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, 2014".

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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 third conducted in these zones for the purpose of providing estimates of kangaroo numbers for the management of the commercial kangaroo harvest. The previous surveys were conducted in 2008 and 2011.
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 sufficient data to estimate the densities of eastern grey kangaroos, common wallaroos and swamp wallabies. These surveys were designed with the aim of obtaining eastern grey kangaroo population estimates with coefficients of variation of 20%. The coefficients of variation for the population estimates obtained for eastern grey kangaroos in the two management zones was of the order of 10%.
4. Eastern grey kangaroo densities were estimated as being 47.23 km^{-2} in the Central Tablelands North management zone and 34.35 km^{-2} in the Central Tablelands South management zone. These densities correspond to population estimates of 1,193,600 and 811,800 kangaroos, respectively.
5. The densities of wallaroos were 3.05 km^{-2} in the Central Tablelands North zone and 1.52 km^{-2} Central Tablelands South zone. The densities of swamp wallabies were 1.19 km^{-2} and 0.89 km^{-2}, respectively.
6. Only eastern grey kangaroos are harvested commercially in the two management zones.

1. Introduction

All states and territories of the Commonwealth of Australia administer, in one form or another, macropod management plans that are aimed principally at the management of the four common species of large kangaroos. An integral part of a number of these kangaroo management plans is the conduct of sustainable, commercial harvesting of one or more of these species (Pople & Grigg 1998). Commercial harvesting is undertaken in Queensland, New South Wales, South Australia, Western Australia and Tasmania. In Tasmania, only one of the four large species of kangaroo is endemic and it is not harvested. The harvested species are two smaller species of macropod; a species of wallaby and a species of pademelon. Commercial harvesting is not currently part of kangaroo management in Victoria, the Australian Capital Territory or the Northern Territory.

In those states where it occurs, commercial 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 appropriate harvest quotas, it is necessary to obtain precise and accurate estimates of the sizes of the kangaroo populations proposed to be harvested. Species-specific quotas are set as proportions of these population estimates.

In NSW, the commercial harvesting of kangaroos is managed in relation to a number of kangaroo management zones established across the inland parts of the state, extending from the tablelands of the Great Dividing Range in the east to the South Australian border in the west (see Fig. 1). Some or all four of those species of macropod identified as large kangaroos, the red kangaroo (*Macropus rufus*), the eastern grey kangaroo (*M. giganteus*), the western grey kangaroo (*M. fuliginosus*) and the common wallaroo (*M. robustus robustus*) are currently harvested from within 14 kangaroo management zones (Anon. 2011).

In New South Wales, the necessary accurate and precise estimates of the sizes of the kangaroo populations proposed to be harvested are obtained using two methods. For the eight inland kangaroo management zones (see Fig. 1), annual population estimates are obtained from broad-scale aerial surveys conducted using fixed-wing aircraft (Anon. 2011). Harvest quotas are set in relation to these population estimates (Gilroy 1999). Because of the general relief of the landscape in those management zones that cover the tablelands and western slopes of the Great Dividing Range, the kangaroo populations there cannot be surveyed using fixed-wing aircraft. They are, instead, currently surveyed on a triennial basis using helicopters, with annual harvest quotas being set retrospectively in relation to the triennial population estimates (Anon. 2011). Conducting these surveys triennially is considered to be a safe option for monitoring kangaroo populations in mesic as opposed to semi-arid rangeland environments (Pople 2003; Payne 2007). The risk of quasi-extinctions occurring in relation the setting of harvest quotas using triennial population estimates is relatively low in mesic environments (Pople 2008). The suitability and effectiveness of helicopter surveys has been demonstrated by Clancy *et al.* (1997), Clancy (1999) and Southwell and Sheppard (2000).

The kangaroo management zones that are surveyed triennially include the three zones in the Northern Tablelands region, the two zones in the Central Tablelands region and the South East NSW zone (Anon. 2011).

Triennial surveys have been conducted in the three Northern Tablelands management zones since 2004 (Cairns *et al.* 2013a), in the South East NSW kangaroo management zone since 2006 (Cairns *et al.* 2013b) and in the two Central Tablelands management zones since 2008 (Cairns & Bearup 2012). Reported here, along with the survey design, survey and data analysis methods used, are the results of a third triennial survey conducted in the two Central Tablelands management zones in September 2014.

2. Survey Areas

The two kangaroo management zones (KMZ) in the Central Tablelands region of NSW are shown in Fig. 1 as Zone 48 (Central Tablelands North) and Zone 49 (Central Tablelands South).

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). The eastern boundary lies between the towns of

Singleton (32° 32' 27" S, 151° 9' 42" E) and Branxton (32° 39' 22" S, 151° 21' 15" E) in the Hunter Valley. The zone is bounded in the west by the Coonabarabran kangaroo management zone (Zone 10), with its western boundary being southwest of the township of Wellington (32° 33' 20" S, 148° 56' 35" E).

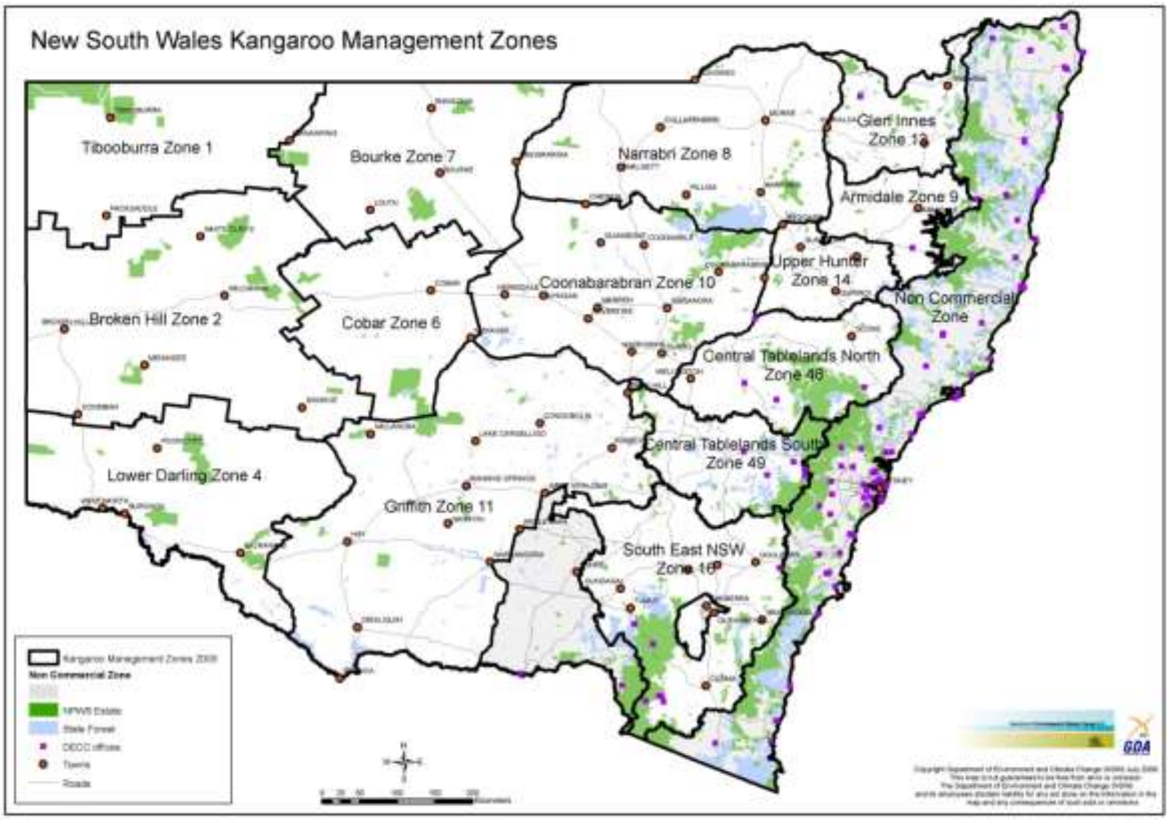

Fig. 1. The 14 kangaroo management zones in NSW administered by the Office of Environment and Heritage. The two Central Tablelands kangaroo management zones are Zone 48 and Zone *49*.

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, it falls within the Brigalow Belt South Biogeographic Region (IBRA) towards the north and 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 *et al.* 2013).

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 lies east of Bathurst (33º 25’ 00” S, 149º 34’ 00” E), in line with the township of Wallerawang (33º 24’ 40” S, 150º 03’ 51” E). It is bounded in the west by the existing Griffith kangaroo management zone (Zone 11); its western boundary being to the east of the townships of Parkes (33º 08’ 00” S, 148º 10’ 00” E) and Forbes (33º 22’ 00” S, 148º 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 only small proportions of their total areas. The principal land use on this freehold land is the grazing of domestic livestock, with grain and oilseed crops comprising 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 very steep, timbered country were deemed to be areas supporting zero to very low densities of kangaroos and were therefore excluded from the areas to be surveyed. The remaining areas were divided on the basis of supporting either relatively 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 recognised as a standard procedure (Cairns *et al.* 2012, 2013), 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 6.2 (Thomas *et al.* 2009). Required to undertake this are GIS shape files for the two management zones and estimates of the survey effort for the survey stratum, i.e. the total length of transect to be surveyed. These survey efforts are determined in relation to particular levels of precision (see below); with only the high and medium density strata of each zone being surveyed.

To enhance the survey design, each management zone was divided into three strata; the boundaries of which are defined in relation to land capabilities and kangaroo density; with reference to the raw survey count information obtained from previous surveys (e.g., Cairns & Lollback 2008; Cairns *et al.* 2012). Defining density strata in relation to the most recent knowledge of kangaroo densities for the purpose of 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

GIS shape files for the two Central Tablelands kangaroo management zones showing land capability attributes were obtained from NSW OEH. 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 the location of state forests, gazetted reserves and national parks, all of which were excluded from the survey areas of each zone. The eight categories of land capability were merged into a smaller number of broader categories to form the initial basis of the three strata to be used in the survey design process.

Land capability attribute 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. Land capability attribute 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 stratum, while 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 stratum. The boundaries of the merged strata were modified in relation to available kangaroo density and raw count information, and 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 & Lollback 2008). The outcomes of the 2008 survey and the 2011 survey (Cairns *et al.* 2012) 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 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.

