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COMPARISON OF SURVEYS OF KANGAROOS IN QUEENSLAND USING HELICOPTERS AND FIXED-WING AIRCRAFT

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Abstract

Kangaroo harvest quotas for each Australian state have been set mainly as proportions of population estimates derived from aerial surveys. Estimating population size from strip transect counts using fixed-wing aircraft has become an established technique, but counts must be adjusted by correction factors to ensure population estimates are both accurate and repeatable. Surveys of kangaroos in Queensland are currently conducted with helicopters using line transect methodology, but cost restricts their use to relatively small survey blocks. Nevertheless, they return more accurate and repeatable estimates of kangaroo density than surveys with fixed-wing aircraft. A comparison of the above two techniques was made along the same transect lines in seven survey blocks (5000-10,000 km^2) in southern and western Queensland, allowing an assessment of the comparative accuracy of the fixed-wing method. For red kangaroos (*Macropus rufus*), required correction factors of 0.7-3.1 were similar to those used previously. However, for eastern grey kangaroos (*M. giganteus*), substantially larger correction factors of 3.4-10.2 were needed to approach true density. For wallaroos (*M. robustus*), correction factors of 3.8-4.8 were required, but can be considered conservative because helicopter-derived density estimates are known to be underestimated by a factor of 2-3. Further work is needed to establish how correction factors for each species should be applied on a broader scale and whether they lead to repeatable estimates of kangaroo density.

Key words: aerial survey, line transect, correction factors, strip transect, wallaroo.

Introduction

Annual quotas for the commercial harvest of kangaroos in various Australian States were introduced in the mid 1970s. Since 1984, quotas (and their associated management plans) have required Commonwealth approval and have been set mainly as a proportion (generally 15-20%) of population estimates of kangaroos in each State. To estimate kangaroo numbers in Queensland, broad-scale aerial surveys using fixed-wing aircraft (usually a Cessna 182) were conducted in 1980 (Caughley and Grigg 1982, Fig. 1) and then annually over 1984-1992 (CSIRO and what is now Environment Australia, unpublished data). The survey area (Fig. 1) covered the main harvest area of the State (Fig. 2) which broadly coincides with the highest densities of kangaroos (Caughley and Grigg 1982). Counts of kangaroos were made in strip transects and, being recognised as incomplete, were adjusted by correction factors to estimate true density.

While there was general acceptance of the results of surveys using fixed-wing aircraft, the use of this method in Queensland drew some criticism (Kirkpatrick and Nance 1985, Hill *et al.* 1987). Despite the use of correction factors, it was argued that such surveys were underestimating kangaroo numbers and were not repeatable, leading to poor descriptions of population trends. In 1991, the Queensland Department of Environment and Heritage (now Queensland Department of Environment, QDoE) introduced helicopters as a platform for surveying kangaroos using line transect methodology. The technique compared favourably with walked line transect surveys (Clancy *et al.* 1997) which can return accurate and repeatable estimates of kangaroo density for tame populations (Southwell 1994). However, in four trials of wild populations, Southwell (1994) reported a possible negative bias of 2-30%, which was attributed to reactive movement and which became more pronounced with increasing density. Southwell (1994) suggested that using an aircraft to increase the speed of the surveyor relative to that of the animals, may be one way of reducing this effect. Clancy *et al.* (1997) reported no trend towards a poorer relationship between the two methods at high macropod densities, suggesting that helicopter surveys still underestimate kangaroo density to some extent.

