Accuracy and consistency in the aerial survey of kangaroos

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ABSTRACT

Accuracy, or bias, is the closeness of a measured value to its true value. It can be of secondary importance in relation to repeatability and precision in a sampling programme, but where management decisions, such as the setting of kangaroo harvest quotas, are involved, accuracy assumes a greater importance. Associated with this is the requirement that the survey method used be consistent. If this is the case, as has been common practice, then the negative, but consistent bias of standard fixed-wing aerial surveys of kangaroos can be redressed through the use of correction factors. The correction factors currently used to account for the negative bias in fixed-wing aerial surveys of kangaroos, which were derived for red kangaroos, have not been found to be suitable for all species likely to be encountered in surveys. This was confirmed by comparison of standard fixed-wing aerial survey counts with those obtained using helicopter line transect surveys. While the currently used correction factors may be suitable for red kangaroos *Macropus rufus*, correction factors of at least 1.5 times these are probably required for eastern and western grey kangaroos *M. giganteus* and *M. fuliginosus*. The standard fixed-wing aerial survey method was found to be spatially density independent and therefore consistent over seven survey blocks in Queensland. If desired, this would allow the derivation of broad-scale correction factors for both red and eastern grey kangaroos of 2.25 and 4.37, respectively. Currently used correction factors range from 2.29 to 2.57, depending on vegetation cover.

INTRODUCTION

Critical to the management and conservation of large kangaroos is the effectiveness of the survey techniques used to monitor their populations. This effectiveness is usually defined in terms of accuracy, repeatability and precision, with the relative importance of these three properties being determined by the specific aims of the monitoring programme.

Accuracy, or bias, is defined as simply being the closeness of a measured value to its true value (Krebs 1989). The transect-based survey techniques usually used to monitor kangaroo populations have been recognized as being negatively biased (Pollock and Kendall 1987; Southwell 1989). Repeatability can be defined as the closeness of repeated measurements of the same item (Southwell 1989), or as constancy of bias among samples (Pople 1999). A technique is generally repeatable if it is unaffected by the conditions under which it is used. Precision is related to the random errors associated with the sampling process and is influenced directly by sampling intensity (Southwell 1989). Precise estimates have low coefficients of variation.

Ordinarily, within the context of wildlife monitoring programmes, repeatability and precision are considered to be relatively more important than accuracy, particularly if the aim of a sampling programme is to follow the trajectory of a population over time as part of the process of ensuring the population's well-being. If this is the case, then a survey technique that is repeatable and relatively precise but produces a biased population index is usually adequate. However, if an estimate of the absolute density of a species is required, as is the case for the setting of harvest quotas for the management of large kangaroos, then accuracy assumes greater importance.

A further characteristic of a survey technique associated principally with accuracy is that of consistency. The relationship between the population density estimate, or an index produced by a particular survey technique, and the true population density can take a number of forms (Caughley 1977; Southwell 1989). For a survey technique to be consistent, the relationship between the density estimate or index produced by it and the actual population density must be linear and pass through the origin such that any proportional change in the population density will be reflected in the same proportional change in the density estimate or index (Southwell 1989).

Consistency, like repeatability and precision, is generally more important than accuracy (Southwell 1989). Consistent but inaccurate (biased) counts produced by a particular survey technique can provide useful population estimates or indices. If the relevant information is available, these counts can be corrected for the inherent bias of the survey technique and estimates of the true population density produced.

THE CURRENT STATUS OF FIXED-WING AERIAL SURVEYS

Aerial surveys of kangaroo populations using fixed-wing aircraft were first conducted in the 1960s (Frith 1964; Newsome 1965; Bailey 1971). Refinement of the survey technique and the development of a set of correction factors to overcome the negative bias inherent in the counts obtained was undertaken by Caughley *et al.* (1976). They used an indirect regression method to develop these correction factors (Caughley *et al.* 1976).

