Using kangaroo surveys to monitor biodiversity

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Abstract

Broad-scale aerial surveys of kangaroo populations have been conducted regularly over vast areas of the rangelands since the 1970s to monitor population trends and to determine harvest quotas. Whilst there is obvious worth in monitoring kangaroos in their own right they may also be useful as surrogates for other elements of the biodiversity and as indicators of environmental change. In the relatively open habitats of the rangelands, conspicuous animals such as kangaroos are amenable to aerial survey. Other survey methods such as direct counts from vehicles or indirect monitoring such as harvest statistics, including catch per unit effort or harvest sex ratio, are restricted in their potential survey frequency and extent due to cost and also vary in their reliability. Kangaroo monitoring programs have several characteristics that make them attractive for monitoring biological diversity in the rangelands. These include systematic design, standardised methods, annual surveys and strong political and bureaucratic support. Other species such as emus and bustards, and feral herbivores such as goats are also counted during aerial surveys, allowing patterns of distribution and trends in their abundance to be determined. Through correlation with rainfall, long-term data for all these species have provided an understanding of their population dynamics. This is valuable, as trend monitoring will be complicated by process error in fluctuating environments. Comparisons of large herbivore population dynamics between areas allows an assessment of varying environmental impacts such as drought, effects of different management regimes such as harvesting and National Park management, and longer-term environmental change. Case studies from Queensland are used to illustrate its usefulness for monitoring environmental change at both state and regional scales.

INTRODUCTION

Managing commercial harvesting of kangaroos has involved setting annual harvest quotas based primarily on estimates of absolute population size. Wildlife authorities rely primarily on aerial surveys to provide population estimates, although these are supplemented with other techniques. Aerial surveys of kangaroo populations have been conducted regularly over large areas of the rangelands in South Australia, Western Australia, New South Wales and Queensland since the 1970s. Due to the scale, frequency and longevity of these surveys, the combined dataset represents a significant resource for understanding and managing the rangelands.

What is not fully appreciated about this extensive, long-term monitoring is that kangaroos may also be useful surrogates for other elements of the biodiversity and as indicators of environmental change. This paper reviews the main approaches currently adopted to the monitoring of kangaroo populations in Australia and discusses the characteristics of these monitoring programs that render them
particularly suitable for incorporation into a broader framework for monitoring biodiversity in the rangelands. A number of empirical case studies from Queensland are then used to demonstrate the potential application of this monitoring as part of a broader biodiversity monitoring program. A diverse set of case studies have been selected to emphasise both the potential and realised usefulness of existing kangaroo monitoring programs for monitoring and interpreting environmental change at a range of temporal and spatial scales.

BACKGROUND TO KANGAROO MANAGEMENT

Pople and Grigg (1997) summarise the history of kangaroo harvesting both by Aborigines and following European settlement in Australia. Kangaroos were not shot in significant numbers until the latter part of the 19th century when some states offered bounties and a skin trade had developed. Even with this early growth in harvesting it was not until the early 1970s, in response to mounting public concern for the conservation of kangaroos, that formalised state management plans for kangaroos were developed. By 1984, legislation required these management plans to have commonwealth approval before they could be undertaken. Management programs were approved for a period of one year and included an annual quota for each species taken commercially. This increased regulation and the imposition of annual harvest quotas in the 1970s provided the major impetus for increased monitoring of kangaroo populations that were subject to commercial harvests. The recent enactment of national biodiversity conservation legislation has further increased the need for robust monitoring programs that meet the information requirements of policy and decision makers and the general public.

Currently there are five species of macropods harvested commercially on the Australian mainland and are therefore subject to management programs approved by the commonwealth:

- Red kangaroo (Macropus rufus), Qld, NSW, SA, WA
- Eastern grey kangaroo (M. giganteus), Qld, NSW
- Western grey kangaroo (M. fuliginosus), NSW, SA, WA
- Common wallaroo or euro (M. robustus), Qld, NSW, SA, WA
- Whiptail wallaby (M. parryi), QLD

The main aims of the various state management programs for kangaroos can be reasonably summarised as ensuring the conservation of each kangaroo species across its natural range whilst allowing culling of animals for both commercial purposes and for damage mitigation. The harvest is essentially managed for sustainable use, although quotas are set conservatively to minimise risk of overharvest. There is obviously a trade-off between yield and damage mitigation, but this has not been well quantified (Pople and McLeod 2000).