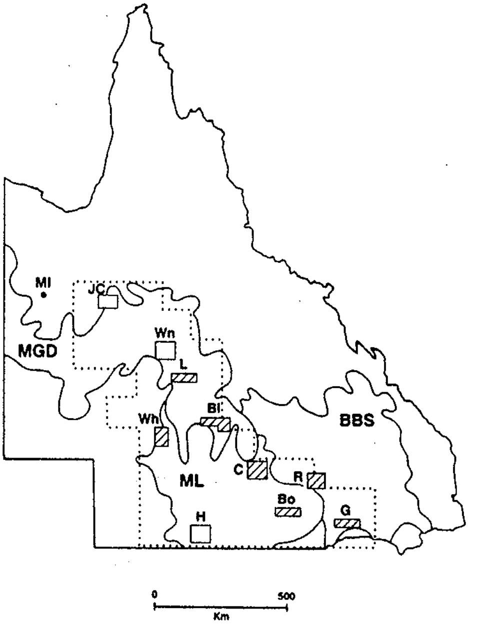

Fig. 1. The 10 helicopter survey blocks used to monitor kangaroo populations in Queensland during 1991-97: Julia Creek (JC), Winton (Wn) (since 1995), Longreach (L), Windorah (Wh), Blackall (Bk), Charleville (C), Roma (R), Hungerford (H), Bollon (Bo) and Goondiwindi (G). Comparison of the two survey methods was conducted in the seven survey blocks which are stippled. The area surveyed by fixed-wing aircraft over 1980-92 is delineated by a dashed line. Also delineated are the mulga lands (ML), Mitchell grass downs (MGD) and brigalow belt south (BBS) biogeographic regions.

Because of the higher running costs of helicopters, surveys for monitoring kangaroo numbers in Queensland have been conducted annually since 1991 in only 9-10 survey blocks (Fig. 1). However, surveys using fixed-wing aircraft offer the only economically feasible means of surveying on a truly broad scale. Their use to assess kangaroo populations on a broad scale continues in States other than Queensland where commercial harvesting of kangaroos occurs.

Conducting surveys simultaneously with both aircraft allows an independent assessment of the comparative accuracy of surveys conducted with fixed-wing aircraft. In a review of monitoring methods for kangaroos, Southwell (1989) highlighted the need to develop correction factors specifically for eastern grey kangaroos (*Macropus giganteus*), possibly the most abundant kangaroo species in Australia (Pople and Grigg 1997) and comprising roughly one-half of the annual harvest offtake of kangaroos in Australia (Ramsay 1994). Furthermore, sightability for all species needed to be assessed over a greater range of environments. Comparisons of a number of fixed-wing survey techniques with helicopter surveys in three of the helicopter survey blocks in Queensland were conducted by Pople *et al.* (1998). They found that fixed-wing line transect methods failed to produce consistently accurate estimates of kangaroo density. Further, their data supported currently used correction factors for red kangaroos (*M. rufus*), but suggested revised estimates for eastern grey kangaroos and common wallaroos (*M. robustus*). A narrower strip transect (100 m cf. 200 m) was also examined, offering smaller correction factors and possibly greater repeatability. This paper expands on the geographic coverage of that comparison and discusses the potential role that both types of aircraft have in the broad-scale monitoring of kangaroo populations.

