dividing Range, with relatively steep, hilly and undulating terrain giving way towards the west to hilly ranges and peaks set in wide valleys. Perhaps the most important defining feature of the geodiversity of this zone is the Canobolas volcanic field of the South Eastern Highlands Biogeographic Region (Sahukar *et al.* 2003).

Most of the land in these two kangaroo management zones is freehold; with state forests, gazetted reserves and national parks comprising small proportions of their total areas. The principal land use is the grazing of domestic livestock, with grain and oilseed crops being a prominent secondary land use. Horticulture and coal mining also feature as significant land uses in both management zones.

For the purposes of designing and conducting kangaroo surveys, those parts of the two management zones dominated by cultivation or mining, along with those dominated geographically by rocky outcrops and some steep, timbered country were deemed to be areas supporting zero to very low densities of kangaroos and were therefore excluded from the survey areas. The remaining areas were divided on the basis of whether they supported medium or high densities of kangaroos. For the areas of the two kangaroo management zones, see Table 1.

3. Survey Design

Following what is now standard procedure (Cairns *et al.* 2009, 2010), the surveys for the two Central Tablelands kangaroo management zones were designed using the automated design capabilities of the most recent version of the DISTANCE software package (Thomas *et al.* 2010); in this case DISTANCE 6.0 Release 2 (Thomas *et al.* 2009). Required for this are GIS shape files of the two management zones and nominal estimates of the survey effort, i.e. the total length of transect to be surveyed in each zone. To enhance the survey design, each shape file was divided into three strata based upon land capability attributes and kangaroo density.

The boundaries of the three strata within each management zone are defined in relation to land capabilities and kangaroo density and survey count information obtained from previous surveys (e.g., Cairns *et al.* 2009). Defining density strata in relation to the most recent knowledge of kangaroo densities before designing a survey is consistent with taking an adaptive management approach to the conduct of aerial surveys in the tablelands management zones.

As well as stratification of the management zones, the survey design required nominal estimates of the survey effort for each of the strata to be surveyed. These survey efforts were determined in relation to particular levels of precision (see below). Only the high and medium density strata of each zone were surveyed.

3.1 Zone Stratification

NSW OEH supplied GIS shape files for the two Central Tablelands kangaroo management zones showing land capability attributes. These files contained the attributes of eight categories of land capability which extend from cultivation, through to mixed farming and grazing, through to grazing only (with decreasing levels of grazing intensity), through to steep, timbered country, through to rocky outcrops. They also contained some information on state forests, reserves and gazetted national parks which were all excluded from the survey areas of each zone. The eight categories of land capability were merged to form the initial basis of the three strata to be used in the survey design process.

Categories 1 and 2, which are representative of areas dominated by cultivation practices, were merged with Category 8, which is representative of rocky outcrops, and some of Category 7 (steep, timbered country) to form the basis of the low kangaroo density stratum within each zone. Categories 3 and 4, which are representative of areas of grazing and low intensity cropping, were merged to form the basis of the designated medium density kangaroo strata. Categories 5 and 6, which are representative of grazing land, and some of Category 7, were merged to form the basis of the high kangaroo density strata. The boundaries of the merged strata were redigitised to create final, simpler versions of the three density strata within each of the two zones. Stratification of the two management zones was initially undertaken for the first kangaroo surveys of these zones conducted in 2008 (Cairns *et al.* 2009). The outcome of these surveys confirmed the broad basis of the stratifications.

The breakdowns of the areas of the two zones into their constituent strata are given in Table 1. In the Central Tablelands North zone, 35% of the area formed the high density stratum, 51% formed the medium density stratum and 14% formed the low density stratum. The low density stratum included parts of the Goulburn River and the Wollemi National Parks. The medium density stratum was divided for the purpose survey design into two sub-strata of approximately equal area which were identified as Mudgee-medium (7,646 km^2) and Hunter-medium (7,406 km^2). A large tract of land dominated by open cast coal mining was excluded from the Hunter-medium sub-stratum. In the Central Tablelands South zone, this breakdown was 36% high density, 62% medium density and 2% low density. For visual representation of the stratification of the zones, see Figs. 2-3.

Table 1. Areas (km^2) of the two Central Tablelands kangaroo management zones (KMZ) divided into three survey strata based upon nominally high, medium and low kangaroo densities. Survey area comprises the medium and high density strata.

Stratum	Kangaroo management zone	
	Central Tablelands North	Central Tablelands South
Total area	29,379	23,102
High density	10,274	8,254
Medium density	15,052	14,378
Low density	4,053	470
Survey area	25,326	22,632

3.2 Survey Effort

In line transect sampling, survey effort is defined as the total length of transect surveyed within an area. 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 the one reported here, aiming for a general level precision of up to 20% is realistic and reasonably cost-effective (Pople *et al.* 2003; Cairns and Lollback 2008; Cairns *et al.* 2009, 2011). For each of the two zones, survey efforts were determined broadly in relation to a target level of precision of 17.5% for estimating eastern grey kangaroo densities.

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

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

where, L_t is the required survey effort for a target level of precision of $cv_t(\hat{D})$ (= 17.5%), and L_0 and $cv_0(\hat{D})$ are the survey effort and attained level of precision, respectively, from a previous or pilot survey; in this case, the most recent previous surveys conducted in these management zones (Cairns and Lollback 2008) were used. Survey efforts were determined separately for those strata within the two zones that were to be surveyed.

For the Mudgee-high stratum of the Central Tablelands North zone, L_0 = 142 km and $cv_0(\hat{D})$ = 29.4%; for the Mudgee-medium stratum of this zone, L_0 = 143 km and $cv_0(\hat{D})$ = 22.4%; and for the Hunter-medium stratum of this zone, L_0 = 128 km and $cv_0(\hat{D})$ = 29.0% for eastern grey kangaroos (Cairns *et al.* 2008). For the high density stratum of the Central Tablelands south zone, L_0 = 253 km and $cv_0(\hat{D})$ = 14.2%, while for the medium stratum, L_0 = 195 km and $cv_0(\hat{D})$ = 31.9% (Cairns *et al.* 2008).

Using the above information, the nominal survey efforts determined for each stratum in the Central Tablelands North zone were 400 km for the Mudgee-high stratum, 235 km for the Mudgee-medium stratum and 350 km for the Hunter-medium stratum. For the Central Tablelands South zone, the survey efforts were determined as 170 km for the high density stratum and 650 km for the medium density stratum.

3.3 Automated Survey Design

The principal aim in 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 violation of one of the assumptions underpinning the analysis method, that of the distribution of objects from the transect line being uniform out to the truncation distance, which can occur 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 each of the high and medium density strata of each of the two management zones using the nominal survey efforts given above as a basis for ensuring adequate survey effort. 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 various survey designs selected for comparison (Strindberg *et al.* 2004; Thomas *et al.* 2009). Once it had been confirmed that the systematic segmented grid sampling design with complete samplers provided a reasonably even coverage of a survey area, a single realisation of that selected design was generated for each survey stratum within each management zone.

For each stratum to be surveyed, all transects (samplers) were of fixed length; being either 10 km or 12 km long. For the Central Tablelands North zone, the selected survey designs comprised 34 transects in the Mudgee-high stratum, 21 transects in the Mudgee-medium stratum and 31 transects in the Hunter-medium stratum (Figure 2). All transects were 10 km long. For the Central Tablelands South zone, the selected survey designs comprised 18 transects in the high density stratum and 43 transects in the medium density stratum (Figure 3). Transects were 10 km long in the high density stratum and 12 km long in the medium density stratum.