3.2 Survey Effort

In line transect sampling, survey effort is defined as the total length of transect surveyed. Although ultimately constrained by cost, survey effort is generally determined in relation to some desired level of precision (i.e. the ratio of standard error to mean). In the conduct of surveys such as the one reported upon here, aiming for a general level precision of 20% would appear to be realistic and reasonably cost-effective (Pople *et al.* 2003; Cairns & Lollback 2008; Cairns *et al.* 2012). For the Central Tablelands North management zone, survey effort for each of the three strata to be surveyed was determined broadly in relation to a target level of precision of 17.5%. For the Central Tablelands South management zone, survey effort for the two strata to be surveyed was determined broadly in relation to a target level of precision of 25%. Overall cost was a constraining factor here.

Table 1. Areas (km^2) of the two Central Tablelands kangaroo management zones divided into three survey strata based upon land capability and kangaroo density.

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

To determine the survey effort required, the method proposed by Buckland *et al.* (2001, p. 243) was used in relation to the precision (measured by the coefficient of determination) of the surveys completed in 2011 (Cairns *et al.* 2012). The survey efforts determined for the high and medium density strata in each of the two kangaroo management zones are given in Table 2. No survey effort was allocated to the low density strata of either of the management zones. Low density strata, which comprised either areas dedicated to cropping or areas of heavily timbered and rugged terrain, were thought to support only trace numbers of kangaroos (Southwell *et al.* 1995; Cairns 2003).

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 6.2 (Thomas *et al.* 2009) increases the likelihood that an optimal design will be achieved (Strindberg *et al.* 2004).

Table 2. The proposed survey efforts determined for a specified coefficient of variation using the method of Buckland *et al.* (2001) and the actual survey efforts applied during the survey.

Survey stratum	Nominal survey effort (km)	Actual survey effort (km)
Central Tablelands North		
High	285.0	300.0
Mudgee-medium	235.0	202.5
Hunter-medium	175.0	190.0
Central Tablelands South		
High	225.0	262.5
Medium	720.0	630.0

DISTANCE 6.2 offers four different classes of 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 do not have 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. This design was tested for survey coverage against a systematic random and a systematic segmented trackline 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 the underlying assumption that the distribution of objects from the transect line is uniform out to the truncation distance; which would not be the case 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 different 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 at either 7.5 km or 10 km in length. For the Central Tablelands North zone, the selected survey designs comprised forty 10-km long transects in the Mudgee-high stratum, twenty-seven 7.5-km long transects in the Mudgee-medium stratum and nineteen 10-km long transects in the Hunter-medium stratum (Fig. 2). For the Central Tablelands South zone, the selected survey designs comprised thirty-five 7.5-km long transects in the high density stratum and eighty-four 7.5-km long transects in the medium density stratum (Fig. 3). The high level of survey effort directed towards this latter stratum was because of the resultant poor precision of the last survey conducted in this stratum (Cairns & Bearup 2012).

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 5-11 September 2014, in accordance with the survey designs developed above (see Section 3.3). Only the 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.

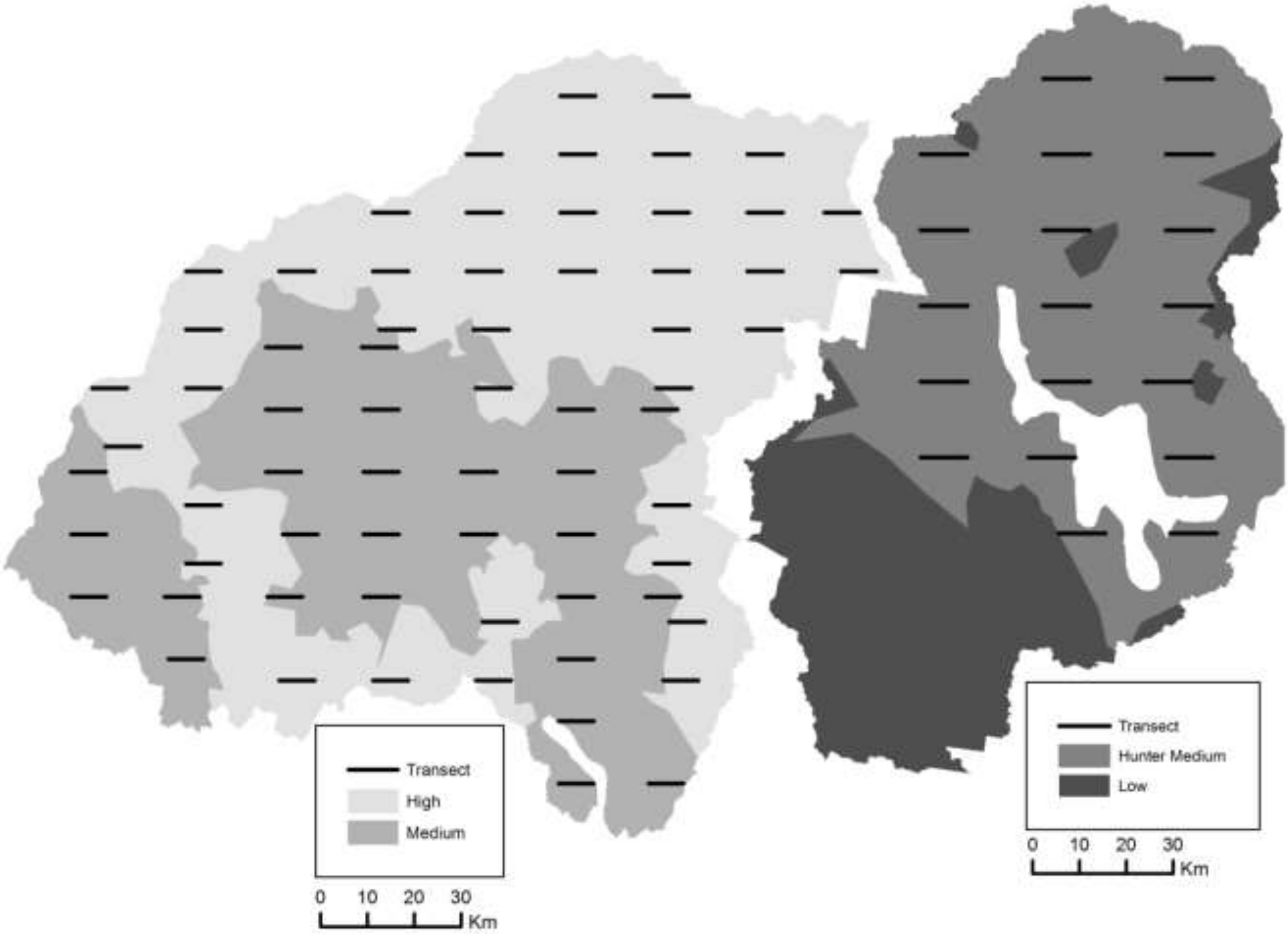

Fig. 2. The Central Tablelands North kangaroo management zone. Shown are the three survey strata; the medium kangaroo density stratum in this case being divided two sub-strata (see legends: Medium and Hunter Medium). The open-cast coal mining area of the Hunter Medium sub-stratum (white) was not considered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

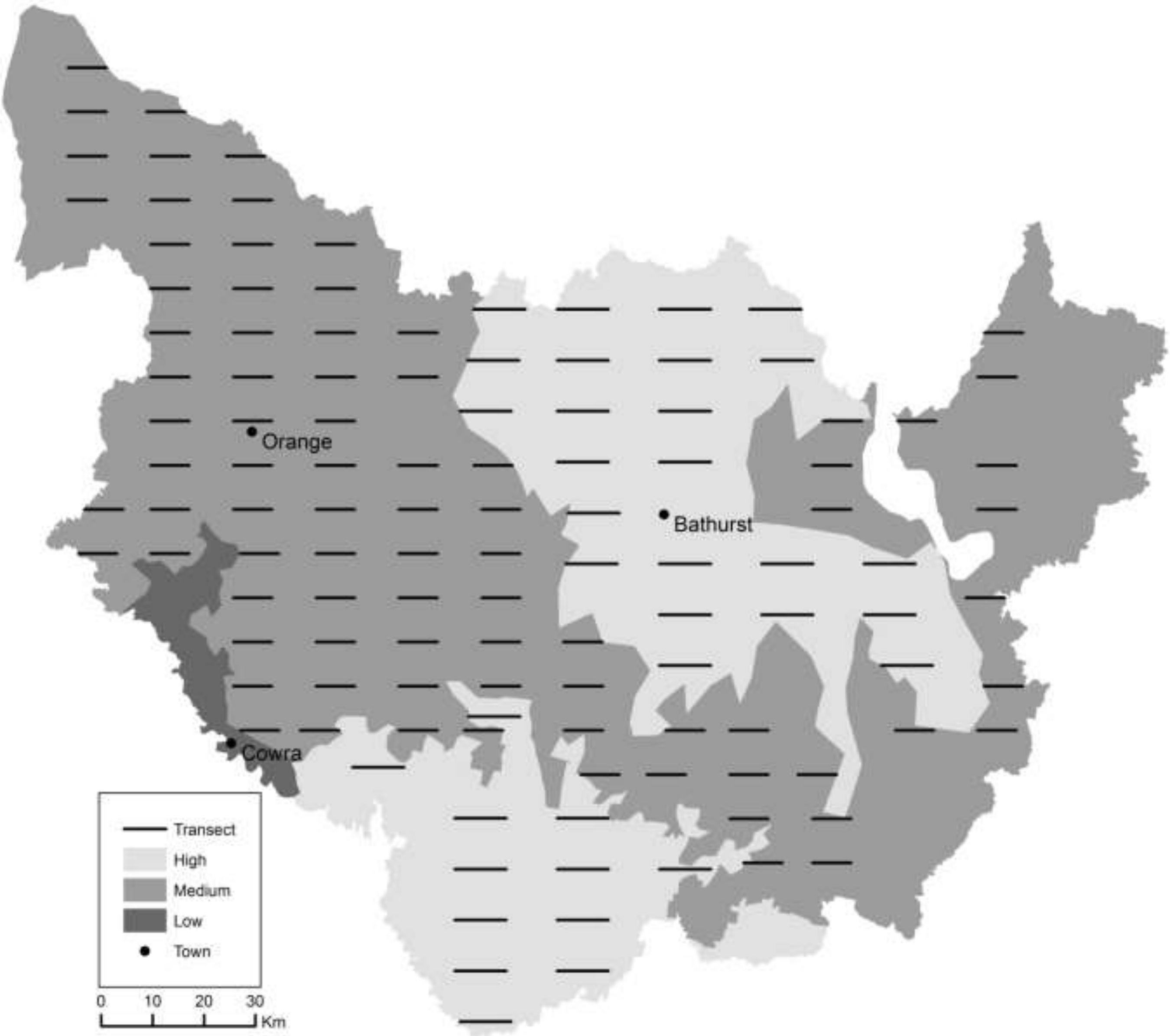

Fig. 3. The Central Tablelands South kangaroo management zone. Shown are the three survey strata, the population centres (towns) and the placement of the survey transects within the high and medium kangaroo density strata. Note that no survey transects were placed into the low density stratum.