Following the standardization of the survey technique and development of the correction factors, broad-scale aerial surveys of kangaroos began to be undertaken on a regular basis throughout Australia in the late 1970s. These surveys became an integral part of the kangaroo management programmes of New South Wales (Caughley *et al.* 1977; J. Caughley *et al.* 1984), South Australia (Caughley and Grigg 1981; Cairns and Grigg 1993), Western Australia (Short *et al.* 1983) and, to a lesser extent, Queensland (Caughley and Grigg 1982). The general approach and methods used in these large-scale surveys are outlined in Caughley and Grigg (1981).

While surveys using fixed-wing aircraft and the correction factors derived by Caughley *et al.* (1976) had been considered suitable for deriving population estimates for the red kangaroo *Macropus rufus* inhabiting open habitats, the accuracy of population estimates for other species using these correction factors in more heterogeneous habitat had come under some scrutiny (Barnes *et al.* 1986; Hill *et al.* 1987). Also, a number of studies since Caughley *et al.* (1976) had proposed alternative, generally higher, correction factors for eastern and western grey kangaroos *M. giganteus* and *M. fuliginosus* (e.g., Short and Bayliss 1985; Southwell *et al.* 1986; Short and Hone 1988; Grice *et al.* 1990). However, the correction factors developed by Caughley *et al.* (1976) continued to be used in relation to the standard fixed-wing method of aerial survey, and the only real change to the technique was the development of a temperature correction factor that could be used in conjunction with the habitat correction factors (Bayliss and Giles 1985; Caughley 1989).

That none of the correction factors derived in more recent studies (see Table 4 in Pople *et al.* 1998a) replaced, in general use, those derived by Caughley *et al.* (1976) can probably be attributed to doubt about the various ways in which the baseline estimates of the true population densities were derived. Nevertheless, some of these studies (Short and Bayliss 1985; Short and Hone 1988; Grice *et al.* 1990) did provide further weight to the argument that the Caughley *et al.* (1976) correction factors were not as generally applicable as first thought, particularly for grey kangaroos.

A NEW APPROACH TO THE PROBLEM OF CORRECTION FACTORS

Mindful of the problems associated with the correction factors that were being used as part of the standard aerial survey method, a new approach to surveying kangaroo populations using a helicopter as the survey platform and the line transect method was developed by Clancy *et al.* (1997). The impetus for this had come from the success that Southwell and Weaver (1993) and Southwell (1994) obtained by using the line transect method in walked ground surveys of kangaroo populations.

In a series of experiments conducted in Queensland, Clancy *et al.* (1997) were able to demonstrate that for both red kangaroos and eastern grey kangaroos there was no difference between the density estimates obtained using helicopter line transect surveys and walked line transect surveys. This, however, was not the case for common wallaroos *M. robustus* for which helicopter line transect surveys underestimated the density estimates of walked line transect surveys (Clancy *et al.* 1997). From the work conducted by Southwell and Weaver (1993) and Southwell (1994), it could be assumed that helicopter line transect surveys were similarly producing accurate estimates of red and eastern grey kangaroo densities.

In further studies conducted in Queensland, Pople *et al.* (1998a,b) compared standard fixed-wing aerial surveys with helicopter line transect surveys. These studies confirmed the suspicion that the Caughley *et al.* (1976) correction factors used to adjust standard fixed-wing survey results were underestimating densities of eastern grey kangaroos (Barnes *et al.* 1986; Hill *et al.* 1987; Clancy *et al.* 1997). Correction factors derived by Pople *et al.* (1998b) for red and eastern grey kangaroos in seven survey blocks ranging over the biogeographic areas of Queensland where these two species are relatively abundant are given in Table 1.

Although derived for a number of survey blocks with varying vegetation cover, it was concluded by Pople *et al.* (1998b) that there was broad agreement between the proposed

Table 1. Correction factors for the density estimates from standard fixed-wing aerial surveys on seven survey blocks in Queensland based upon concurrent density estimates obtained from helicopter line transect surveys in the same blocks. No correction factor has been derived for red kangaroos in the Goondiwindi block because of a very low and imprecise density estimate. Where they have been given, the standard errors are those that have been derived by using individual transect lines in blocks as replicates and treating the two survey methods as a form of double sampling. (Data from Pople *et al.* 1998b).