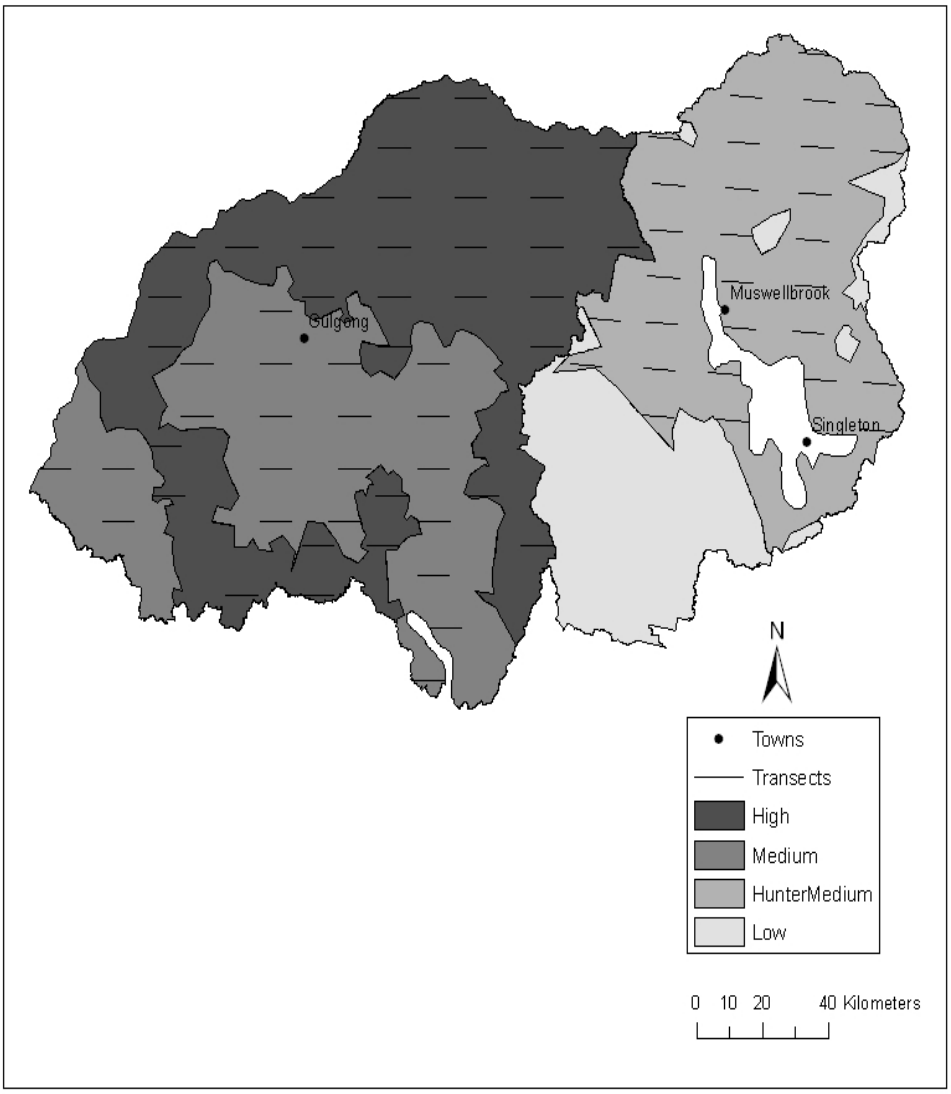


Figure 2. The Central Tablelands North kangaroo management zone. Shown are the three survey strata; the medium kangaroo density stratum being divided two sub-strata (see legend: Medium and Hunter Medium). The open-cast coal mining area of the Hunter Medium sub-stratum was not considered as part of the survey area (white). Shown also are the population centres (towns) and the placement of the survey transects within the high and medium kangaroo density strata. Note that no survey transects were placed into the low density stratum.

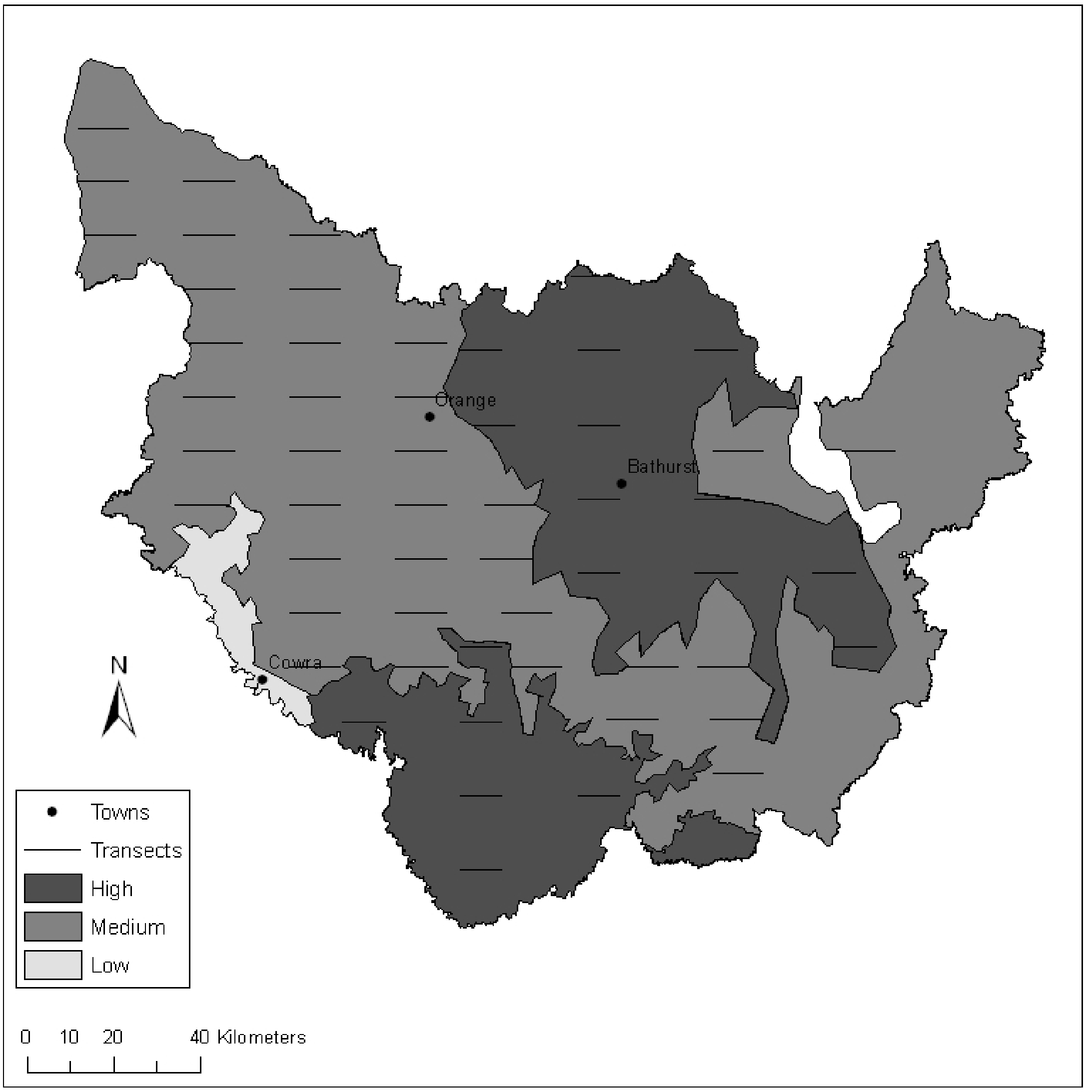


Figure 3. The Central Tablelands South kangaroo management zone. Shown are the three survey strata, the population centres (towns) and the placement of the survey transects within the high and medium kangaroo density strata. Note that no survey transects were placed into the low density stratum.

4. Survey Methods

The aerial surveys of the Central Tablelands North and Central Tablelands South kangaroo management zones were conducted as helicopter surveys during the period 19-27 September, 2011. The surveys were conducted in accordance with the survey designs developed above (see Section 3.3); with each zone being considered a separate entity and subdivided into three strata based principally upon land use capability, and modulated in relation to known and assumed kangaroo densities. Those strata identified as supporting high and medium densities of eastern grey kangaroos were surveyed. The method of line transect sampling (Buckland *et al.* 2001; Thomas *et al.* 2002) was used.

In the original designs for the surveys, there was a total of 147 transects to be flown across the two management zones. All except eight of these transects were flown. In the Central Tablelands North zone (KMZ 48), 34 transects were flown in the Mudgee-high stratum, 21 transects were flown in the Mudgee-medium stratum and 29 transects were flown in the Hunter-medium stratum. In the Central Tablelands North zone (KMZ 49), 18 transects were flown in the high density stratum and 37 transects were flown in the medium density stratum.

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 (NPWS) and Scott Seymour (NPWS) were the observers. Mike Saunders (NPWS) joined the survey as a trainee observer and, after an initial period of training, replaced one of the trained observers as an observer on some transects flown during the later stages of the survey. Scott Bowers was the principal pilot for the surveys. The seating of the observers in relation to the left-hand or right-hand side of the aircraft was allocated randomly for each survey session.

4.1 Helicopter Line Transect Surveys

In conducting the survey, the helicopter, a Eurocopter AS350 Ecureuil (Squirrel), 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. 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 nominal distance classes perpendicular to the transect line of 0-20 m, 20-40 m, 40-70 m, 70-100 m and 100-150 m,. The distance classes were delineated on metal booms extending from either side of the helicopter. The exact distances on either side of the aircraft corresponding to these nominal distance classes were determined from measurements made on the boom at the end the survey.

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 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. For the purpose of data analysis, the exact transect lengths were equal to the nominal survey lengths of the original survey designs (see Table A.1, Appendix 1).

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 $0 \leq x \leq w$ 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.* 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 zone 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 parsimonious detection function 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 relation to 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 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 for the whole of each management zone.

5. Results and Discussion

Each of the two kangaroo management zones surveyed was subdivided into three strata based upon land capability and relative eastern grey kangaroo densities (see Section 3.1). Only the high and medium kangaroo density strata were surveyed. The low density stratum was assumed to support less than trace numbers of eastern grey kangaroos and wallaroos. A summary of the raw counts of the four species of macropod inhabiting the survey regions is given in Table 2. The numbers of macropod sightings for each transect and the raw counts of each species comprising these sightings are given in Table A.1.

Table 2. Number of transects, survey effort (km) and raw counts of macropods for each of the survey strata in the two Central Tablelands kangaroo management zones.

Kangaroo management zone/stratum	No. of transects	Effort (km)	Raw counts: Eastern grey kangaroos	Common wallaroos	Red-necked wallabies	Swamp wallabies
Central Tablelands North						
Mudgee-high	34	340	1,276	57	10	25
Mudgee-medium	21	210	622	11	2	11
Hunter-medium	29	290	550	129	36	80
Central Tablelands South						
High	18	180	539	11	4	20
Medium	37	444	506	6	2	16

In determining population estimates for the kangaroos and wallabies in each management zone, where possible, the data were analysed separately for each constituent stratum and the results combined to produce whole-zone population and density estimates. This was possible for eastern grey kangaroos, but not for wallaroos, red-necked wallabies or swamp wallabies. For wallaroos and swamp wallabies, the results for each survey stratum within each zone were combined in order to complete the analyses. There were not enough data for estimates to be made of the red-necked wallaby populations.

The CDS analysis engine of DISTANCE 6.0 (Thomas *et al.* 2010) was used to analyse the survey results. Although the distance categories were nominated as being 0-20 m, 20-40 m, 40-70 m, 70-100 m and 100-150 m these were adjusted following a remeasuring of the markers on the boom at the end of the surveys. The final, adjusted distance categories used in the analyses were 0-20 m, 20-40 m, 40-65 m, 65-105 m and 105-135 m.