All allocated transects were flown during the survey. In the Central Tablelands North zone (KMZ 48), 40 transects were flown in the high density stratum, 27 transects were flown in the Mudgee-medium stratum and 19 transects were flown in the Hunter-medium stratum. In the Central Tablelands South zone (KMZ 49), 35 transects were flown in the high density stratum and 84 transects were flown in the medium density stratum.

All surveys were conducted within either the 2-3 hour period following sunrise or the 2-3 period before sunset. David Bearup (NPWS), Scott Seymour (NPWS) and Mike Saunders (NPWS) were rotated as observers. Paul Caristo was the 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 Bell LongRanger, with the two rear doors removed was flown along each transect line at a ground speed of 93 km h^{-1} (50 kts) and at a height of 61 m (200 ft) above the ground. Navigation was by a global positioning system (GPS) receiver (Garmin GPSMAP 275c©). 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. r. robustus*), red-necked wallabies (*M. rufogriseus*) and swamp wallabies (*Wallabia bicolor*) seen in the different delineated distance classes from the helicopter were voice-recorded. The presence of other, non-target species was noted. Voice-recorded information was transcribed at the end of each survey session. The survey transects were either 7.5 km or 10 km in length. Because no rest breaks were taken by the observers on any transect during the survey sessions, for the purpose of data analysis, all transect lengths were exact and equal to those allocated survey in the original survey designs.

4.2 Data Analysis

The analysis of distance sampling data such as those collected here first involves the estimation of the detection probability of clusters of animals within the covered region (the designated survey strip), then the estimation of the density of animals within the covered region given this detection probability and, finally, the estimation of the number of animals in the survey region given the density of animals in the covered region (Borchers & Burnham 2004). Survey results were recorded as the sightings of clusters of kangaroos within distance classes 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 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). The determination of the value of P_a is integral to the density estimation process.

To do this, the data from the helicopter line transect surveys, which were in the form of the sizes of clusters of animals sighted within the listed distance categories, were analysed using DISTANCE 6.2 (Thomas *et al.* 2009; Thomas *et al.* 2010). DISTANCE 6.2 has three different analysis engines for estimating the detection function (Thomas *et al.* 2009). Two of these, the conventional distance sampling (CDS) analysis engine and the multiple-covariate distance sampling (MCDS) analysis engine were used here. For the analysis, data for each management zone were stratified on the basis of the stratification used in the design and conduct of the surveys.

For analyses using the CDS analysis engine, comparisons were made amongst a suite of six detection function models. Each of these models comprised a key function that, if required, can be adjusted by a cosine or polynomial series expansion containing one or more parameters (Buckland *et al.* (2001). The different models considered were: a 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. Although post-stratification can be used as part of the model fitting process with the CDS analysis engine, this was precluded from being used in the present analyses because of the rotation of three observers and the decision to use stratification as part of the process.

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.* 2009). These covariates can be either factor (qualitative or categorical) or non-factor (continuous) and have the 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.* 2009). Covariates used in these analyses were related to individual detections of clusters of kangaroos and were identified as observer, survey aspect and cloud cover. These were included in the analyses separately and in pairs. 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.

In determining kangaroo densities using these analysis engines, if the observed sizes of detected clusters (s) are independent of distance from the transect 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 observed in the study area. If, however, the observed sizes of detected clusters are found to be dependent upon the perpendicular distance from the transect line, then, $\bar{s}$ is replaced by a value determined from a regression of this relationship (Buckland *et al.* 2001).

The results of the analyses conducted using the range 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 x log-likelihood + 2[p +1]*; where *p* is the number of parameters in the model) was generally selected as the detection function. However, 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 functions; with any model with an unrealistic spike at zero distance, rather than a distinct 'shoulder' near the transect line, being likely to be rejected. Although available as an option to improve goodness-of-fit, no manipulation of the grouping intervals was undertaken for this purpose.

While population 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 each analysis engine and not just the model selected to determine the empirical estimates. This was expected to improve the robustness of the estimation of these statistics (Buckland *et al.* 2001). The 95% confidence limits presented were the 2.5% and 97.5% quantiles of the respective bootstrap estimates.

The data were analysed to determine separate kangaroo population density and abundance estimates for the high and medium density strata of each management zone, with these estimates being combined to produce whole-zone estimates of density and abundance.

Eastern grey kangaroo data were analysed at the level of survey stratum within management zone. Data for the less common species were analysed at the level of survey area (high and medium density strata combined) within 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). Of the three strata within each zone, only the high and medium kangaroo density strata were surveyed. The low density stratum was assumed to support fewer than trace numbers of kangaroos and was therefore not surveyed.

In the Central Tablelands North kangaroo management zone (Zone 48, Fig. 1), 40 transects comprising 300 km of survey effort were flown across the high density stratum (Fig. 2). A total of 2,283 eastern grey kangaroos were counted on these transects, along with 66 wallaroos. Of the other species of macropod present, there were 29 swamp wallabies (*Wallabia bicolor*) counted, but no sightings made of red-necked wallabies (*M. rufogriseus*). Twenty-seven transects comprising 202.5 km of survey effort were flown across the Mudgee-medium density stratum (Fig. 2). A total of 1,318 eastern grey kangaroos were counted on these transects, along with 17 wallaroos, and 14 swamp wallabies. No red-necked wallabies were sighted. Nineteen transects comprising 190 km of survey effort were flown across the Hunter-medium density stratum (Fig. 2). A total of 910 eastern grey kangaroos were counted on these transects, along with 59 wallaroos and 19 swamp wallabies. Four red-necked wallabies were also sighted on these transects. As well as the sightings of macropods, there were also incidental sightings made in all three survey strata of feral goats (*Capra hircus*), feral pigs (*Sus scrofa*), deer and foxes (*Vulpes vulpes*). The numbers of clusters of macropods sighted on each transect and the total raw counts of each macropod species comprising these sightings are given in Appendix 1,Table A1.

In the Central Tablelands South zone (Zone 49, Fig. 1), 35 transects comprising 262.5 km of survey effort were flown across the high density stratum (Fig. 3). A total of 1,833 eastern grey kangaroos were counted on these transects, along with 32 wallaroos and 30 swamp wallabies. Eighty-four transects comprising 630 km of survey effort were flown across the medium density stratum of this zone (Fig. 3). A total of 2,395 eastern grey kangaroos were counted on these transects, along with 33 wallaroos and 34 swamp wallabies. No red-necked wallabies were sighted in either stratum. As well as the sightings of macropods, a small number of sightings were made across both strata of feral goats, feral pigs and foxes. The numbers of clusters of macropods sighted on each transect and the total raw counts of each macropod species comprising these sightings are given in Appendix 1,Table A1.

In determining population estimates for kangaroos and wallabies in each of the two management zones, where it was possible to do so, data were analysed separately for each survey stratum and the results combined to produce whole-zone density and abundance estimates. This could be done for eastern grey kangaroos, but not for wallaroos or swamp wallabies, for which the sightings from each survey stratum were combined within each zone in order to complete the analyses. There were no red-necked wallabies sighted in the Central Tablelands South zone and not enough data to be able to an estimate the population of this species in the Central Tableland North zone.

The analyses used to determine the densities and abundances of eastern grey kangaroos conformed to the generally well understood framework for analysing distance sampling data, as presented in Buckland *et al.* (2001). Both the CDS and the MCDS analysis engines of DISTANCE 6.2 (Thomas *et al.* 2010) were used. The most parsimonious (specific) detection function 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 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. In each instance, a Half-normal/Cosine model with OBSERVER as a covariate proved to be the most parsimonious model of those tested. In the Central Tablelands North zone, the difference between the final MCDS-derived model and the CDS-derived model was, as indicated by difference in AIC values, was substantial (ΔAIC = 27.40). This was also the case for the Central Tablelands South zone (ΔAIC = 6.40). The general forms of the Half-normal/Cosine detection functions for the three strata in the Central Tablelands North zone and the two strata in the Central Tablelands South zone are shown in Figs. A2.1-A2.5 of Appendix 2. Although not shown, the inclusion of the OBSERVER covariate in these models has the effect of altering the scale of the detection function, but not its general form.

In relation to each of the detection function models, estimates are given in Table 3 of the associated probabilities that a cluster of kangaroos in the survey strip (in this instance a strip 150 m wide) will be detected (P_a) during a survey and the related effective strip width (ESW). The effective strip width is interpreted as the perpendicular distance from the transect centreline (i.e. the half-strip width) for which as many animals (kangaroos) are detected beyond that distance as remain undetected within that distance (Buckland *et al.* 2001). In other words, if all the animals on the survey strip were being detected, this would only be possible if the width of the survey strip (W) was equivalent to the ESW on either side of the transect centreline. By virtue of the way it is determined (= $W \times P_a$), the higher the value of P_a, the wider will be the ESW. The respective estimates of P_a showed little variation across survey strata; ranging from 0.36 to 0.42. The respective estimates of the ESW determined in relation to the results of these surveys were also relatively similar; ranging from 53 m to 63 m.

Table 3. The survey effort, number of sightings of clusters of eastern grey kangaroos (n), analysis engine used (see text), detection function model (including covariates), and the probability that a cluster of kangaroos in the survey strip is detected (P_a) and the effective strip width (ESW). MCDS is the multiple-covariate distance sampling engine.