Survey block	Red kangaroos	Eastern grey kangaroos
Longreach	1.67 ± 0.37	10.18 ± 9.14
Windorah	3.14	9.50
Blackall	2.63 ± 0.44	5.02 ± 1.05
Charleville	3.09	5.09 ± 1.27
Bollon	1.75	3.99 ± 1.20
Roma	0.74	3.41 ± 0.68
Goondiwindi	—	7.56 ± 1.89

correction factors for red kangaroos (Table 1) and those derived by Caughley *et al.* (1976). The correction factors that had been derived by Caughley *et al.* (1976) ranged from 2.29 to 2.53, depending upon the type of habitat.

In the case of eastern grey kangaroos, the correction factors derived by Pople *et al.* (1998b) for the seven survey blocks (Table 1) were between 1.5 times and 4 times the general correction factors derived by Caughley *et al.* (1976). Despite the broad range of these correction factors, the details of which are discussed by Pople *et al.* (1998b), there is a clear indication that correction factors double those that have been used are required if reasonably accurate estimates of eastern grey kangaroo numbers are to be obtained. Also, although the data are limited (Short and Bayliss 1985; Short and Hone 1988), this could also be the case for western grey kangaroos.

CONSISTENCY

If helicopter line transect surveys provide density estimates that can be assumed to be accurate (Clancy *et al.* 1997; Pople *et al.* 1998a), then the relationship between these estimates and those derived from standard fixed-wing aerial surveys of the same areas can be used to assess whether or not the fixed-wing method is consistent. Figure 1 shows the relationships between red and eastern grey kangaroo densities derived using standard fixed-wing aerial surveys and helicopter line transect for seven survey blocks in Queensland (Pople *et al.* 1998b).

Linear regressions fitted to the data in Figure 1 were found to be significant (red kangaroo: $r^2 = 0.90$; $t_4 = 5.86$, $P < 0.01$; eastern grey kangaroos: $r^2 = 0.85$; $t_5 = 5.34$, $P < 0.01$), but with intercepts not significantly different from zero (red kangaroos: $t_4 = 0.51$, $P > 0.50$; eastern grey kangaroos: $t_5 = 0.56$, $P > 0.50$). This therefore allowed the fitting of the simpler model of a linear regression