The most parsimonious detection function models fitted to the results of the surveys of eastern grey kangaroos in the two management zones are given in Table 3. Single models were fitted to the results for the Mudgee-high stratum in the Central Tablelands North zone and the two survey stratum in the Central Tablelands South zone. Two models, derived in relation to post-stratification on the basis of observer, were fitted to the results of the Mudgee-medium and Hunter-medium strata. In each instance, the most parsimonious (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-A2.5, of Appendix 2.

In relation to each of the detection function models in Table 3, 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 effective strip widths (ESW). 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 0.30 to 0.53. By virtue of the way it is determined (= WxP_a), the higher value of P_a, the wider will be the ESW. The effective strip widths determined in relation to the results of these surveys ranged from 41 m to 71 m. The ESW is interpreted as the width of the survey strip whereby if all animals (kangaroos) are detected out to that distance, and none beyond, then the expected number of animals detected would be the same for the actual survey (Buckland *et al.* 2001). 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 two management zones, it also reflects the possible influence of weather conditions and light on sightability. Separating the influence of these two factors would be difficult. In relation to this, however, the values of these statistics were generally higher than those determined from the previous surveys conducted in these kangaroo management zone (Cairns *et al*. 2009). Survey conditions were perhaps somewhat better during the present surveys than previously.

The initial density estimates obtained from of the analyses of the eastern grey kangaroo data are given in Table 4. These are results determined at the level of survey stratum; having in two instances been post-stratified. 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_5 = 0.93; P = 0.002). In other words, cluster size was essentially similar across all

Table 3. The survey effort, 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 (ESW) for the survey of the eastern grey kangaroo populations in the two Central Tablelands kangaroo management zones. In some instances, post-stratification on the basis of observer (DB and SS) was used to determine the most parsimonious detection function models.

Kangaroo management zone/stratum	Effort (km)	n	Model	P_a	ESW (m)
Central Tablelands North					
Mudgee-high	340	419	Hazard-rate	0.53	70.6
Mudgee-medium	210	97	Half-normal (DB)	0.40	54.4
		96	Uniform/Cosine (SS)	0.45	60.7
Hunter-medium	290	201	Uniform/Cosine (DB)	0.50	67.6
		171	Hazard-rate (SS)	0.45	60.1
Central Tablelands South					
High	180	182	Hazard-rate	0.38	51.4
Medium	444	155	Hazard-rate	0.30	41.0

of the five strata comprising the survey areas. Bootstrap confidence intervals and coefficients of variation have been determined in relation to these densities. For the Central Tablelands North zone, these coefficients of variation were of acceptable levels for the Mudgee-high and Hunter-medium strata, but were somewhat high for the Mudgee-medium stratum. For the Central Tablelands South zone, the coefficients of variation for both strata were higher than preferred; indicating possible problems with the stratification of this zone. Now that it has been surveyed twice, consideration could be given to redefining the three strata within this zone.

Table 4. Results of the helicopter line transect surveys of eastern grey kangaroos conducted in the Central Tablelands kangaroo management zones in September, 2011. Given are the survey stratum area, the form of post-stratification used (observer: DB and SS), density of clusters of kangaroos sighted (D_s) and kangaroo population density (D). Given in association with the two density estimates are the bootstrap confidence intervals and coefficients of variation (CV %). Details of the most parsimonious detection function models used to determine these densities are given in Table 3.

Kangaroo management zone/stratum	Area (km^2)	Post-stratification	Kangaroo densities (km^{-2})					
			D_s	95% bootstrap confidence interval	CV (%)	D	95% bootstrap confidence interval	CV (%)
<u>Central Tablelands North</u>								
Mudgee-high	10,274	–	8.73	6.07 – 12.23	17.8	23.88	15.96 – 33.38	18.7
Mudgee-medium	7,646	DB	4.24	2.29 – 6.57	42.6	14.70	7.75 – 21.34	41.6
		SS	3.77	2.03 – 4.90	21.9	10.03	4.74 – 14.15	25.6
Hunter-medium	7,406	DB	5.12	3.71 – 7.00	16.0	13.50	9.44 – 18.37	16.7
		SS	4.90	3.39 – 7.26	19.3	10.55	7.34 – 15.75	19.8
<u>Central Tablelands South</u>								
High	9,078	–	9.83	6.83 – 13.09	22.4	22.10	13.64 – 34.04	28.0
Medium	6,021	–	4.26	2.84 – 8.14	41.5	11.51	4.52 – 18.63	38.2

The density and abundance estimates for the eastern grey kangaroos in each of the survey strata of the two management zones are given in Table 5. Densities were found to be similar across the three strata of the Central Tablelands North zone. Based upon this and the outcome of the initial survey conducted in this zone (Cairns *et al.* 2009), some consideration could also be given to the way in which this management zone is currently stratified in relation to the design and conduct of the survey. In the Central Tablelands South zone eastern grey kangaroo density in the high density stratum was twice that in the medium density stratum. The coefficients of variations for the Central Tablelands South strata remained as given in Table 4.

The estimated total number of eastern grey kangaroos in the Central Tablelands North zone represented a substantial increase (40%) in the size of the population estimated from the initial survey conducted in this zone in 2008 (Cairns *et al.* 2009). Juxtaposed to this, in the Central Tablelands South zone there was a decline of 35% between the estimated eastern grey kangaroo population from this survey and that of the initial survey. Such substantial shifts in numbers in areas that share a long common boundary is unlikely to be readily explained in relation to the respective levels of kangaroo harvesting in these zones or the dynamics of eastern grey kangaroo populations, particularly given that these two zones are mesic in their environment and that the prevailing climatic conditions over the past three years have been relatively favourable. It is more likely that the almost corresponding proportional shifts in numbers between two zones of similar size could be attributed to the increase in the dimension of the survey between 2008 and 2011 and, perhaps, a movement north of kangaroos across the long boundary between the two zones.

The results of the analyses of the wallaroo and swamp wallaby survey results are given in Tables 6 and 7. Too few red-necked wallabies (Table 6) were sighted to determine density estimates for this species. To estimate wallaroo and swamp wallaby numbers in the Central Tablelands North zone, there were enough data to determine the detection function models separately for each of these species within this zone. However, the opposite situation existed in relation to the Central Tablelands South zone. In order to estimate wallaroo and swamp wallaby numbers for this zone, the survey results were combined with those from the Central Tablelands North zone and a global detection function model determined. The

Table 5. The eastern grey kangaroo population densities (D) and abundances (N) for the strata surveyed within the Central Tablelands North and Central Tablelands South kangaroo management zones. Given in association with the estimates are bootstrap confidence intervals. The abundances shown in bold are the combined, whole-zone estimates.

Kangaroo management zone/stratum	D (km^{-2})	95% bootstrap confidence interval	N	95% bootstrap confidence interval	CV (%)
Central Tablelands North					
Mudgee-high	23.88	15.96 – 33.38	245,300	164,010 – 342,990	18.7
Mudgee-medium	24.74	15.61 – 32.36	189,140	119,340 – 247,470	18.6
Hunter-medium	24.05	18.83 – 31.02	178,150	139,460 – 229,760	12.8
			612,590		
Central Tablelands South					
High	22.10	13.64 – 34.04	182,390	112,620 – 280,960	28.0
Medium	11.51	4.52 – 18.63	165,440	65,020 – 267,790	38.2
			347,830		

density estimates of wallaroos and swamp wallabies in the Central Tablelands South zone were calculated in relation to this global detection function model. In the case of both species, the most parsimonious detection function models were Half-normal/Cosine models. That the separate models determined for the Central Tablelands North zone and the global models were of same form is not surprising; sightings of wallaroos and swamp wallabies from this zone dominated the pooled data sets. The forms of the detection function models given in Table 5 are shown in Figs. A2.6-2.9 of Appendix 2.

In both management zones, P_a for wallaroos was estimated at 0.40 and the ESW estimated at 55 m (Table 6). The values of these statistics were comparable to those estimated for eastern grey kangaroos (Table 2). Comparable estimates of

Table 6. The area surveyed, survey effort, number of sightings of clusters of animals (n), the detection function model, the probability that a randomly-selected cluster of animals in the survey strip is detected (P_a) and the effective strip width (ESW) for common wallaroos, red-necked wallabies and swamp wallabies in the Central Tablelands North and Central Tablelands South kangaroo management zones..

Kangaroo management zone	Area (km^2)	Effort (km)	n	Model	P_a	ESW
Central Tablelands North	25,326	840				
Wallaroos			121	Half-normal/Cosine	0.41	55.6
Red-necked wallabies			34	–	–	–
Swamp wallabies			92	Half-normal/Cosine	0.25	33.3
Central Tablelands South	22,632	1,464				
Wallaroos			19	Half-normal/Cosine	0.40	54.0
Red-necked wallabies			6	–	–	–
Swamp wallabies			39	Half-normal/Cosine	0.24	33.0

these statistics from the 2008 survey (Cairns *et al.* 2009) were not available because in that instance there were insufficient data to calculate them. However, compared with estimates from the three Northern Tablelands management zones, these values were higher than those for the Glen Innes and Armidale zones (Figure 1), but similar to those for the Upper Hunter zone, the zone that is closest to the Central Tablelands zones. The values of P_a for swamp wallabies were estimated at 0.25 and the ESW estimated at 33 m; this being probably indicative of this species being somewhat more cryptic in the landscape.