Kangaroo management zone	Effort (kms)	n	Analysis engine	Model	Covariates	P_a	ESW (m)
Central Tablelands North							
High	300.0	614	MCDS	Half-normal/Cosine	OBSERVER	0.41	61.1
Mudgee-medium	202.5	341	MCDS	Half-normal/Cosine	OBSERVER	0.38	53.3
Hunter-medium	190.0	268	MCDS	Half-normal/Cosine	OBSERVER	0.36	57.7
Central Tablelands South							
High	262.5	607	MCDS	Half-normal/Cosine	OBSERVER	0.37	55.3
Medium	630.0	671	MCDS	Half-normal/Cosine	OBSERVER	0.42	62.7

The variation in these statistics, although not large, probably reflects the extent of the variation in the general sightability of eastern grey kangaroos across the differing broad landscapes of the survey strata within the two management zones. Although cloud cover, which is essentially a surrogate for light conditions, was not included as a covariate in any of the detection function models, it these statistics may also reflect to some extent the possible influence of weather conditions and light on sightability. The inclusion of only the single covariate of OBSERVER in the detection function models ins indicative of the significance of the differences between the three observers compared to the other possible covariates of aspect and cloud cover.

The densities of clusters of eastern grey kangaroos and the corresponding population densities within the two strata of each of the two kangaroo management zone are given in Table 4. Bootstrap confidence intervals and coefficients of variation have been determined in relation to these densities. The precision of the estimates of both cluster density and kangaroo density, as indicated by the coefficients of variation, were all considered to be more than acceptable; being <20%. This is a marked improvement on the precision of the estimates obtained in the previous two surveys conducted in these management zones (*Cairns et al.* 2009; Cairns & Bearup 2012). This is likely to be due to an increased survey effort in relation to targeted levels of precision and the use of relatively short transects of a constant length.

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. In both management zones, densities were found to be considerably higher in the high density strata than in the medium density strata. In the Central Tablelands North zone, the density of kangaroos in the high density stratum was on average 75% greater than is was in the two medium density strata. In the Central Tablelands South zone the density of kangaroos in the high density stratum was almost twice that of the density in the medium density strata.

Previous surveys of these two management zones were undertaken in 2008 (Cairns *et al.* 2009) and 2011 (Cairns & Bearup 2012). Between 2008 and 2011, there was an estimated 40% increase in the eastern grey kangaroo population in the Central Tablelands North management zone and an estimated 35% decrease in the population in the Central Tablelands South management zone. Overall, however, there was effectively no change between 2008 and 2011 in the sizes of the eastern grey kangaroo populations of the two management zones combined. The changes in numbers that did occur could almost be seen as being complementary and could perhaps have been attributed to some extent to the movement of animals between zones (see Table 6, Cairns & Bearup 2012). Substantial changes in numbers in areas that share a long common boundary as do these management zones are unlikely to be readily explained by the levels of kangaroo harvesting or demographic processes. This can be emphasised by the fact that these two zones are mesic in their environment and that the prevailing climatic conditions over the past three years have been relatively favourable with around average rainfalls. It is more likely that the almost corresponding proportional shifts in numbers between two zones of similar size could be attributed to some movement north of kangaroos across the long boundary between the two zones and perhaps the increase in the dimension of the survey between 2008 and 2011.

Table 4. Results of the helicopter line transect surveys of eastern grey kangaroos conducted in the Central Tablelands kangaroo management zones in September, 2014. Given are the areas of the survey strata, the densities of clusters of kangaroos sighted (D_s) and kangaroo population densities (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		Kangaroo densities (km^{-2})					
	Area (km^2)	D_s	95% bootstrap confidence interval	CV (%)	D	95% bootstrap confidence interval	CV (%)
Central Tablelands North							
Mudgee-high	10,274	16.80	12.38 – 21.20	13.3	43.63	38.45 – 69.80	15.3
Mudgee-medium	7,646	14.60	9.48 – 17.33	18.8	29.73	31.39 – 69.56	19.8
Hunter-medium	7,406	13.23	9.52 – 19.83	15.6	21.66	24.51 – 48.52	16.6
Central Tablelands South							
High	9,078	20.91	15.82 – 26.33	12.3	52.33	39.65 – 65.85	12.6
Medium	6,021	8.49	7.18 – 11.90	13.6	26.42	22.37 – 37.84	13.7

The estimated sizes of the populations of eastern grey kangaroos in the two management zones are given in Table 5. The total number of eastern grey kangaroos in the Central Tablelands North zone represented a substantial increase (95%) in the size of the population estimated from the survey conducted in this zone in 2011. In the Central Tablelands South zone, numbers increased by in excess of 130% between 2011 and 2014. Across the two management zones combined, this represented more than a doubling in numbers over the three years between the two surveys.

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 given 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					
High	43.63	38.45 – 69.80	551,310	395,050 – 717,100	15.3
Mudgee-medium	29.73	31.39 – 69.56	376,140	240,000 – 531,840	19.8
Hunter-medium	21.66	24.51 – 48.52	266,150	181,480 – 359,340	16.6
			1,193,600	966,270 – 1,449,500	10.1
Central Tablelands South					
High	52.33	39.65 – 65.85	431,920	327,280 – 557,970	12.6
Medium	26.42	22.37 – 37.84	379,920	321,630 – 544,090	13.7
			811,840	704,770 – 1,019,900	9.5

By taking the results of the three triennial surveys conducted over the past six years, the longer term trends in eastern grey kangaroo numbers in the two management zones can be assessed. In analysing these trends it was found that over the six year period, 2008-2014, eastern grey kangaroo numbers have shown an exponential rate of increase of 5.6% per annum in the Central Tableland North management zone and 2.3% in the Central Tableland South management zone. If only the period between the last two surveys was considered, then the annual rates of increase for this period were 7.5% and 9.5% for the Central Tableland North and Central Tableland South management zones, respectively. Such an annual rate of population increase is considered comparable to the rates of increase estimated for other species of large kangaroo (Bayliss 1985; Cairns and Grigg 1993; Cairns *et al.* 2000).

The results of the analyses of the wallaroo and swamp wallaby survey data are given in Tables 6 and 7. Too few red-necked wallabies were sighted to determine density estimates for this species. The most parsimonious detection function models for wallaroos were Half-normal/Cosine models, with the model in the Central Tablelands North including OBSERVER as a covariate. The most parsimonious detection function model for swamp wallabies was a Half-normal/Cosine model in the Central Tablelands North zone and a Hazard-rate/Polynomial in the Central Tablelands South zone. The forms of the detection function models given in Table 6 are shown in Figs. A2.6-2.9 of Appendix 2.

The respective estimates of P_a and the associated ESW for wallaroos and swamp wallabies showed some differences between the two management zones (Table 6). Overall, these values were considerably higher for wallaroos than they were for swamp wallabies; but were somewhat lower than the values determined for eastern grey kangaroo (Table 3).

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 below those of the eastern grey kangaroo populations. In relation to this, the sightability of wallaroos has 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 and, as a result of this, 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. r. erubescens*) numbers by a factor of 1.50 in undulating terrain and 1.88 in steep terrain when compared with the results of walked line transect surveys (S. C. Cairns, A. R. Pople & J. Gilroy, *unpubl. data*). Taking this into account, the final estimates of wallaroo density and abundance have been corrected (x1.85; see Table 8).

Table 6. The survey effort, number of sightings of clusters of animals (n), DISTANCE 6.2 analysis engine used (see text), the detection function model, the probability that a 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. CDS is the conventional distance sampling engine; MCDS is the multiple-covariate distance sampling engine.

Kangaroo management zone	Effort (km)	n	Analysis engine	Model	P_a	ESW
<u>Central Tablelands North</u>	692.5					
Wallaroos		73	MCDS	Half-normal/Cosine (+ OBSERVER)	0.39	58.6
Red-necked wallabies		4	–	–	–	–
Swamp wallabies		51	CDS	Half-normal/Cosine	0.23	34.5
Central Tablelands South	892.5					
Wallaroos		36	CDS	Half-normal/Cosine	0.31	46.3
Red-necked wallabies		–	–	–	–	–
Swamp wallabies		60	CDS	Hazard-rate/Polynomial	0.27	40.2

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. Management zone densities are determined in relation to the total area of the zone (i.e. the high, medium and low density strata) from the estimates of total abundances determined in relation to those strata actually surveyed (i.e. the high and medium strata). Both of the Central Tablelands kangaroo management zones are larger than each of 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 (Fig. 1). Both support larger and higher density populations of eastern grey kangaroos than do the three Northern Tablelands management zones (9.1-20.3 km^{-2}; see Table 9, Cairns *et al*. 2013a) and the South East NSW management zone (17.9-34.2 km^{-2}; see Table 7, Cairns *et al*. 2013b).

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 densities (km^{-2})					
Kangaroo management zone	D_s	95% bootstrap confidence interval	CV (%)	D	95% bootstrap confidence interval	CV (%)
<u>Central Tablelands North</u>						
Wallaroos	0.90	0.59 – 1.22	17.7	1.65	1.01 – 2.39	21.4
Swamp wallabies	1.07	0.62 – 2.09	37.1	1.19	0.68 – 2.32	38.8
<u>Central Tablelands South</u>						
Wallaroos	0.46	0.21 – 0.85	55.5	0.82	0.36 – 1.56	53.6
Swamp wallabies	0.84	0.55 – 1.20	19.2	0.89	0.58 – 1.30	19.5

The surveys conducted in these 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 readily achieved for eastern grey kangaroos across all strata surveyed where the coefficients of variation for the estimates of eastern grey kangaroo numbers were in the range 13-20% (Table 4). For the whole-zone population estimates the level of precision was twice the target level (Table 5). For wallaroos, the target level of precision was attained only in the Central Tablelands North management zone. The level of precision of the estimate for the Central Tablelands South management zone was quite low in relation to the low population density (Table 7).

From a precautionary point of view, the precise estimates of eastern grey kangaroo numbers would allow harvest quotas for these two kangaroo management zones to be set with a degree of confidence. In relation to this, wallaroos are not harvested commercially from the Central Tablelands management zones.