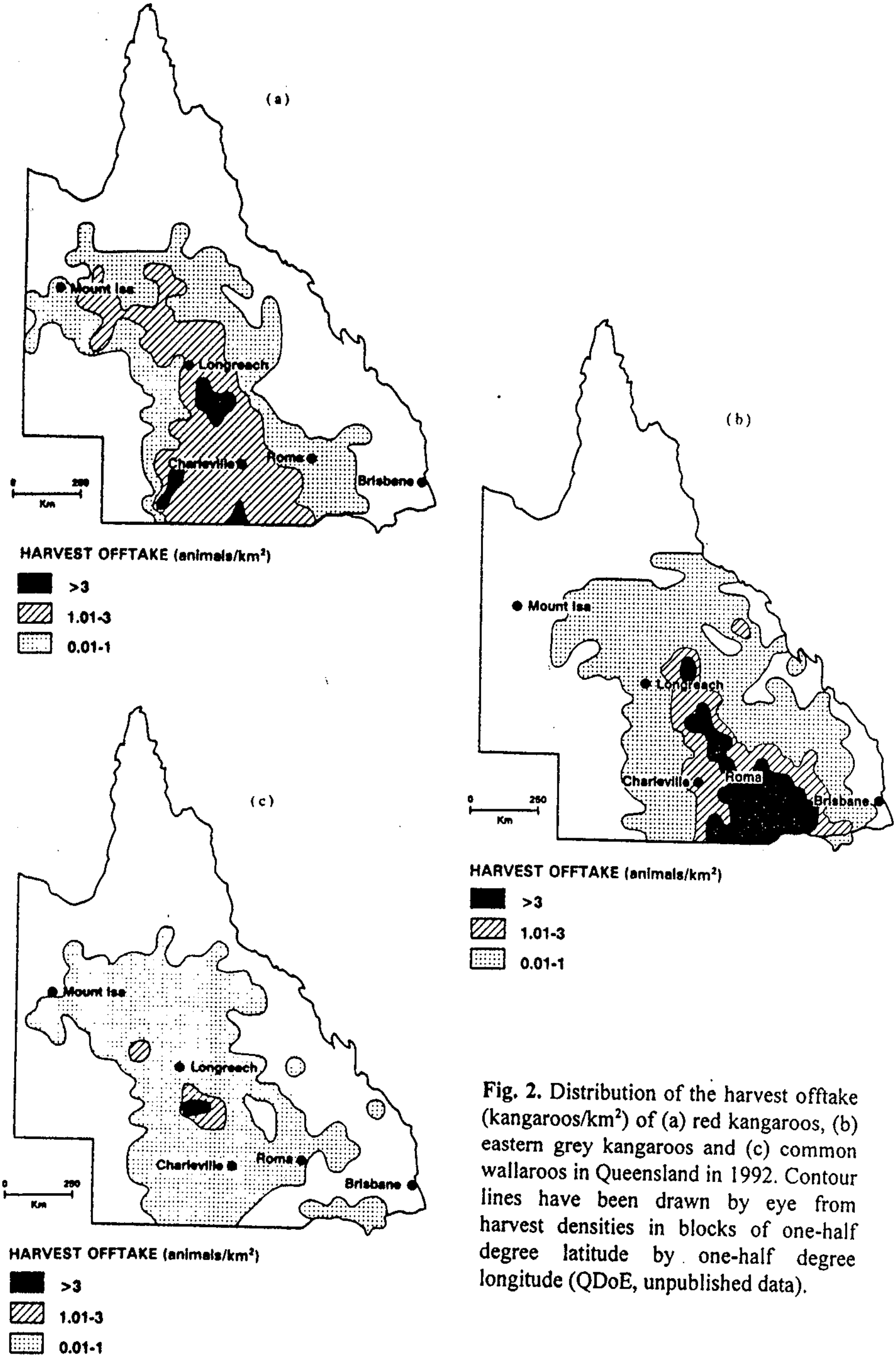

Fig. 2. Distribution of the harvest offtake (kangaroos/km^2) of (a) red kangaroos, (b) eastern grey kangaroos and (c) common wallaroos in Queensland in 1992. Contour lines have been drawn by eye from harvest densities in blocks of one-half degree latitude by one-half degree longitude (QDoE, unpublished data).

Methods

Survey blocks

The study was conducted in seven survey blocks located in the brigalow belt south, the mulga lands and the Mitchell grass downs biogeographic regions of southern and western Queensland (Fig. 1). The regional habitat of each block, based upon the Atlas of Australian Resources (Australian Survey and Land Information Group 1990), is:

1. *Longreach* - approximately 5000 km^2 and dominated by open tussock grasslands of Mitchell grasses (*Astrebla* spp.), with some areas of low open *Acacia* woodland with a lower stratum of tussock grasses.

2. *Windorah* - approximately 5000 km^2 and dominated by tall open *Acacia* shrubland with a lower stratum of tussock and hummock grasses, and by open tussock grassland.

3. *Blackall* - approximately 7500 km^2 and dominated by open tussock grasslands, low open *Acacia* woodlands with a lower stratum of tussock grasses, and low open to closed *Acacia* woodlands with no significant lower stratum vegetation.

4. *Charleville* - approximately 10,000 km^2 and dominated by low *Acacia* and *Eucalyptus* woodlands with a lower stratum of tall shrubs and tussock grasses, and low open *Acacia* and *Eucalyptus* woodland with a lower stratum of tussock grasses.

5. *Bollon* - approximately 5000 km^2 and dominated by *Acacia* and *Eucalyptus* woodlands with a lower stratum of tussock grasses, and by *Casuarina* open woodland with a lower stratum of tussock grasses.