The estimated densities of clusters and population densities of wallaroos and swamp wallabies along with their bootstrap confidence intervals and coefficients of variation are given in Table 7. Both these species exist at densities that are considerably lower than those of the eastern grey kangaroo populations in these management zones. In relation to this, the sightability of wallaroos has usually been reported to be lower than for eastern grey kangaroos. Clancy *et al.* (1997) found that this was the case in relation to surveys of wallaroos in southwestern Queensland

Table 7. The density of clusters of animals sighted (D_s) and population density (D).for common wallaroos and swamp wallabies in the Central Tablelands North and Central Tablelands South kangaroo management zones. Given in association with the two density estimates are the bootstrap confidence intervals and coefficients of variation (CV %). Details of the most parsimonious detection function models used to determine these densities are given in Table 6.

Kangaroo management zone	Kangaroo densities (km^{-2})					
	D_s	95% bootstrap confidence interval	CV (%)	D	95% bootstrap confidence interval	CV (%)
Central Tablelands North						
Wallaroos	1.29	0.89 – 1.82	18.3	1.96	1.32 – 2.83	18.9
Swamp wallabies	1.64	1.04 – 2.29	19.6	2.04	1.23 – 2.89	21.2
Central Tablelands South						
Wallaroos	0.28	0.14 – 0.51	34.8	0.42	0.20 – 0.76	35.7
Swamp wallabies	0.95	0.56 – 1.35	22.0	1.10	0.66 – 1.55	21.4

and, as a result of this, then suggested that helicopter line transect surveys of wallaroos in this landscape would be likely to underestimate wallaroo numbers by a factor of 1.85 when compared with the results of walked line transect sampling. Supportive of these findings was the outcome of a similar study conducted in the Barrier Ranges of western NSW in 1998 from which it was found that helicopter line transect sampling underestimated euro (*M. robustus erubescens*) numbers by a factor of 1.50 in undulating terrain and 1.88 in steep terrain when compared with the results of walked line transect surveys (S. C. Cairns, A. R. Pople & J. Gilroy, *unpubl. data*). Taking this into account, the final estimates of wallaroo density and abundance have been corrected (x1.85; see Table 8).

The whole-zone population estimates of abundances and densities of eastern grey kangaroos and wallaroos in the two management zones are given in Table 8. Zone densities are determined in relation to the area of all three survey strata from the estimates of total abundance determined in relation to those strata actually surveyed. Both of the Central Tablelands kangaroo management zones are larger

Table 8. Estimated whole-zone total abundances (N) and population densities (D) of eastern grey kangaroos and common wallaroos in the Central Tablelands North and Central Tablelands South kangaroo management zones. Given in association of these estimates are the combined areas of the three survey strata within each kangaroo management zone. The numbers for common wallaroos have been corrected by a multiple of 1.85 (see text).

Kangaroo management zone	Area (km^2)	Eastern grey kangaroos		Common wallaroos	
		N	D (km^{-2})	N	D (km^{-2})
Central Tablelands North	25,326	612,590	24.19	91,780	3.62
Central Tablelands South	22,632	347,830	15.37	17,400	0.77

than the three Northern Tablelands management zones, but each is equal in size to about three-quarters the area of the current South East NSW management zone (Figure 1). Both support larger, higher density populations of eastern grey kangaroos than do the three Northern Tablelands management zones (see Table 9, Cairns *et al*. 2011). The Central Tablelands South zone supports a population broadly equivalent in terms of density to that supported South East NSW management zone (see Table 7, Cairns *et al*. 2010).

The surveys conducted in these two kangaroo management zones were designed with the intention of providing population estimates with coefficients of variation of 15-20% for eastern grey kangaroos and, 30% for wallaroos. This was essentially achieved in relation to the Central Tablelands North zone, with coefficients of variation of 13-19% for eastern grey kangaroos and a coefficient of variation of 19% for wallaroos. The outcome of the survey for wallaroos was unexpectedly good, particularly since the design of the survey had been based solely on prior information about the eastern grey kangaroo populations. It was not, however, achieved in relation to the Central Tablelands South zone, where the coefficients of variation for eastern grey kangaroos were 28-38% and a coefficient of variation for wallaroos was 36%. The reason for this poor precision, particularly in relation to the estimates for the eastern grey kangaroo populations might lie with the stratification of the zone. With a total survey effort of 1,464 km of transects having been flown in this zone it is probably unlikely that, a further increase in allocated survey effort would be cost-effective in terms of improving precision. With regard to this, it should be noted that a survey effort of 840 km of transects was flown to the slightly larger Central Tablelands North zone for a more than acceptable outcome in terms of precision of estimation. While increasing survey effort would most likely improve precision, redefining the boundaries of the three survey strata within the zone could achieve a favourable outcome at much less cost. It is anticipated that, now that both the Central Tablelands kangaroo management zones have been surveyed on two occasions, there will be enough information available to effectively redesign the boundaries of the survey strata of each of them.

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. 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 helping the flight crew plan each day's survey. Scott Bowers and his crew provided excellent and obliging service with the helicopter. Their attention to OH&S issues was well appreciated. Scott Seymour more than ably filled a seat as an experienced observer and Mike Saunders obligingly continued his training as an observer. Natasha Crook and Nereda Christian provided invaluable GIS support with regard to the design of the survey and production of the final report.

7. References

Anon. (2006). *New South Wales Commercial Kangaroo Management Plan 2007-2011*. Department of Environment and Conservation. 63 pp.

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. A., Burnham, K. P., Laake, J. L., Borchers, D. L. and Thomas, L. (2001). *Introduction to Distance Sampling: estimating abundance of biological populations*. Oxford University Press, Oxford.

Cairns, S. C. (2003). *A report to the New South Wales National Parks & Wildlife Service on the consultancy: Kangaroo Monitoring New England Tablelands Helicopter Survey.* Unpublished report to New South Wales National Parks & Wildlife Service, Dubbo, NSW. 18 pp.

Cairns, S. C. (2004a). *A report to the New South Wales Department of Environment and Conservation on the consultancy: Kangaroo Monitoring – Redesign and Analysis of the Northern Tablelands Region Helicopter Survey.* Unpublished report to New South Wales National Parks and Wildlife Service, Dubbo, NSW. 45 pp.

Cairns, S. C. (2004b). *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. (2007a). *A report to the New South Wales Department of Environment and Climate Change on the consultancy: 'Kangaroo Monitoring – Design and Analysis of the Northern Tablelands Region Helicopter Survey'.* Unpublished report to New South Wales National Parks and Wildlife Service, Dubbo, NSW. 40 pp.

Cairns, S. C. (2007b). *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 Lollback, G. W. (2008). *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. 45pp.

Cairns, S. C., Lollback, G. W. and Bearup, D. (2009). *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 Office of Environment and Heritage, Dubbo, NSW. 49 pp.

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.

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.

New South Wales National Parks & Wildlife Service. (2001). *The New South Wales Kangaroo Management Program. A management program for the utilisation of four kangaroo species in NSW.* (New South Wales National Parks and Wildlife Service: Sydney) http://www.nationalparks.nsw.goc.au/npws.nsf/Contents/Kangaroo+management+program

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

Pople, A. R. (2003). Harvest Management of Kangaroos during Drought. Unpublished report to New South Wales National Parks & Wildlife Service, Dubbo, NSW. 27 pp.

Pople, A. R. (2008). Frequency and precision of aerial surveys for kangaroo management. *Wildlife Research* **35**: 340-348.

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

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

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., & 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. and 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. and 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 2. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. 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 two Central Tablelands kangaroo management zones

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 two kangaroo management zones surveyed. The survey are each identified in relation to the survey stratum to which they belong within a management zone by the second letter of their identification code (H = high, M = medium).

Transect	Length (*km*)	No. of sightings	Raw counts *EGK*	*CW*	*RNW*	*SW*
Central Tablelands North						
MH01	10.0	31	63	4	-	-
MH02	10.0	4	7	2	-	-
MH03	10.0	129	3	4	-	-
MH04	10.0	50	142	2	2	4
MH05	10.0	57	100	6	2	5
MH06	10.0	30	33	3	-	2
MH07	10.0	9	21	-	-	-
MH08	10.0	6	45	-	-	-
MH09	10.0	37	91	5	-	-
MH10	10.0	16	39	-	-	-
MH11	10.0	3	5	-	-	-
MH12	10.0	6	10	2	-	-
MH13	10.0	3	2	-	-	2
MH14	10.0	7	9	-	2	-
MH15	10.0	5	13	-	-	-
MH16	10.0	10	21	7	1	-
MH17	10.0	21	67	2	2	-
MH18	10.0	3	2	6	-	-
MH19	10.0	4	14	-	-	1
MH20	10.0	13	203	-	-	-
MH21	10.0	3	2	-	-	1
MH22	10.0	13	34	7	1	2
MH23	10.0	7	35	-	-	-
MH24	10.0	4	12	-	-	1
MH25	10.0	5	16	-	-	1
MH26	10.0	21	40	2	-	1
MH27	10.0	6	22	-	-	-
MH28	10.0	3	7	1	-	-
MH29	10.0	2	2	1	-	-
MH30	10.0	27	56	2	-	2
MH31	10.0	26	85	1	-	-
MH32	10.0	1	2	-	-	-
MH33	10.0	22	53	-	-	2
MH34	10.0	8	19	-	-	1
HM01	10.0	13	14	-	5	5