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	1,192,600	47.23	77,320	3.05
Central Tablelands South	22,632	811,830	34.35	34,450	1.52

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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 clusters of macropods and the raw counts of individual eastern grey kangaroos (*EGK*), common wallaroos (*CW*), red-necked wallabies (*RNW*) and swamp wallabies (*SW*) for each of the transects surveyed within the two Central Tablelands kangaroo management zones. Each transect is identified in relation to the survey stratum to which it belongs by a letter code (H = high, M = medium).

Transect	Length *(km)*	No. of sightings	Raw counts *EGK*	*CW*	*RNW*	*SW*
Central Tablelands North						
CNH01	7.5	37	102	8	-	1
CNH02	7.5	22	88	-	-	1
CNH03	7.5	11	57	1	-	-
CNH04	7.5	9	66	-	-	-
CNH05	7.5	65	325	5	-	-
CNH06	7.5	29	110	13	-	2
CNH07	7.5	16	68	-	-	-
CNH08	7.5	3	24	-	-	-
CNH09	7.5	27	108	-	-	1
CNH10	7.5	8	26	-	-	-
CNH11	7.5	12	37	-	-	-
CNH12	7.5	6	10	-	-	-
CNH13	7.5	13	56	-	-	-
CNH14	7.5	2	3	-	-	-
CNH15	7.5	34	148	-	-	-
CNH17	7.5	6	24	-	-	2
CNH18	7.5	2	3	-	-	-
CNH19	7.5	12	122	-	-	-
CNH21	7.5	26	60	-	-	2
CNH22	7.5	11	27	1	-	2

CNH23	7.5	10	19	-	-	2
CNH24	7.5	18	29	-	-	1
CNH25	7.5	6	11	-	-	-
CNH26	7.5	35	128	-	-	4
CNH27	7.5	7	20	-	-	-
CNH28	7.5	2	2	1	-	-
CNH29	7.5	6	17	-	-	1
CNH30	7.5	33	107	3	-	-
CNH31	7.5	-	-	-	-	-
CNH32	7.5	2	4	1	-	-
CNH33	7.5	15	49	1	-	1
CNH34	7.5	4	24	-	-	-
CNH35	7.5	9	35	-	-	-
CNH36	7.5	17	67	-	-	2
CNH37	7.5	26	150	1	-	1
CNH38	7.5	14	44	-	-	3
CNH39	7.5	41	118	15	-	-
CNH40	7.5	29	137	-	-	-
CNH41	7.5	23	75	3	-	-
CNH42	7.5	20	77	3	-	3
HN01	10	22	43	-	1	2
HN02	10	6	30	-	-	1
HN03	10	3	15	-	-	-
HN04	10	12	36	-	-	-
HN05	10	15	54	-	-	-
HN06	10	16	47	-	-	1
HN07	10	13	24	2	-	-

HN08	10	1	2	-	-	-
HN09	10	16	64	-	-	1
HN10	10	4	3	3	-	-
HN11	10	15	34	3	1	1
HN12	10	6	26	-	-	-
HN13	10	26	95	2	1	-
HN14	10	13	25	4	-	1
HN15	10	13	34	2	-	-
HN16	10	26	115	5	-	4
HN17	10	27	62	21	-	1
HN18	10	56	133	10	1	6
HN19	10	31	68	7	-	1
CNM01	7.5	18	90	-	-	1
CNM02	7.5	16	41	-	-	-
CNM03	7.5	-	-	-	-	-
CNM04	7.5	32	103	-	-	-
CNM05	7.5	5	5	-	-	2
CNM06	7.5	19	86	-	-	-
CNM07	7.5	3	14	-	-	-
CNM08	7.5	25	77	-	-	-
CNM09	7.5	-	-	-	-	-
CNM10	7.5	14	38	-	-	1
CNM11	7.5	15	78	1	-	2
CNM12	7.5	7	50	-	-	-
CNM13	7.5	46	147	1	-	1
CNM14	7.5	17	66	1	-	-
CNM15	7.5	2	3	-	-	-

CNM16	7.5	24	88	-	-	-
CNM17	7.5	-	-	-	--	-
CNM18	7.5	18	62	2	-	2
CNM19	7.5	23	100	-	-	-
CNM20	7.5	10	34	-	-	1
CNM21	7.5	15	36	1	-	3
CNM22	7.5	8	35	1	-	-
CNM23	7.5	2	14	-	-	-
CNM24	7.5	9	25	-	-	-
CNM25	7.5	15	45	-	-	-
CNM26	7.5	23	81	10	-	1
CNM27	7.5	-	-	-	-	-
Central Tablelands South						
CSH01	7.5	33	118	-	-	-
CSH02	7.5	9	12	1	-	-
CSH03	7.5	25	60	1	-	-
CSH04	7.5	10	27	-	-	-
CSH05	7.5	38	95	-	-	-
CSH07	7.5	23	53	-	-	-
CSH08	7.5	33	64	1	-	3
CSH09	7.5	28	88	-	-	-
CSH10	7.5	15	44	1	-	1
CSH11	7.5	10	27	1	-	1
CSH12	7.5	12	19	3	-	3
CSH13	7.5	7	9	-	-	1
CSH14	7.5	34	91	1	-	-

	CSH15	7.5	22	61	-	-	4
	CSH16	7.5	11	19	-	-	2
	CSH17	7.5	19	61	-	-	1
	CSH18	7.5	8	26	-	-	-
	CSH19	7.5	17	46	1	-	1
	CSH20	7.5	7	14	-	-	-
	CSH21	7.5	4	15	-	-	-
	CSH22	7.5	18	63	4	-	1
	CSH23	7.5	14	44	-	-	-
	CSH25	7.5	4	4	-	-	2
	CSH26	7.5	8	23	5	-	-
	CSH27	7.5	18	38	-	-	1
	CSH28	7.5	10	15	-	-	2
	CSH29	7.5	16	41	-	-	-
	CSH30	7.5	13	33	-	-	1
	CSH31	7.5	29	86	2	-	-
	CSH32	7.5	19	64	4	-	-
	CSH33	7.5	33	66	-	-	2
	CSH34	7.5	11	19	-	-	2
	CSH35	7.5	33	147	-	-	2
	CSH36	7.5	51	200	-	-	-
	CSH37	7.5	14	41	7	-	-
	CSM02	7.5	-	-	-	-	-
	CSM03	7.5	7	27	-	-	-
	CSM05	7.5	8	30	-	-	-
	CSM06	7.5	16	30	11	-	2
-	CSM08	7.5	1	2	-	-	-

CSM09	7.5	3	27	-	-	-
CSM10	7.5	5	5	-	-	2
CSM11	7.5	-	-	-	-	-
CSM13	7.5	-	-	-	-	-
CSM14	7.5	13	69	-	-	-
CSM15	7.5	1	1	-	-	-
CSM16	7.5	3	8	-	-	-
CSM17	7.5	3	5	-	-	3
CSM18	7.5	1	6	-	-	-
CSM19	7.5	5	16	-	-	1
CSM20	7.5	-	-	-	-	-
CSM21	7.5	2	-	2	-	2
CSM22	7.5	-	-	-	-	-
CSM23	7.5	-	-	-	-	-
CSM24	7.5	8	18	-	-	2
CSM25	7.5	8	35	-	-	-
CSM26	7.5	-	-	-	-	-
CSM27	7.5	13	17	-	-	5
CSM28	7.5	18	49	1	-	-
CSM29	7.5	21	55	-	-	2
CSM30	7.5	3	10	2	-	-
CSM31	7.5	17	82	-	-	-
CSM32	7.5	37	126	-	-	1
CSM33	7.5	-	-	-	-	-
CSM34	7.5	9	21	1	-	-
CSM35	7.5	4	6	1	-	-
CSM36	7.5	6	24	-	-	-
CSM37	7.5	17	55	-	-	-

CSM38	7.5	8	19	-	-	1
CSM39	7.5	20	62	1	-	-
CSM40	7.5	-	-	-	-	-
CSM41	7.5	18	92	-	-	-
CSM42	7.5	10	72	4	-	-
CSM43	7.5	3	15	-	-	-
CSM45	7.5	9	17	-	-	-
CSM46	7.5	1	2	-	-	-
CSM47	7.5	5	10	-	-	-
CSM48	7.5	14	43	-	-	-
CSM49	7.5	1	2	-	-	-
CSM50	7.5	-	-	-	-	-
CSM51	7.5	11	68	-	-	-
CSM52	7.5	2	3	-	-	-
CSM54	7.5	34	72	3	-	2
CSM55	7.5	2	3	-	-	-
CSM56	7.5	12	37	-	-	-
CSM57	7.5	5	16	-	-	-
CSM58	7.5	11	27	-	-	-
CSM60	7.5	8	17	-	-	1
CSM62	7.5	-	-	-	-	-
CSM64	7.5	15	36	-	-	1
CSM65	7.5	3	8	-	-	-
CSM66	7.5	2	18	-	-	-
CSM68	7.5	9	6	-	-	5
CSM69	7.5	18	52	-	-	-
CSM72	7.5	12	47	-	-	-
CSM73	7.5	9	44	-	-	-

CSM74	7.5	1	1	-	-	-
CSM75	7.5	7	25	-	-	-
CSM76	7.5	-	-	-	-	-
CSM78	7.5	2	3	-	-	-
CSM79	7.5	17	45	-	-	2
CSM80	7.5	26	93	-	-	-
CSM81	7.5	23	87	-	-	-
CSM82	7.5	12	50	-	-	1
CSM84	7.5	19	47	-	-	-
CSM85	7.5	-	-	-	-	-
CSM86	7.5	13	19	3	-	1
CSM87	7.5	13	25	2		1
CSM88	7.5	1	3	-	-	-
CSM89	7.5	3	5	-	-	-
CSM90	7.5	-	-	-	-	-
CSM91	7.5	5	14	-	-	-
CSM92	7.5	13	69	2	-	-
CSM93	7.5	1	2	-	-	-
CSM94	7.5	27	142	-	-	-
CSM95	7.5	7	54	-	-	-
CSM96	7.5	10	24	-	-	-
CSM97	7.5	24	74	-	-	-
CSM98	7.5	23	91	-	-	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.