6. *Roma* - approximately 10,000 km^2 and dominated by tussock grasslands mostly sown to cereal crops, by *Eucalyptus* and conifer open woodland with a lower stratum of tussock grasses, and by *Eucalyptus* and *Casuarina* open woodland with a lower stratum of tussock grasses.

7. *Goondiwindi* - approximately 5000 km^2 and dominated by *Eucalyptus* woodland with a tall shrub understorey, and by *Eucalyptus* and *Casuarina* open woodland with a lower stratum of tussock grasses.

Sheep grazing is the principal form of land use in all of the blocks, with cereal crops being grown in the Roma and Goondiwindi blocks. In the Blackall, Charleville and Bollon blocks, much of the original vegetation has been 'pulled' with tractors and chains, but not cleared, leaving large areas of fallen timber and regenerating vegetation. The Longreach and Windorah blocks are naturally open.

The three main commercially harvested species of kangaroos in Queensland, the eastern grey kangaroo, the red kangaroo and the common wallaroo occur at varying densities in these blocks and were the subjects of this study.

Helicopter line transect surveys

A helicopter (Bell 47 KH4) with the doors removed was flown at a ground speed of 93 km/h, 61 m above the ground. Two observers occupying the rear seats counted kangaroos seen on either side of the aircraft. The sightings of individual kangaroos were placed into 25 m distance classes up to 125 m perpendicular to the transect line, measured from directly below the observer. Sightings were recorded into micro-cassette recorders. The distance classes were delineated on aluminium poles extending perpendicularly from either side of the helicopter.

The observers counted in five minute units with a 30 s break between them. A full description of this method is given in Clancy *et al.* (1997).

Parallel east-west transects, 10 km apart, were flown across each of the seven survey blocks. Each transect was divided into two survey lines, each approximately 40 km long and separated by a 10 km interval which was flown but where kangaroos were not recorded. An exception was the Windorah block, where single, undivided 40 km transect lines were flown. Eight survey lines were flown across the Longreach, Windorah, Bollon and Goondiwindi blocks, 12 survey lines were flown across the Blackall block, 15 lines were flown across the Roma block, and 16 lines were flown across the Charleville block. The exact distances were determined by a global positioning receiver. Surveys were conducted within the three hours after sunrise and the two hours before sunset in late May and early June 1992. An exception was the Goondiwindi survey, which was conducted in March 1992.

Fixed-wing aircraft surveys

The fixed-wing surveys were undertaken with a high-winged aircraft (Cessna 182) flown at a ground speed of 185 km/h and a height above the ground of 76 m. Two observers occupying the rear seats counted individual kangaroos seen in a 200 m wide strip on either side of the aircraft. The strips were delineated by markers on the wing struts and start some distance out from a point on the ground directly below the aircraft. Sightings were recorded into micro-cassette recorders. The observers counted in 97 s units with a 7 s break between them (Caughley and Grigg 1982). Navigation was aided by a global positioning receiver. Surveys were conducted in sunny conditions within the two hours after sunrise and the two hours before sunset, and all were flown in June 1992 (with the exception of the Goondiwindi block which was flown in March 1992), within three weeks of the helicopter surveys. All the transect lines of a survey block were usually flown during any single morning or afternoon session. Observers assessed the average canopy cover for each 97 s unit as being either open, light, medium or dense. Where appropriate, intermediate scores were used. Air temperature was also recorded at survey height at the start and finish of each transect line.

Data analysis

Kangaroo densities were calculated for each survey block for both the helicopter line transect method and the fixed-wing strip transect method. Each species of kangaroo present in each block was treated separately.

Data from the helicopter line transect surveys (HLT) were analysed using the computer program DISTANCE (Laake *et al.* 1993). The analytical procedures followed those recommended by Buckland *et al.* (1993) and are described in full in Clancy *et al.* (1997) and Pople *et al.* (1998). Line transect methodology allows survey-specific correction for visibility bias. The decline in visibility away from the transect line is described by the perpendicular distances to sightings, to which a number of robust models are fitted. The best model (probability density function) was selected according to its shape and Akaike's Information Criterion (a combination of goodness of fit and simplicity) (Buckland *et al.* 1993).