HM02	10.0	31	24	14	7	12
HM03	10.0	53	72	9	2	5
HM04	10.0	21	40	9	-	-
HM05	10.0	15	42	3	-	2
HM06	10.0	22	46	18	1	1
HM07	10.0	35	40	13	1	4
HM08	10.0	18	34	1	1	4
HM09	10.0	48	73	18	-	-
HM10	10.0	21	28	2	-	3
HM11	10.0	12	18	8	-	-
HM12	10.0	22	30	9	-	1
HM13	10.0	5	11	-	-	-
HM14	10.0	45	18	10	8	16
HM15	10.0	9	14	2	1	-
HM16	10.0	3	5	-	-	-
HM17	10.0	24	31	10	-	-
HM18	10.0	4	19	-	-	-
HM19	10.0	28	182	-	1	-
HM20	10.0	11	31	-	-	-
HM21	10.0	7	13	2	1	-
HM22	10.0	6	4	-	-	2
HM23	10.0	-	-	-	-	-
HM24	10.0	19	47	-	-	1
HM25	10.0	30	50	-	8	10
HM26	10.0	11	25	-	-	2
HM27	10.0	7	12	-	-	2
HM28	10.0	24	56	-	-	7
HM29	10.0	6	15	1	-	-
MM01	10.0	7	18	-	-	-
MM02	10.0	5	14	-	-	-
MM03	10.0	6	10	1	-	-
MM04	10.0	13	34	-	-	5
MM05	10.0	5	-	2	1	3
MM06	10.0	23	80	1	-	-
MM07	10.0	17	42	2	-	-
MM08	10.0	-	-	-	-	-
MM09	10.0	-	-	-	-	-
MM10	10.0	4	15	-	-	-
MM11	10.0	1	1	-	-	-
MM12	10.0	33	115	1	-	-
MM13	10.0	3	3	2	-	-
MM14	10.0	16	37	1	1	3
MM15	10.0	21	57	1	-	-
MM16	10.0	10	19	1	-	-
MM17	10.0	20	57	-	-	-
MM18	10.0	3	11	-	-	-

MM19	10.0	16	65	-	-	-
MM20	10.0	6	37	-	-	-
MM21	10.0	6	17	-	-	-
Central Tablelands South				-	-	-
CH01	10.0	1	1			
CH02	10.0	8	22	-	-	-
CH03	10.0	11	42	-	-	-
CH04	10.0	24	50	-	-	1
CH05	10.0	7	12	-	1	1
CH06	10.0	4	7	-	-	2
CH07	10.0	2	6	-	-	-
CH08	10.0	4	1	-	-	3
CH09	10.0	20	69	-	-	1
CH10	10.0	5	12	1	-	-
CH11	10.0	13	22	2	-	1
CH12	10.0	11	16	1	-	1
CH13	10.0	10	10	3	1	1
CH14	10.0	35	119	1	1	3
CH15	10.0	6	10	-	-	-
CH16	10.0	39	106	2	-	4
CH17	10.0	7	11	-	1	1
CH18	10.0	12	23	1	-	1
CM01	12.0	3	3	-	1	-
CM02	12.0	-	-	-	-	-
CM03	12.0	6	24	-	-	-
CM04	12.0	1	-	-	-	1
CM05	12.0	2	9	-	-	-
CM06	12.0	-	-	-	-	-
CM07	12.0	10	30	1	-	2
CM08	12.0	1	2	-	-	-
CM09	12.0	6	4	-	-	3
CM10	12.0	2	3	-	-	-
CM11	12.0	2	5	-	-	-
CM13	12.0	20	69	-	-	1
CM14	12.0	3	15	-	-	-
CM15	12.0	4	8	-	-	-
CM17	12.0	4	18	-	-	-
CM18	12.0	6	14	-	-	-
CM19	12.0	-	-	-	-	-
CM20	12.0	7	5	-	-	3
CM21	12.0	2	6	-	-	-
CM23	12.0	1	-	-	-	1
CM24	12.0	24	73	2	-	-
CM25	12.0	5	10	-	-	-

CM26	12.0	1	1	-	-	-
CM28	12.0	10	26	-	-	-
CM29	12.0	8	46	-	-	1
CM30	12.0	2	5	-	-	-
CM31	12.0	5	11	1	-	-
CM32	12.0	12	48	-	-	-
CM33	12.0	4	6	-	-	-
CM34	12.0	2	10	-	-	-
CM35	12.0	3	2	-	1	-
CM36	12.0	5	1	1	-	2
CM37	12.0	9	35	-	-	-
CM38	12.0	3	4	1	-	-
CM39	12.0	1	-	-	-	1
CM40	12.0	3	5	-	-	-
CM42	12.0	6	8	-	-	1

Appendix 2

The detection function models for eastern grey kangaroos (*M. giganteus*), common wallaroos (*M. r. robustus*) and swamp wallabies (*W. bicolour*) in the strata surveyed within the two Central Tablelands kangaroo management zones.

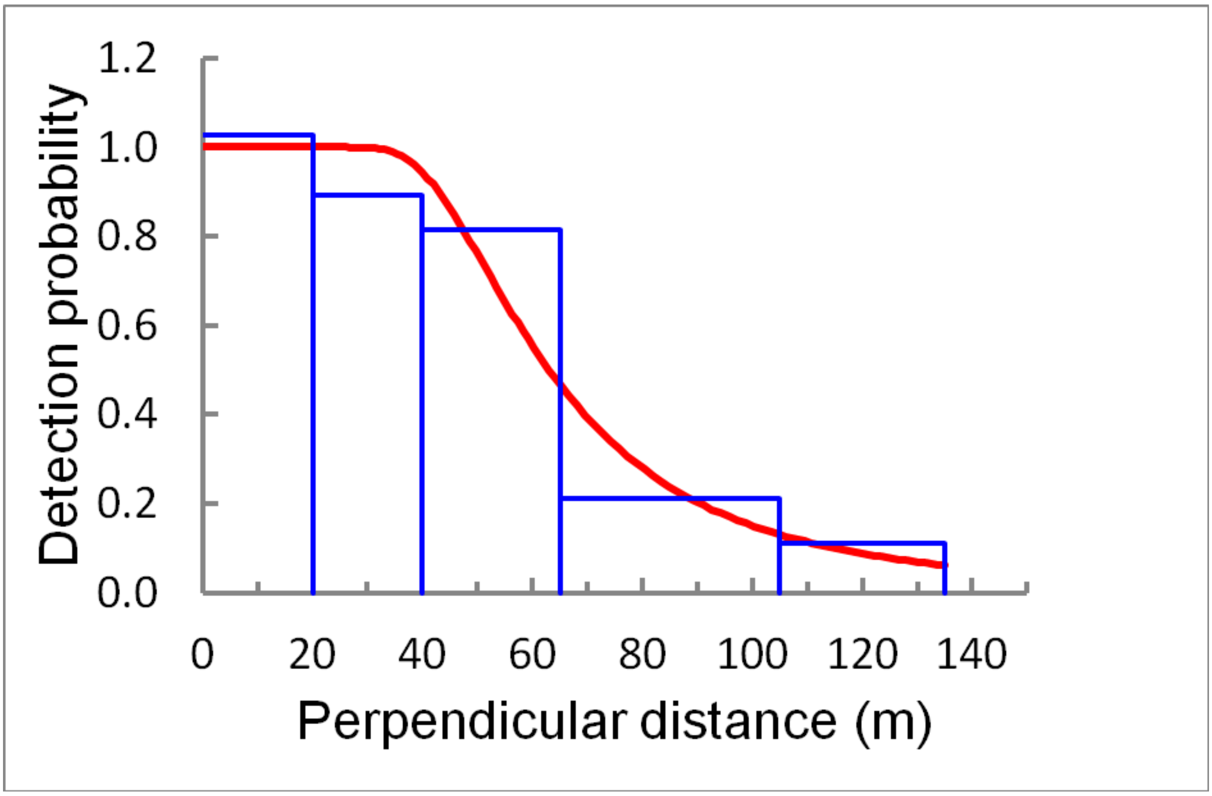
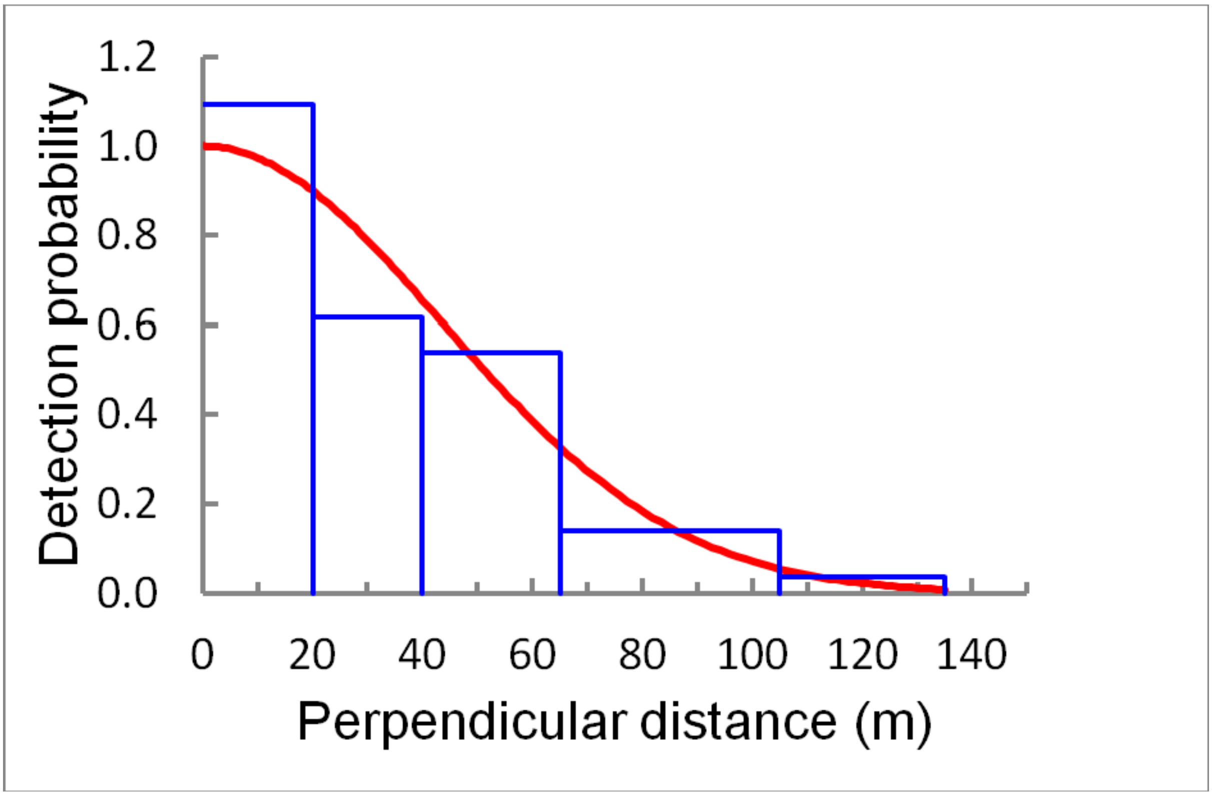


Figure A2.1. The Hazard-rate detection function for eastern grey kangaroos in the Mudgee-high stratum of the Central Tablelands North kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see Table 2).