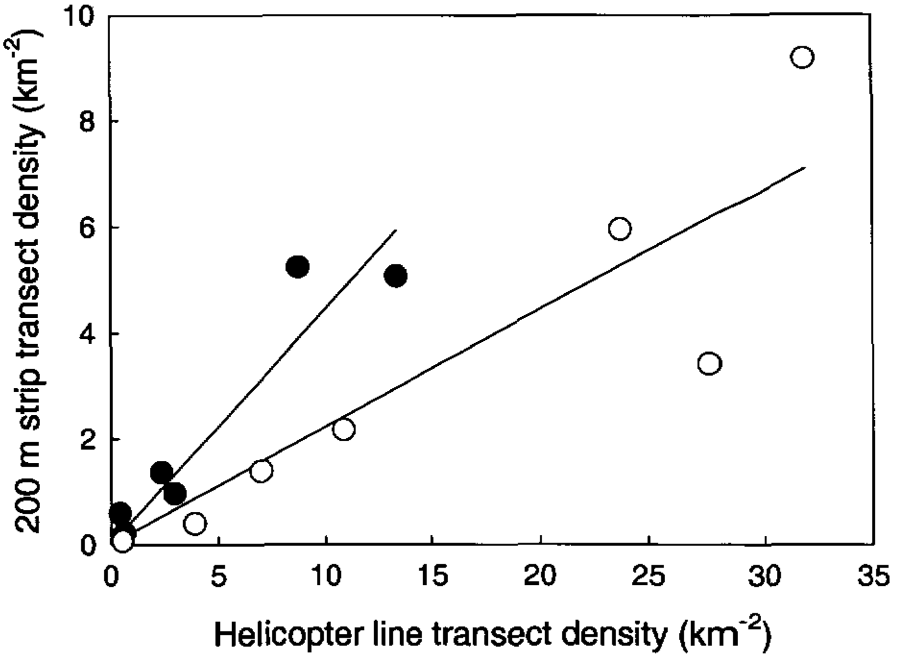

Figure 1. The relationships between kangaroo densities derived from standard 200 m fixed-wing strip transect surveys and helicopter line transect survey for red kangaroos (●) and eastern grey kangaroos (O). The linear regressions passing through the origin are confirmation that the standard 200 m fixed-wing strip transect method of aerial survey is consistent. (Data from Pople *et al.* 1998b).

through the origin to these data. Fitting such a model shows that the standard fixed-wing aerial survey method is consistent (Southwell 1989). The two regressions of this form shown in Figure 1 are $y = 0.445x$ for red kangaroos and $y = 0.229x$ for eastern grey kangaroos, where y is the fixed-wing aerial survey density estimate and x is the helicopter line transect density estimate.

The fitting of linear regressions to the data shown in Figure 1 assumes that the relationships between the fixed-wing aerial survey density estimates and helicopter line transect density estimates were spatially density independent. To ensure that this was the case, the linear form of the power relationship ($\log y = \log a + b \log x$) was also fitted to the data and the regression coefficient (b) tested against a null model of one. A full explanation of this model is given in Pople (1999). For both red and eastern grey kangaroos, the regression coefficients were found not to be significantly different from one (red kangaroos: $t_4 = 0.84$, $P > 0.50$; eastern grey kangaroos: $t_5 = 2.07$, $P > 0.05$), thus confirming that the relationships between fixed-wing aerial survey density estimates and helicopter line transect density estimates were in fact density independent and consistent.

DISCUSSION

It appears from recent experimental work (Pople *et al.* 1998a,b) that, although the correction factors developed by Caughley *et al.* (1976) remain acceptable for estimating red kangaroo numbers, they are not suitable for eastern grey kangaroos nor, perhaps, western grey kangaroos. Correction factors at least 1.5 times greater than those developed by Caughley *et al.* (1976) would be needed to provide accurate population estimates of grey kangaroos. At what scale these correction factors should be derived and applied, however, is still a point of debate (Pople 1999).

One approach that can be taken to this problem is to derive broad-scale, species-specific correction factors that could be applied across a range of habitat types and kangaroo densities. With the standard fixed-wing method of aerial survey having been shown here to be spatially consistent across a number of different survey blocks in Queensland (Pople *et al.* 1998b), the reciprocals of the regression coefficients of the two relationships shown in Figure 1 could be used as general, broad-scale correction factors. For red kangaroos, the correction factor derived this way would be 2.25, which is a value similar to the Caughley *et al.* (1976) correction factors. For eastern grey kangaroos, the correction factor derived this way would be 4.37, which is slightly less than twice the Caughley *et al.* (1976) correction factors. An alternative would be to derive and use separate regional correction factors such as those shown in Table 1. This would be appropriate if the linear regression between fixed-wing aerial survey density estimates and helicopter line transect density estimates, such as those shown in Figure 1, failed to conform to the normal error model because of regional differences in bias due to, say, the influence of habitat.

Kangaroo densities differ on a regional basis. Despite this, the different densities of red and eastern grey kangaroos in the seven survey blocks used by Pople *et al.* (1998b) did not influence the overall relationship between fixed-wing aerial survey density estimates and helicopter line transect density estimates. Hence, the standard fixed-wing aerial survey method could be considered to be spatially density independent and therefore consistent. However, because populations rarely remain static, there is a possibility that the relationship between fixed-wing aerial survey density estimates and the true population density could be temporally density dependent. The likelihood of there being temporal density dependence between fixed-wing aerial survey density estimates has been examined by Pople (1999) in relation to repeatability.

ACKNOWLEDGEMENTS

The writing of this paper benefited greatly from discussions with Tony Pople.

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