Density estimates (D) were determined as:

$$D = \frac{nf(0)}{2L} \qquad (1)$$

where, n is the number of sightings, $f(0)$ is the probability density function of the perpendicular density data at zero distance from the survey transect and L is the total length of the survey transect (Buckland *et al.* 1993). Data were analysed as individual sightings rather than as clusters of animals. Variance estimates for survey block densities were calculated as:

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

where, CV(n) is the coefficient of variation for the number of sightings on transect lines and CV(f(0)) is the coefficient of variation of the probability density function of the perpendicular density data at zero distance (Buckland *et al.* 1993).

The sample counts for the 200 m fixed-wing strip transects were expressed both as raw, uncorrected densities (ST) and as densities corrected for habitat and temperature (CST). Both these densities were calculated using counts from both sides of the aircraft pooled. Habitat correction factors, applied to densities in each 97 s unit, were 2.29 for open vegetation cover, 2.36 for light cover, 2.43 for medium cover and 2.57 for dense cover (Caughley *et al.* 1976). If the average temperature for a transect line was >15°C, then the density estimate for CST was multiplied by 1/(1.474 - 0.0316T), where T is the temperature (°C) (Caughley 1989). Standard errors of the densities in the survey blocks were determined from the variation in density among transect lines.

Revised correction factors, representing the factor that uncorrected fixed-wing estimates would need to be multiplied to equal the helicopter estimates, were calculated for each species in each block. Where possible, standard errors were calculated using transect lines as replicates and treating the two survey methods as a form of double sampling (Cochran 1977, Pollock and Kendall 1987).

The observers' assessment of canopy cover on each fixed-wing survey unit was converted to a numerical score and then averaged for each transect line. These scores were 10 for open, 30 for light, 60 for medium and 90 for dense. Transect habitat scores were then averaged within each block. The relationship between correction factors and habitat across blocks was then examined using Spearman rank correlation coefficients (Zar 1984).

Because surveys were not conducted simultaneously, some variability would be expected at the scale of a transect line as a result of the movement of animals. This, however, was considered to be negligible at the scale of a survey block. For this reason and the fact that sample sizes are appreciably smaller on transect lines, the survey methods were compared at the scale of a survey block. Furthermore, an analysis of these data at the scale of a transect line yielded almost identical results (Pople *et al.* 1993).

Comparisons of the different survey methods were made using single-factor, repeated-measures analyses of variance (Winer *et al.* 1991). The three survey methods (HLT, ST and CST) were treated as the repeated (within) factors applied to each survey block. In an analysis such as this, each block acts as its own control and all between block variation is excluded from the experimental error (Neter *et al.* 1990). All density estimates were transformed to the logarithm base ten.

Results

Mean density of red kangaroos in six of the survey blocks estimated by the helicopter (HLT) and fixed-wing surveys (ST) are given in Table 1 along with the 'corrected' density estimates for ST (CST). Density was too low to be estimated at Goondiwindi. Comparison of the six sets of density estimates resulted in a significant difference between survey methods (F = 18.77, d.f. = 2, 10, $P < 0.001$). *A posteriori* comparison of means (Newman-Kuels procedure, Winer *et al.* 1991) revealed that only ST differed significantly from HLT ($P < 0.01$). The use of habitat and temperature correction factors to determine CST eliminated this difference ($P >$ 0.10).

Table 1. Densities (± s.e.) of red kangaroos (per km^2) in six survey blocks estimated by line transect surveys (HLT) flown by a helicopter, and corrected (CST) and uncorrected (ST) strip transect surveys flown by a fixed-wing aircraft. For full explanation of these methods see text.