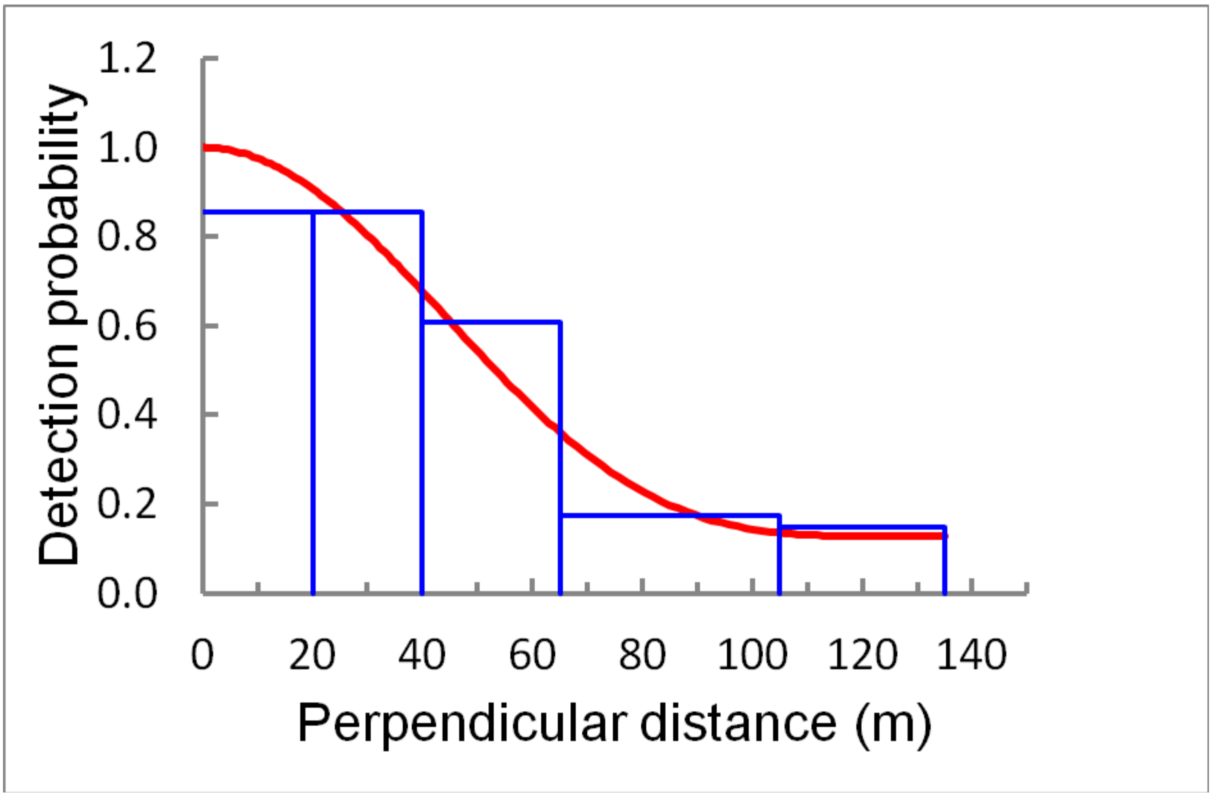


Figure A2.2. The Half-normal (top) and Uniform/Cosine (bottom) detection functions for eastern grey kangaroos in the Mudgee-medium stratum of the Central Tablelands North kangaroo management zone. These detection functions were derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see Table 2). For the analysis, the data were post-stratified by observer: DB (top) and SS (bottom).

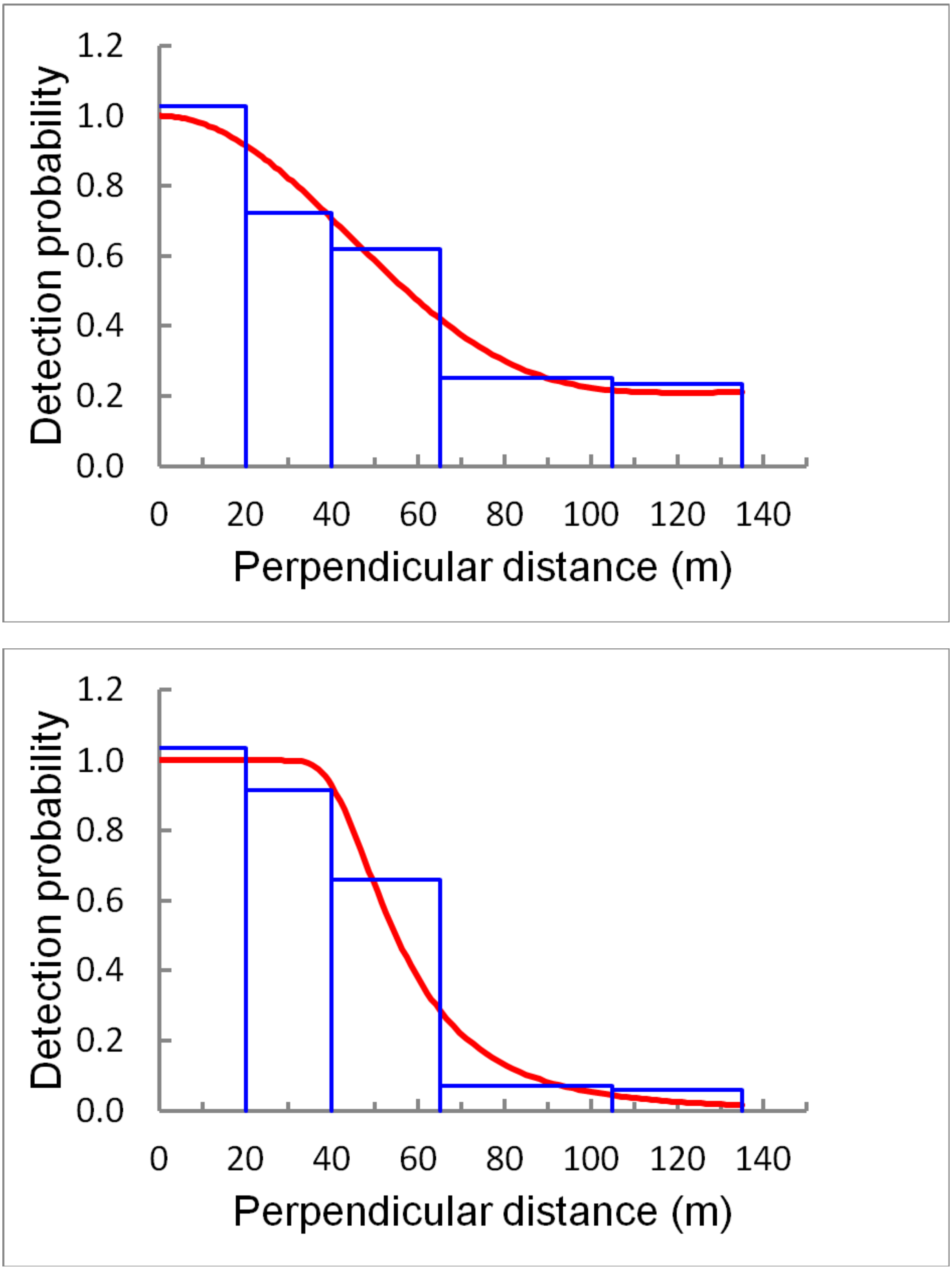


Figure A2.3. The Uniform/Cosine (top) and Hazard-rate (bottom) detection functions for eastern grey kangaroos in the Hunter-medium stratum of the Central Tablelands North kangaroo management zone. These detection functions were derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see Table 2). For the analysis, the data were post-stratified by observer: DB (top) and SS (bottom).