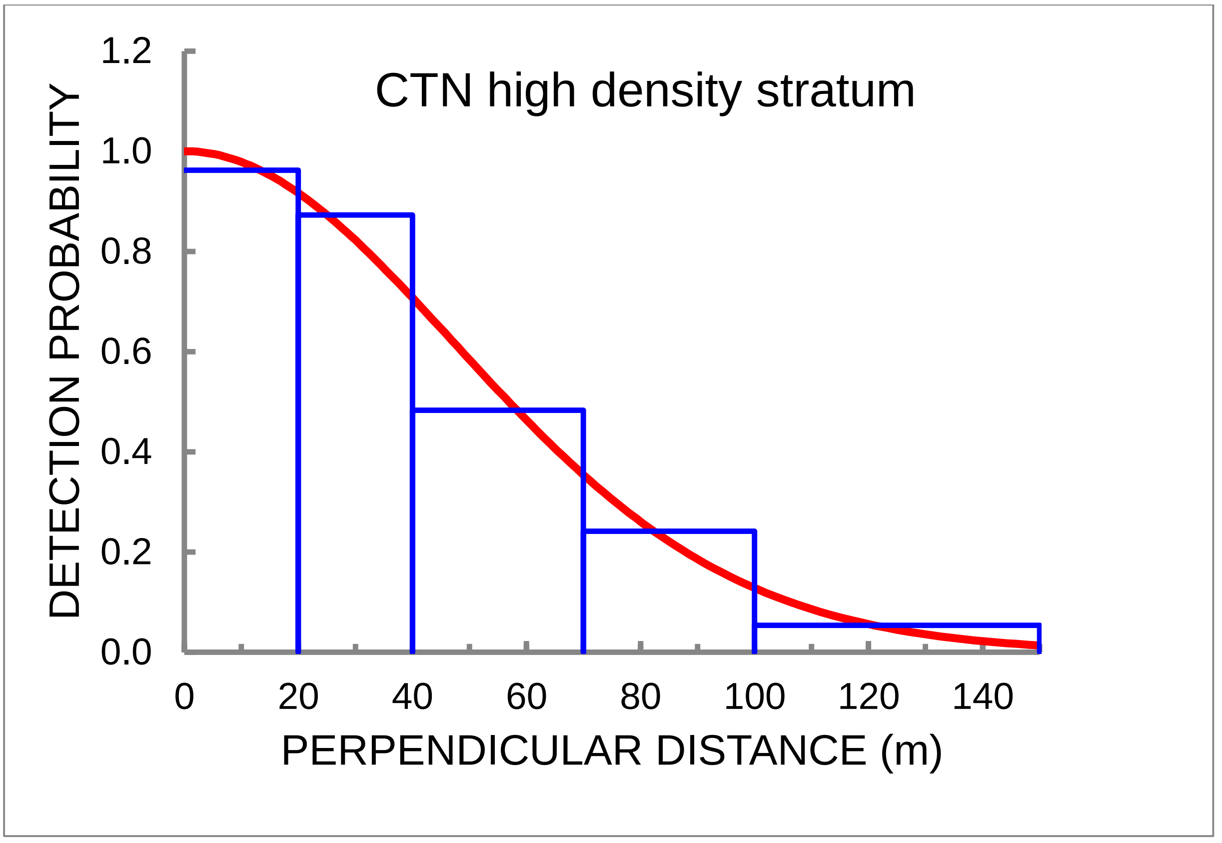

Fig. A2.1. The Half-normal/Cosine detection function for eastern grey kangaroos in the high density stratum of the Central Tablelands North kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.2 (for further details, see Table 3).

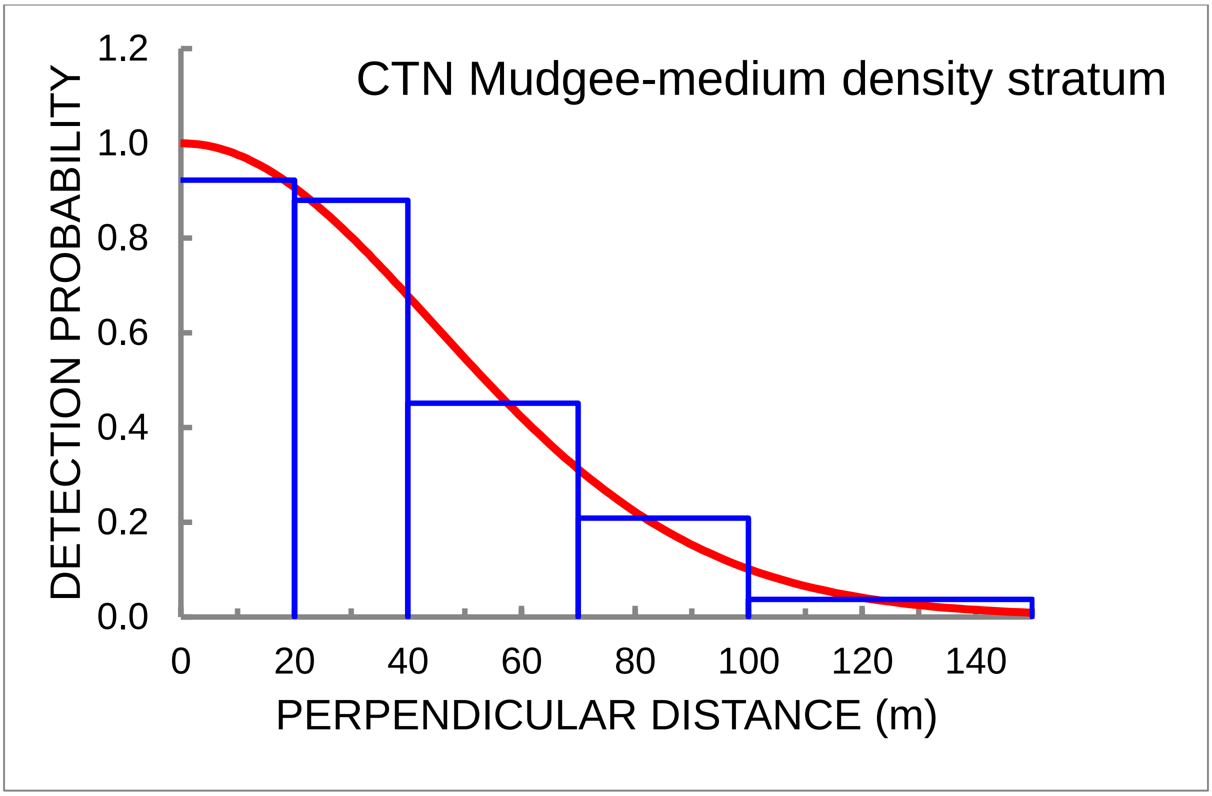

Fig. A2.2. The Half-normal/Cosine detection function for eastern grey kangaroos in the Mudgee-medium density stratum of the Central Tablelands North kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.2 (for further details, see Table 3).

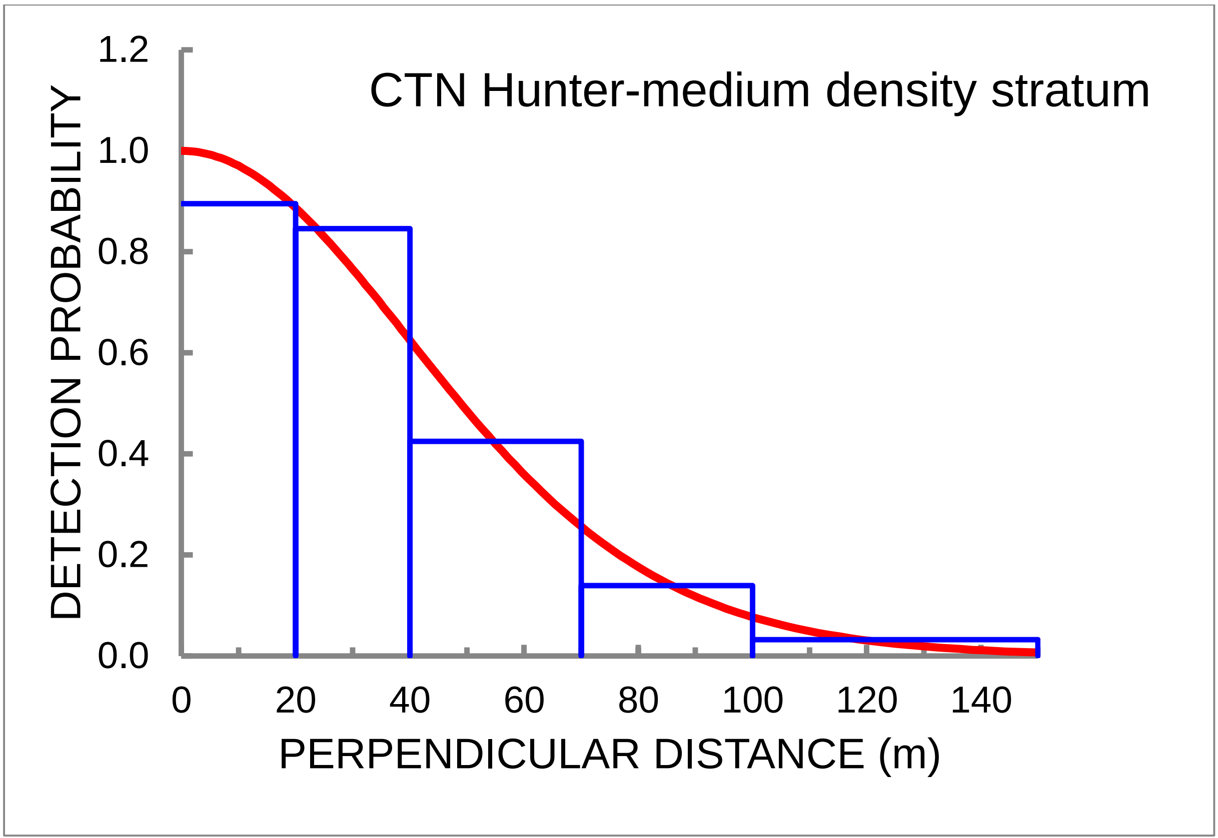

Fig. A2.3. The Half-normal/Cosine detection function for eastern grey kangaroos in the Hunter-medium density stratum of the Central Tablelands North kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.2 (for further details, see Table 3).