Survey block	HLT	ST	CST
Longreach	8.74 ± 1.24	5.23 ± 1.13	12.68 ± 2.54
Windorah	0.66 ± 0.29	0.21 ± 0.09	0.58 ± 0.22
Blackall	13.32 ± 2.22	5.07 ± 0.71	12.20 ± 1.14
Charleville	2.97 ± 1.76	0.96 ± 0.39	2.58 ± 1.06
Bollon	2.36 ± 0.56	1.35 ± 0.54	3.22 ± 1.28
Roma	0.43 ± 0.16	0.58 ± 0.17	1.62 ± 0.49

Eastern grey kangaroo density was estimated in all seven survey blocks (Table 2). There was a significant difference between survey methods ($F = 102.48$, d.f. = 2, 12, $P < 0.001$). Results of an *a posteriori* comparison of means (Newman-Kuels procedure) showed that both ST and CST differed significantly from HLT ($P < 0.001$).

Common wallaroo density was estimated in three blocks (Table 3). Density was too low to be estimated in the other blocks. No correction factors are currently employed for wallaroo counts in strip transects on fixed-wing surveys, so only raw counts were analysed. These were significantly lower than the helicopter counts ($F = 444.99$, d.f. = 1, 2, $P < 0.01$).

Table 2. Densities (± s.e.) of eastern grey kangaroos (per km^2) in seven survey blocks estimated by line transect surveys (HLT) flown by a helicopter, and corrected (CST) and uncorrected (ST) strip transect surveys flown by a fixed-wing aircraft. For full explanation of these methods see text.

Survey block	HLT	ST	CST
Longreach	3.92 ± 1.16	0.39 ± 0.18	0.97 ± 0.47
Windorah	0.57 ± 0.22	0.06 ± 0.05	0.17 ± 0.17
Blackall	10.84 ± 0.91	2.16 ± 0.48	5.25 ± 1.14
Charleville	7.00 ± 2.07	1.38 ± 0.28	3.68 ± 0.74
Bollon	23.72 ± 4.65	5.95 ± 2.24	14.31 ± 5.35
Roma	31.88 ± 5.33	9.16 ± 1.25	22.20 ± 3.05
Goondiwindi	25.77 ± 3.17	3.41 ± 0.42	10.02 ± 2.73

Table 3. Densities (± s.e.) of common wallaroos (per km^2) in three survey blocks estimated by line transect surveys (HLT) flown by a helicopter, and uncorrected (ST) strip transect surveys flown by a fixed-wing aircraft. For full explanation of these methods see text.

Survey block	HLT	ST
Longreach	1.41 ± 0.55	0.37 ± 0.15
Blackall	13.35 ± 1.80	3.26 ± 0.69
Charleville	0.38 ± 0.11	0.08 ± 0.03

Table 4. Correction factors (± s.e.) developed from previous studies and in the present study (representing the factor by which the uncorrected density estimates from fixed-wing surveys would need to be multiplied in order to equal the helicopter line transect estimates). The correction factors given for wallaroos in the present study are conservative, because the helicopter line transect density estimates are known to be negatively biased by a factor of 2-3. Dashes indicate the species was at a density too low to be estimated. Mean habitat scores and coefficients of variation (CV) for each block are also shown. All correction factors have been developed for 200 m strip transect counts using the same fixed-wing aircraft aerial survey method. Open refers to grassland and open shrubland; wooded refers to vegetation ranging from low open woodland to woodland, and includes mulga tall shrubland.

Survey block/ Source	Habitat (CV)	Red kangaroos	Eastern grey kangaroos	Common wallaroos	Western grey kangaroos
Longreach	25 (0.11)	1.67 ± 0.37	10.18 ± 9.14	3.81	
Windorah	35 (0.00)	3.14	9.50	-	
Blackall	37 (0.08)	2.63 ± 0.44	5.02 ± 1.05	4.10 ± 0.66	
Charleville	59 (0.04)	3.09	5.09 ± 1.27	4.75	
Bollon	58 (0.06)	1.75	3.99 ± 1.20	-	
Roma	34 (0.11)	0.74	3.41 ± 0.68	-	
Goondiwindi	41 (0.13)	-	7.56 ± 1.89	-	
Previous studies:					
Bailey (1971)	open	1.8			
Caughley *et al.* (1976)	open	2.3			
Caughley *et al.* (1976)	wooded	2.4			
Short & Bayliss (1985)	open	1.8			4.8
Short and Bayliss (1985)	wooded	2.8			16.7
Short & Hone (1988)	open	2.5		11.1	5.9
Southwell *et al.* (1986)	open	1.8		3.9	
Southwell *et al.* (1986)	wooded	4.2		23.3	
Grice *et al.* (1990)[A]	wooded	3.8 ± 1.3	3.5 ± 1.4		

[A] Standard error calculated from the difference between two estimates.