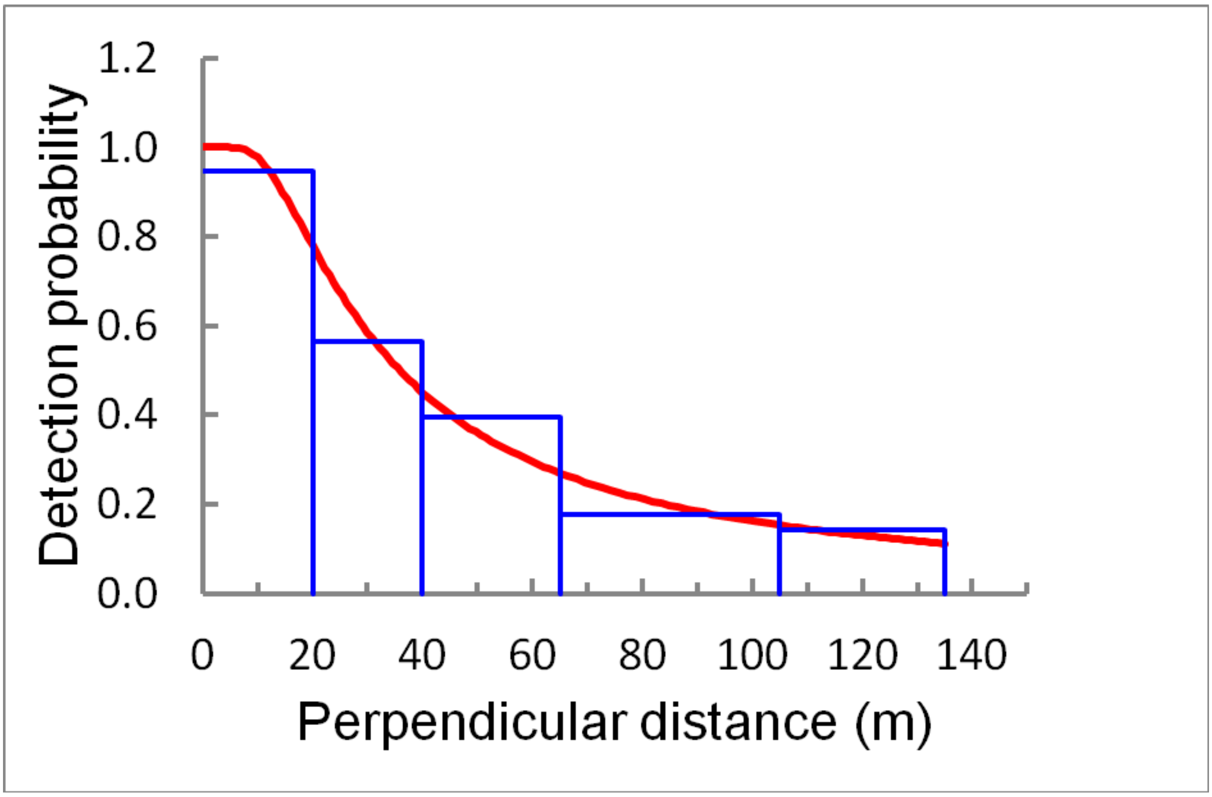


Figure A2.4. The Hazard-rate detection function for eastern grey kangaroos in the high density stratum of the Central Tablelands South kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see Table 2).

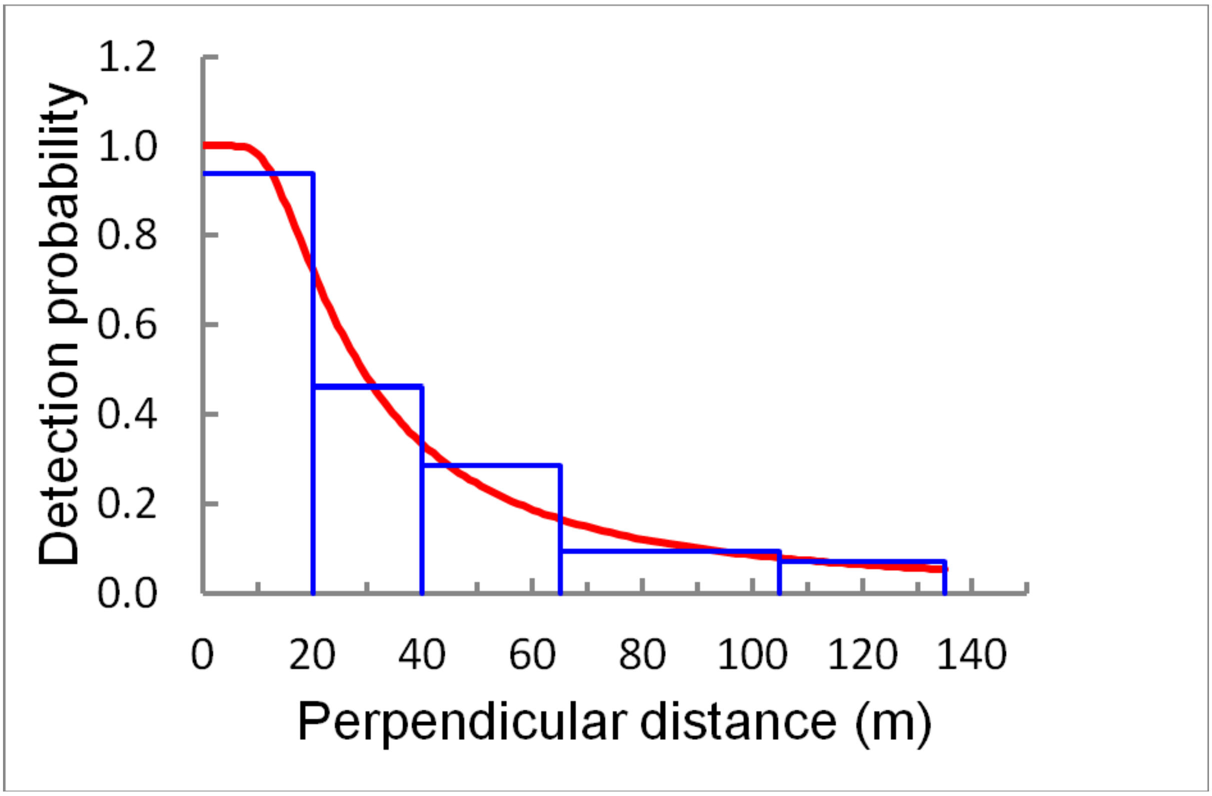


Figure A2.5. The Hazard-rate detection function for eastern grey kangaroos in the medium density stratum of the Central Tablelands South kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see Table 2).

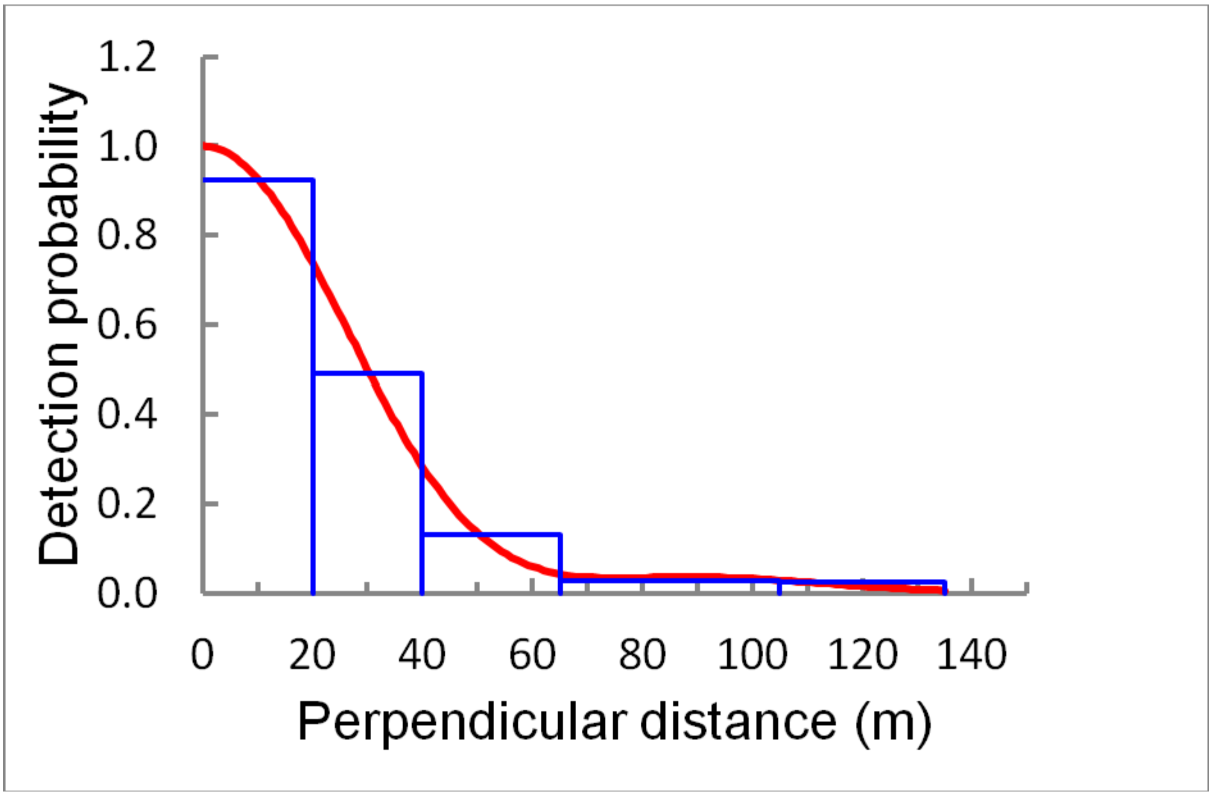


Figure A2.6. The Half-normal/Cosine detection function for common wallaroos in the Central Tablelands North kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see Table 5).