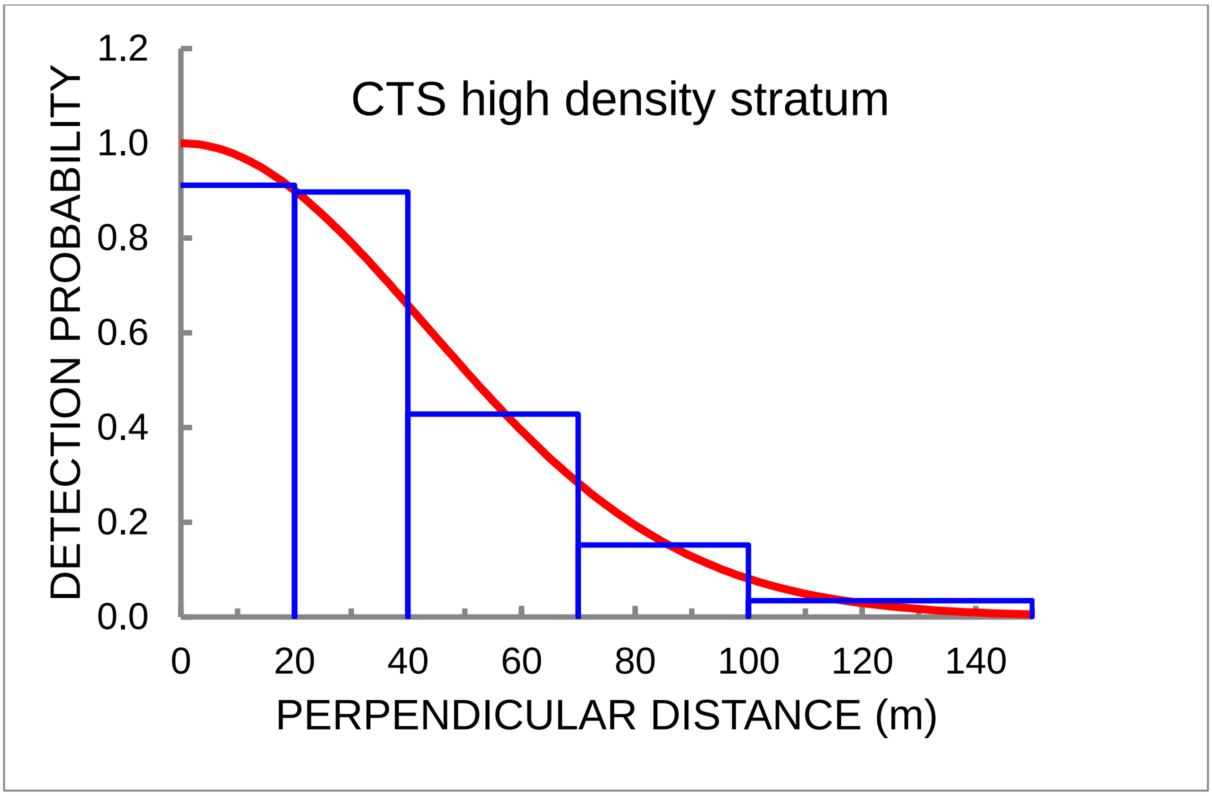

Fig. A2.4. The Half-normal/Cosine detection function for eastern grey kangaroos in the high density stratum of the Central Tablelands South kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.2 (for further details, see Table 3).

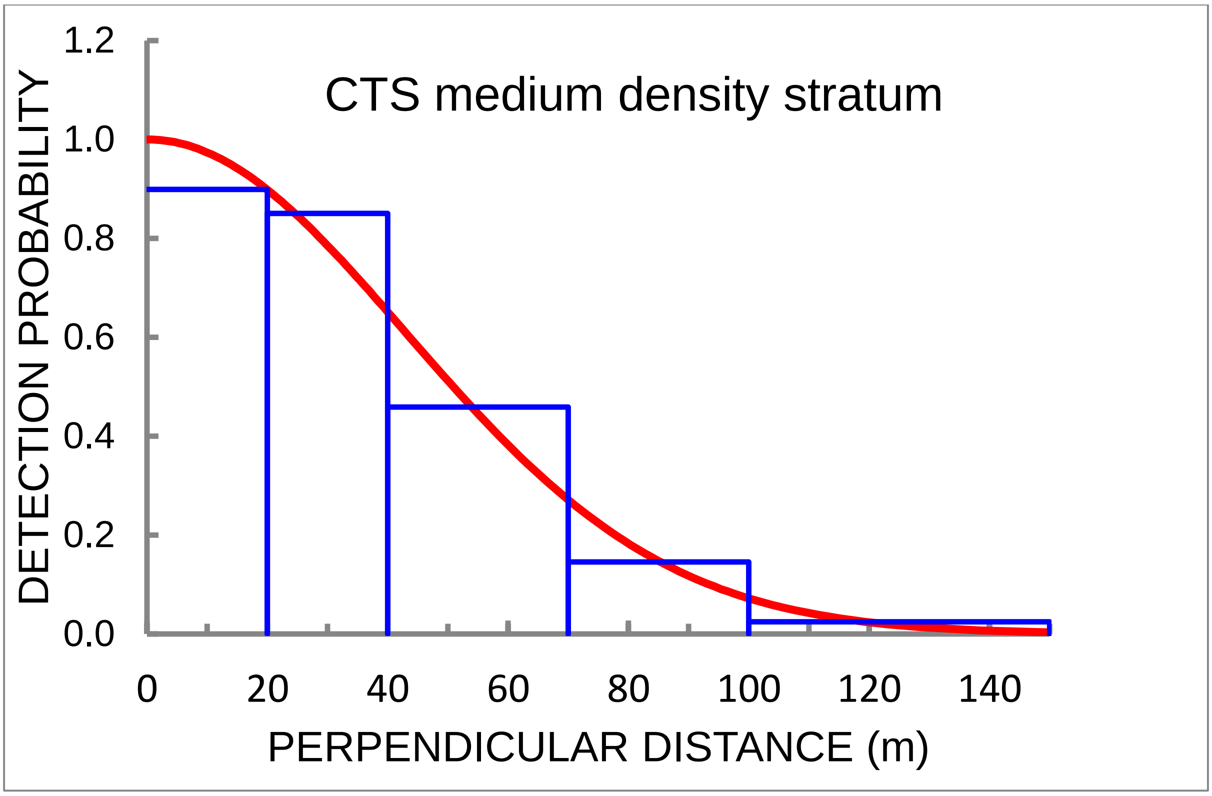

Fig. A2.5. The Half-normal/Cosine detection function for eastern grey kangaroos in the medium density stratum of the Central Tablelands South kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.2 (for further details, see Table 3).

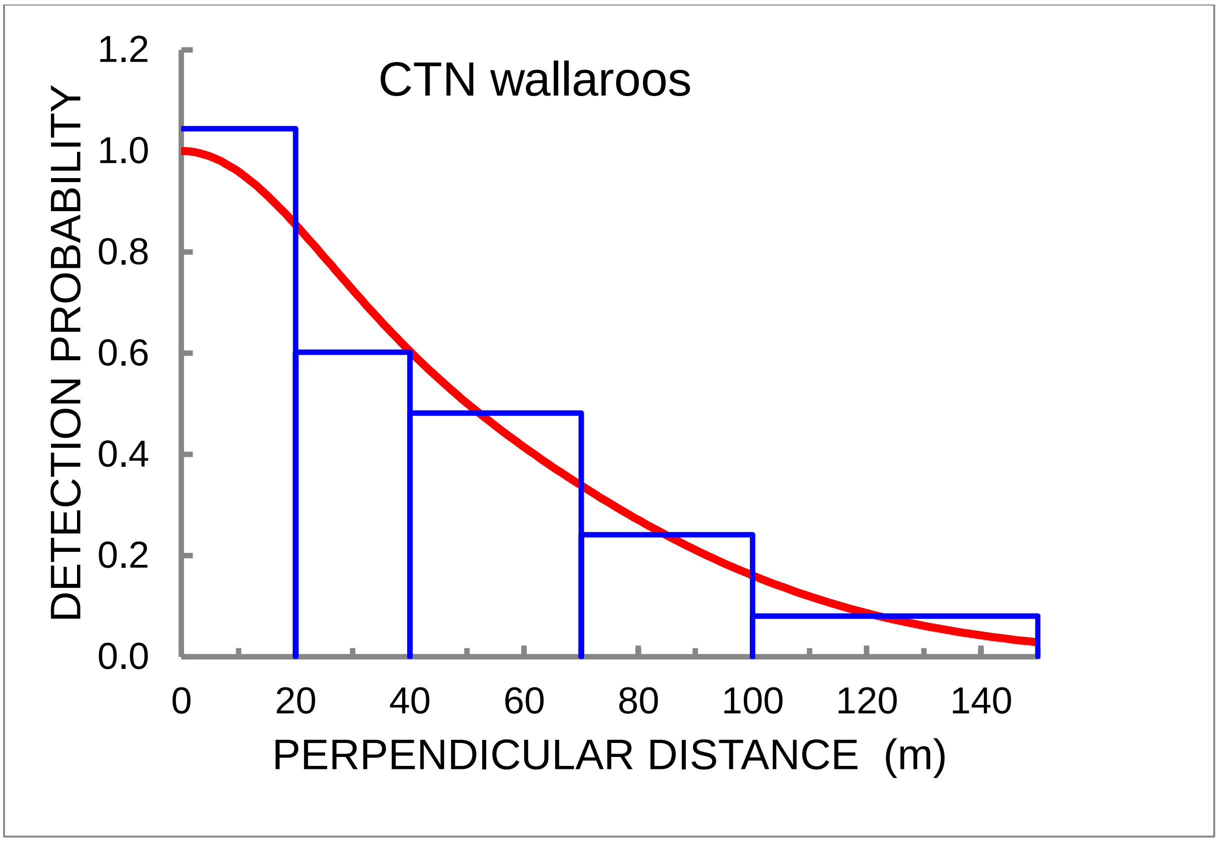

Fig. A2.6. The Half-normal/Cosine detection function for common wallaroos in the Central Tablelands North kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.2 (for further details, see Table 6).