Revised correction factors for each species in each block are given in Table 4 along with mean habitat scores for each block. Correction factors derived from previous studies are also shown. Pople *et al.* (1998) also reported results for the Longreach and Blackall blocks, but only for eight (cf. 15) lines of the Charleville block. Mean habitat scores were uncorrelated with these correction factors for both red kangaroos (r_s = 0.49, d.f. = 4, $P > 0.20$) and eastern grey kangaroos (r_s = -0.29, d.f. = 5, $P > 0.50$). Because wallaroo density was estimated in only three blocks, a correlation coefficient was not calculated.

Discussion

Accuracy

Confidence in the revised correction factors in Table 4 hinge largely on the accuracy of the helicopter surveys. For red kangaroos and eastern grey kangaroos, Clancy *et al.* (1997) found such surveys to be as accurate as walked line transect surveys over a broad range of environmental conditions. For wallaroos, densities estimated from helicopter surveys were negatively biased by a factor of 2-3 (Clancy *et al.* 1997). However, this bias was relatively consistent, allowing some evaluation of the bias of density estimates obtained using fixed-wing surveys.

The ability of fixed-wing surveys to estimate kangaroo numbers depends upon the application of appropriate correction factors. One option is for the correction factors derived in this study to be generalised to areas outside survey blocks, such as a region of similar habitat. This study has identified some of the spatial variability in sightability. For red kangaroos, sightability was best in the open Mitchell grass downs around Longreach and worst in the timbered country around Charleville. However, some correction factors do not correspond to overall vegetation cover in the block, but this can probably be attributed to poor (imprecise) estimates of low densities. Standard errors could only be calculated for correction factors on two survey blocks (Table 4). Nevertheless, the values are similar to the currently used correction factors and those developed in other studies (Table 4).

Eastern grey kangaroos require much larger correction factors than are currently employed to estimate true density from fixed-wing surveys. This problem has been highlighted for many years (Southwell 1989). Again, there was poor correspondence between correction factors and vegetation cover in the survey block. This may again have been the result of imprecise estimates of low densities. This problem was exacerbated in the more open blocks where eastern grey kangaroos were associated with pockets of woodland. The large standard error for the correction factor at Longreach (Table 4) reflects this clumped distribution and the small number (n = 4) of replicates (the result of pooling transect lines to increase sample size). The result at Goondiwindi may, in part, reflect the warmer temperatures of the March survey and the possible inadequacy of the temperature correction (see below). This seasonal influence on accuracy had been identified previously by Caughley (1989).

Wallaroos require large correction factors, particularly if the negative bias of the helicopter surveys is taken into account, making them poor subjects for these fixed-wing surveys as random errors will be large. Use of a narrower survey strip would reduce this problem (e.g. 100 m, Pople *et al.* 1998).

It is still not clear whether to apply correction factors at a regional scale (e.g. the correction factors in Table 4 applied to a region of similar habitat), to continue applying them at the scale of a survey unit, or to apply them at an even finer scale of each animal sighted (Pople *et al.* 1998). These finer scales would theoretically account for shifts in habitat use that occur during the day, with temperature and with changes in food availability. The correction factors determined from this study can not be simply translated to another scale. Determining correction factors at these finer scales would be difficult, requiring a different set of experiments to those conducted here, and may still be specific to regions. Nevertheless, the results of this study suggest regional differences in visibility bias beyond those suggested by the extent of vegetation cover in an area. Further comparisons could at least assess the generality of regionally applied correction factors.