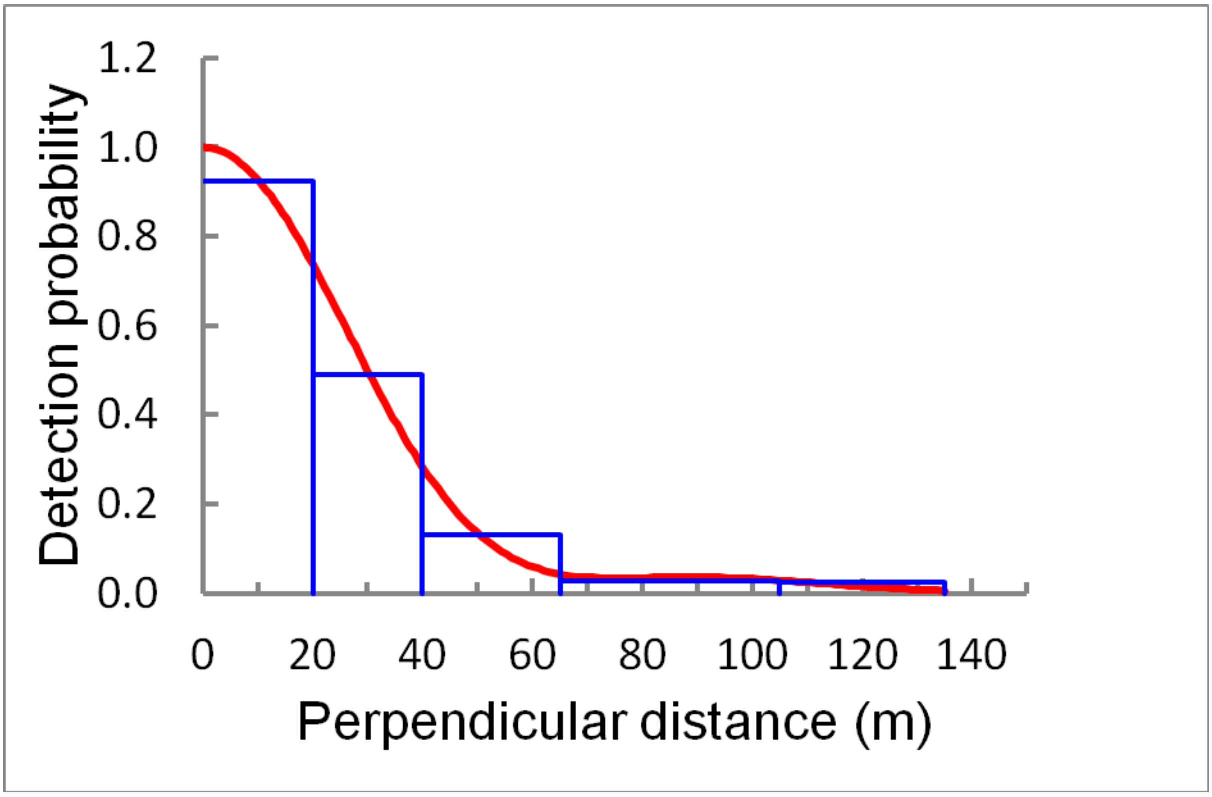


Figure A2.7. The Half-normal/Cosine detection function for swamp wallabies in the Central Tablelands North kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see Table 5).

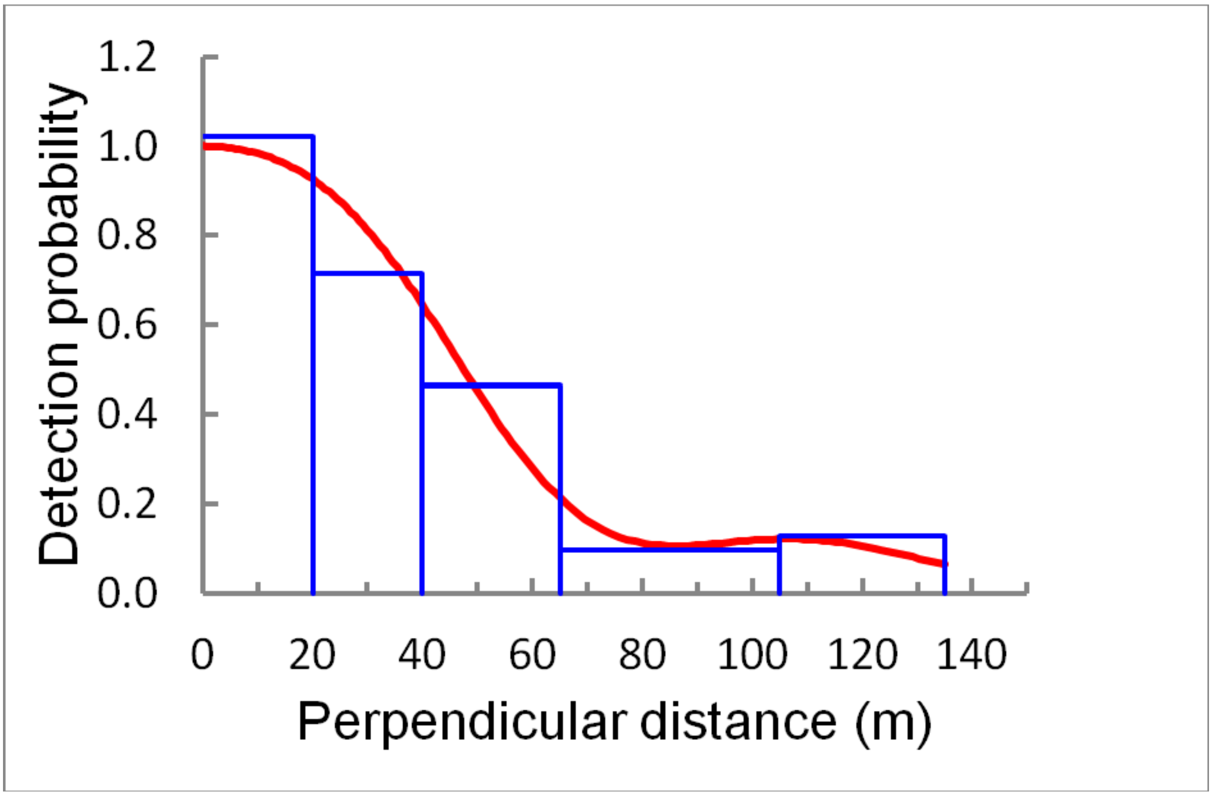


Figure A2.8. The Half-normal/Cosine detection function for common wallaroos in the Central Tablelands South kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see Table 5).

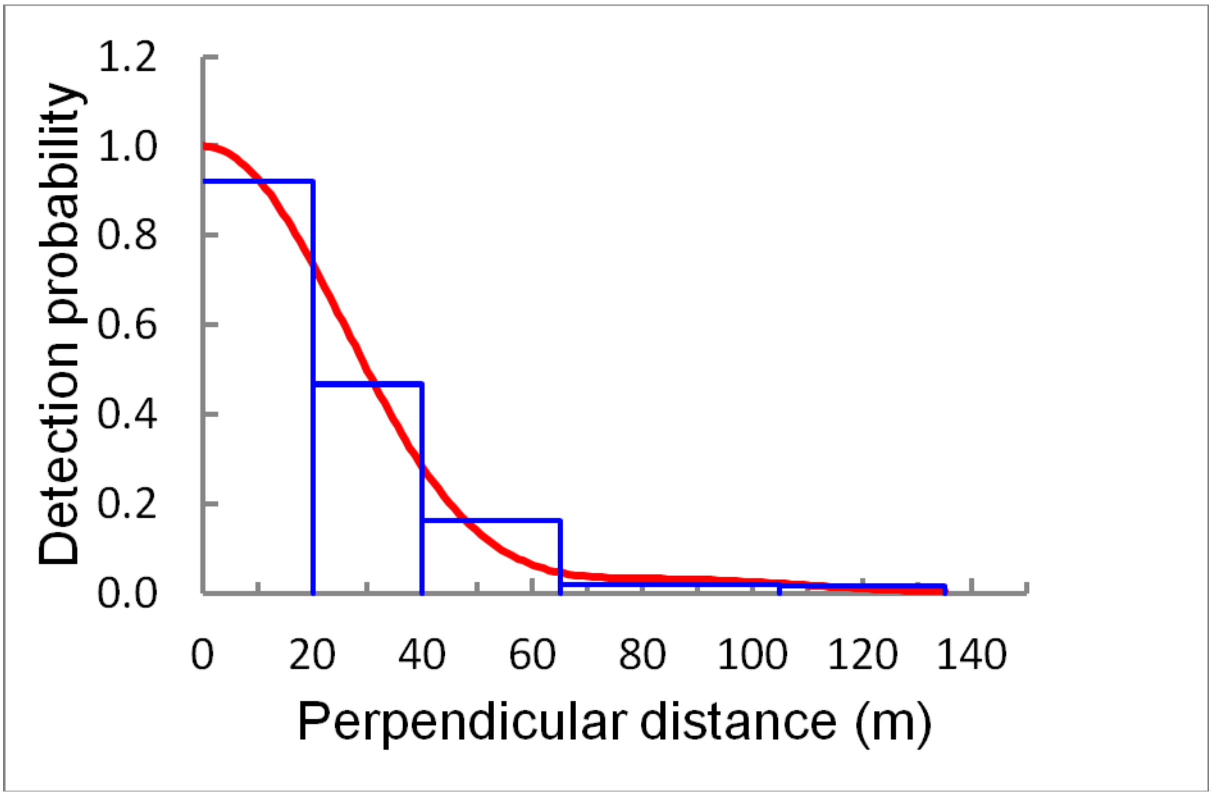


Figure A2.9. The Half-normal/Cosine detection function for swamp wallabies in the Central Tablelands South kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.0 (for further details, see Table 5).