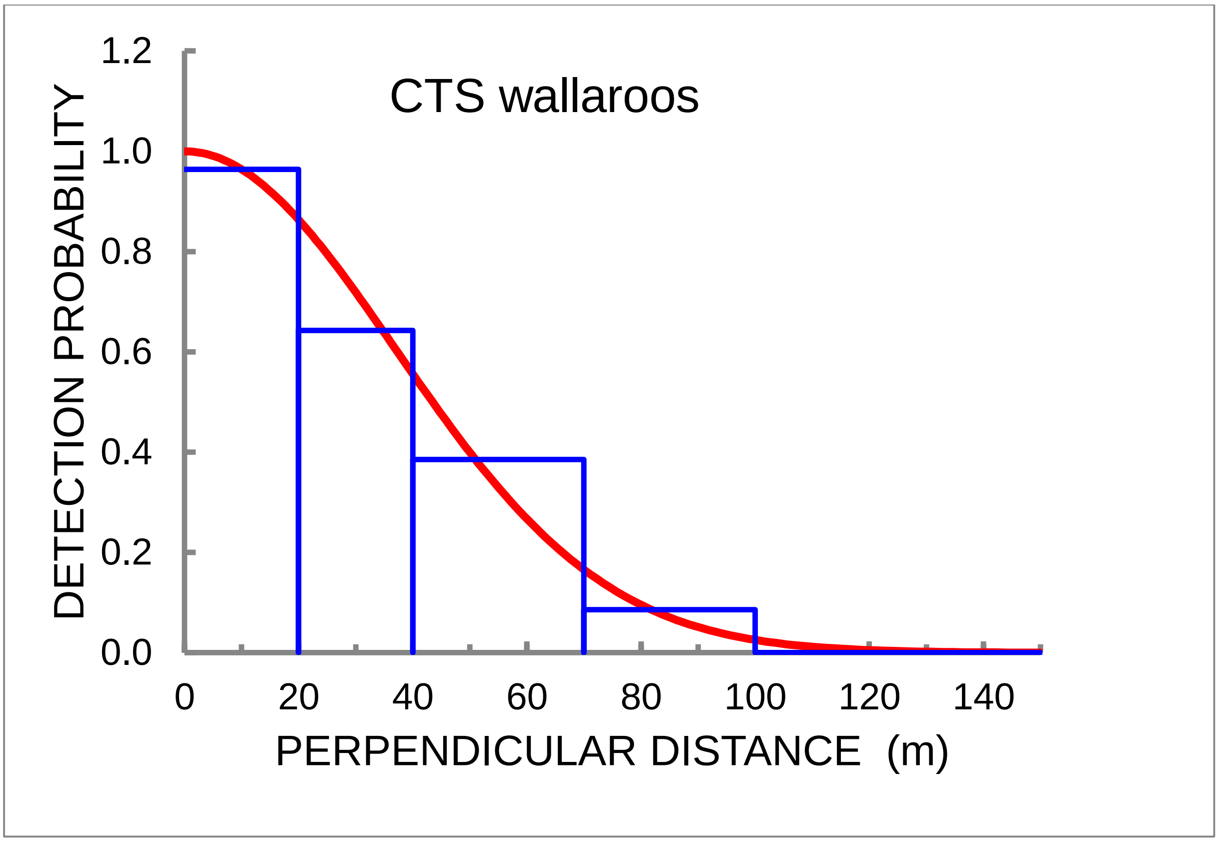

Fig. A2.6. The Half-normal/Cosine detection function for common wallaroos in the Central Tablelands South kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.2 (for further details, see Table 6).

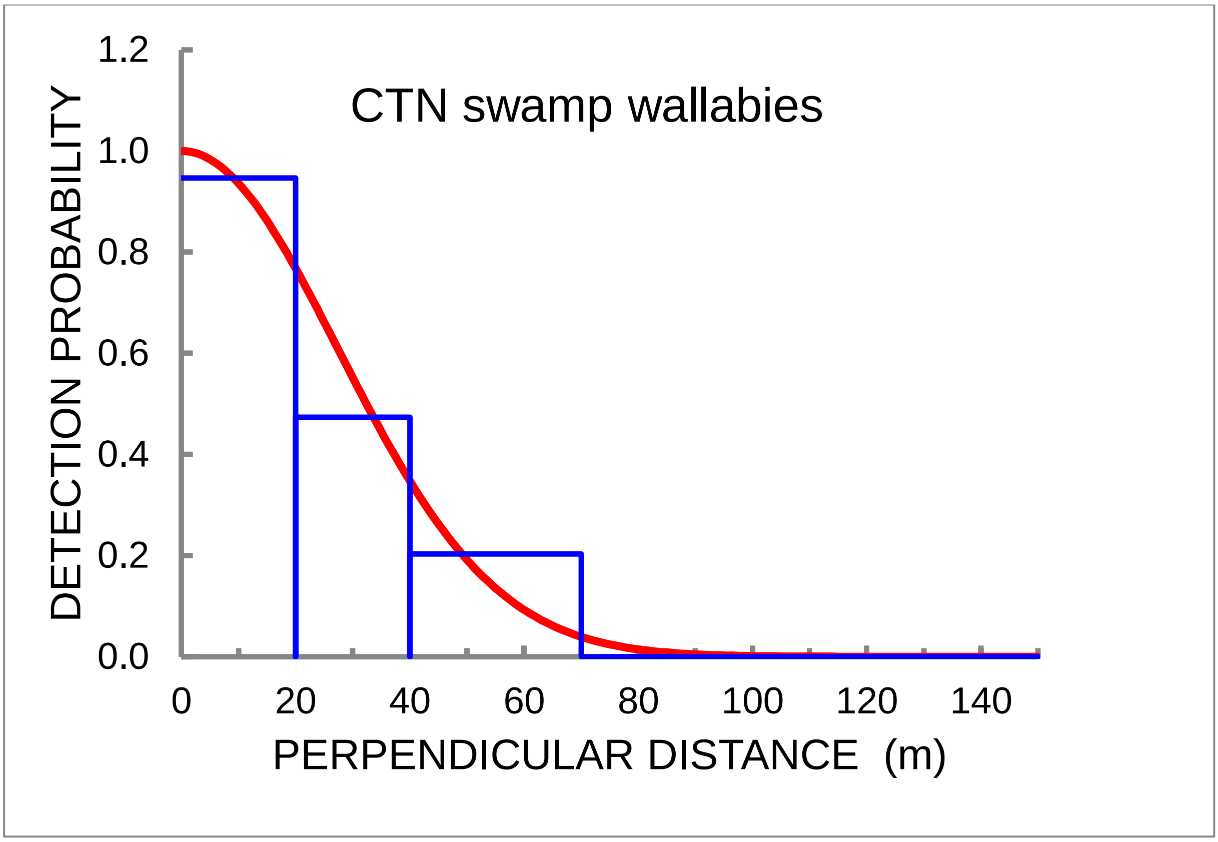

Fig. A2.7. The Half-normal/Cosine detection function for swamp wallabies in the Central Tablelands North kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.2 (for further details, see Table 6).

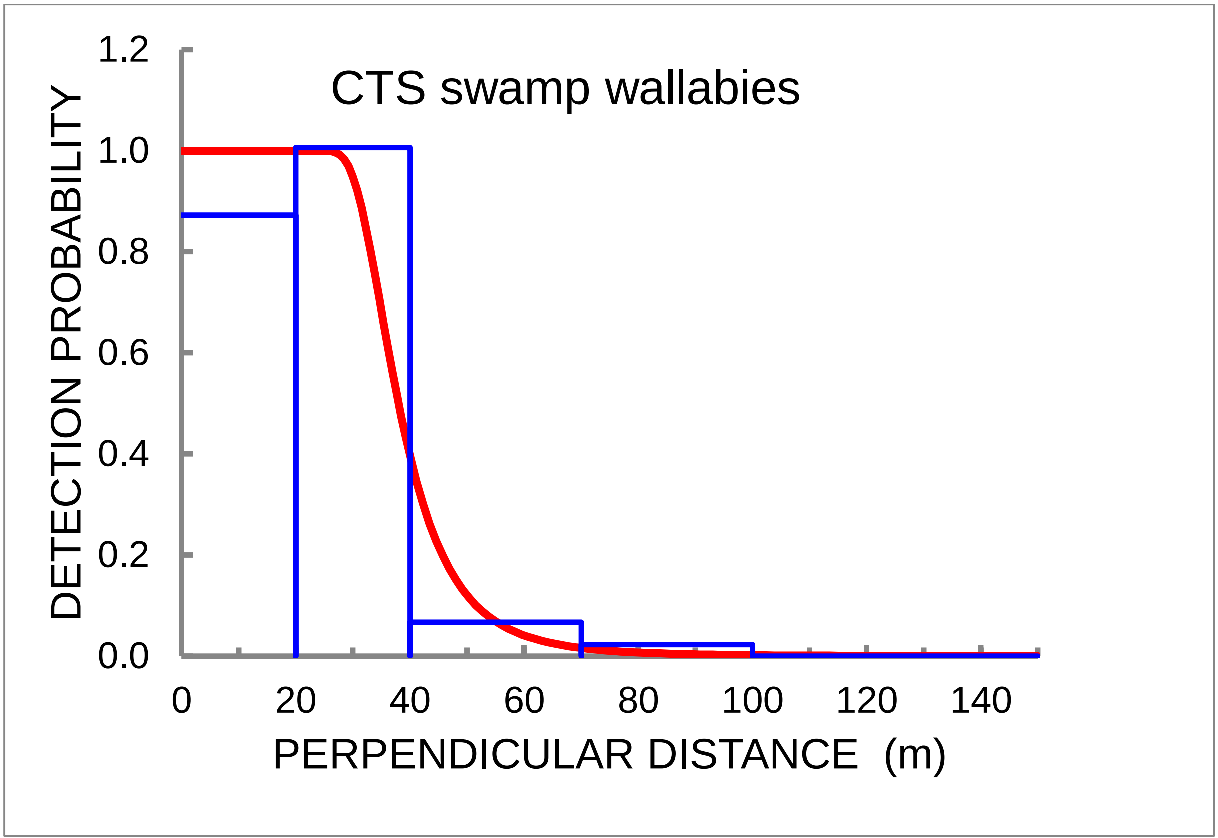

Fig. A2.8. The Hazard-rate/Polynomial detection function for swamp wallabies in the Central Tablelands South kangaroo management zone. This detection function was derived using the CDS analysis engine of DISTANCE 6.2 (for further details, see Table 6).