For the Blackall survey block, species identification was a problem during fixed-wing surveys, casting some doubt on the correction factors for all species in this survey block. This problem was identified also by Grigg *et al.* (1997) during kangaroo surveys by ultralight aircraft in the Blackall survey block. Frequently, sightings would include aggregations of all three macropod species. This was less of a problem for helicopter surveys which are flown lower and slower than are fixed-wing surveys, and where visibility is not impeded by windows. It is a problem peculiar to (but not unique to) the Blackall region, where wallaroo density is particularly high (Table 3), and this is reflected in the harvest density (Fig. 2*c*). It would be important to maintain helicopter surveys in this area for these reasons alone.

Repeatability

Strict standardisation of a number of factors influencing sightability of kangaroos from fixed-wing aircraft is required to ensure repeatability of the technique. These factors include strip width, height above the ground, observer, temperature, cloud cover, time of day and season (see review by Southwell 1989). Caughley (1989) distinguished factors that could be standardised from those that could be randomised and reduced to statistical noise. Standardisation can only be achieved within limits, but if the extremes of a factor are not too marked and the levels of that factor are sampled a number of times during a survey, then it can safely be randomised (Caughley 1989). Where a factor can be neither standardised nor randomised, then it needs to be corrected for. Caughley (1989) identified temperature >15°C as needing correction to ensure repeatability. To be generally true, temperature would need to account for a suite of influences on sightability such as changes in kangaroo behaviour and habitat use (Hill *et al.* 1985, Short and Hone 1988). Correcting for habitat, required to convert strip transect counts to absolute densities, can also improve repeatability by accounting for altered habitat associations of animals between surveys. This can happen only if the correction factor is applied at the scale of each animal sighted (Pople *et al.* 1998). Comparisons between helicopter and fixed-wing surveys over a number of years have been conducted in the Blackall survey block (A.R. Pople and T.F. Clancy, unpublished data) which will provide some assessment of the repeatability of fixed-wing surveys.

Broad-scale surveys in Queensland

Over the past twenty years, 43-68% of the commercial harvest of all kangaroo species in Australia has been taken in Queensland (Pople and Grigg 1997). Furthermore, quotas have been met regularly in Queensland, whereas they are only now being approached in other States. It could be argued, therefore, that accurate assessment of kangaroo numbers is most critical in Queensland.

An obvious shortcoming of helicopter surveys is that cost prohibits their use across large areas. They are approximately three times the cost per kilometre of a fixed-wing aircraft and have reduced range. Furthermore, this does not take into account greater labour costs for the more time-consuming helicopter surveys. Ultralight aircraft offer a cheaper alternative capable of similar accuracy to helicopters (Grigg *et al.* 1997). Their limited crew comfort and range, and slow speed for transport flights, restrict their large-scale application. However, they could be particularly useful where surveys of properties rather than regions are required. Previously there were regulatory difficulties associated with the commercial use of an ultralight aircraft in this way, but the difficulties seem now to have been resolved. The helicopter survey blocks in Queensland (Fig. 1) were chosen as representative samples of the fixed-wing survey area, based on previous fixed-wing surveys. They also provide regional density estimates with adequate precision (the ratio of the standard error to the mean). Broad-scale fixed-wing surveys in Queensland (Fig. 1) have been conducted along two transect lines for every degree of latitude (Caughley and Grigg 1982), representing a sampling intensity of approximately 0.75%. While this is adequate for a Statewide estimate, it would be insufficient for regional estimates (Caughley 1979).

The region to the east of the survey area shown in Fig. 1, comprising the eastern highlands, is not amenable to aerial survey because of heavy vegetation cover and steep terrain. For a large part of this region, population estimates for large macropods were obtained from foot surveys conducted by Southwell *et al.* (1997). These surveys have provided the basis for setting quotas in similar areas of New South Wales and have given confidence to the sustainability of the whiptail wallaby (*M. parryi*) harvest in Queensland (Southwell *et al.* 1995).

In summary, this study has quantified the extent to which eastern grey kangaroos and common wallaroos have been underestimated by surveys using fixed-wing aircraft in Queensland, and confirmed the accuracy of such surveys for red kangaroos. The results suggest a future shift to regional corrections for bias, partly because of regional differences, but also because revised estimates have been derived at this scale. Further work is needed to confirm this and assess whether these corrections lead to repeatable estimates of kangaroo density.

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