Annual commercial quotas are currently set by state management agencies at between 10-20% of the estimated population size. This represents a tracking strategy, with the quota fluctuating with the population as it fluctuates in response to environmental conditions. This strategy has a number of advantages over alternative strategies, including a low risk of over- or underharvest in a stochastic environment (Caughley 1977), simplicity, robustness to bias in population estimates (Milner-Gulland et al.)
2001) and allowing harvest policy to be proactive rather than reactive (McCallum 1999). Employing this type of strategy does require regular estimates of absolute population size and not simply an index. Trends in indices, while of interest, are secondary.

Monitoring kangaroos for harvest management has lead to a significant body of work describing the distribution and dynamics of both harvested and unharvested kangaroo populations (see Pople & Grigg 1997 for an overview). This, along with regular absolute population estimates from data independent of the harvest, has provided a public confidence in kangaroo management (i.e. the harvest is demonstrably sustainable, McCallum 1999). Extensive monitoring data have allowed refinement of management, and this process is continuing.

KANGAROO MONITORING METHODS

Southwell (1989) provides an extensive review of the techniques used for monitoring the abundance of kangaroo and wallaby populations. Since that review there has been significant refinement and development of techniques (Pople & Grigg 1997, Pople in press). Woinarski et al. (2000) considered it somewhat ironic that arguably the most coherent and scientifically robust programs for monitoring Australian fauna derive from perceptions of over-abundance and pest problems rather than a desire to regularly review the conservation status of the species involved. Nonetheless, they concluded that the current programs for monitoring kangaroos demonstrated that, with adequate incentives, impressive wildlife monitoring systems could be built and attract ongoing support from a range of interests.

The array of techniques applied to monitor kangaroo populations can be classified as either direct or indirect. Direct monitoring entails actual counts of animals whereas indirect monitoring involves inferring population size and trend from either counts of animal signs or on information on animals taken from hunters or harvesters (Pople & Grigg 1997).

Direct monitoring methods

Aerial Surveys

Aerial survey is feasible in relatively open habitats such as the rangelands, and for relatively conspicuous species such as kangaroos that are visible during daylight hours. Aerial survey provides the advantage of rapid coverage of transects, allowing large areas to be surveyed with sufficient precision in a short period of time. Surveys have been flown with either fixed-wing aircraft or helicopters, using either strip transect or line transect methods (see Edwards et al. this volume). Helicopters have advantages over fixed wing aircraft in being able to travel more slowly and lower, and provide better visibility, but are considerably more expensive to operate (Clancy et al 1997). Ultralight aircraft are a cheaper alternative, but are limited to small-scale surveys (Grigg et al. 1997). Both helicopters and ultralights have been successfully used as platforms for line transect sampling to estimate absolute density of kangaroos, although wallaroo density is still underestimated (Clancy et al 1997, Grigg et al. 1997). Counts of kangaroos in strip transects using fixed-wing aircraft need to be corrected to estimate absolute density and a variety of techniques have been used to
develop correction factors (see Pople in press for a recent review). Kangaroo
densities are still underestimated when line transect methods are used from fixed-wing
aircraft (Pople et al. 1998). Line transect methods (Buckland et al. 1993) are
attractive because they provide survey-specific correction for visibility bias, which
can vary between areas and seasonally. Furthermore, confidence intervals from line
transect sampling readily incorporate sampling error and visibility error, which is less
straightforward when applying independently derived correction factors, and has not
been standard practice (Pople in press). Double sampling (McCallum 1999) or line
transect double counting (Borchers et al. 1998) could address this problem for fixed-
wing surveys.

Broad scale aerial surveys of kangaroos began in the mid-1970s and were being
conducted in all states by the early 1980s (see Pople & Grigg 1997 for details).
Survey frequency has varied between states, but has generally been annual. Surveys
have systematically covered the sheep rangelands in each of the states, where most
harvesting occurs, although a system of monitor blocks was used in New South Wales
prior to 1983 and have been used in Queensland since 1991. Line transect sampling
from helicopters is used in the monitor blocks in Queensland. In Western Australia,
surveys were conducted triennially, but now one of three zones is surveyed in turn
each year. These broad-scale surveys are supplemented with less frequent aerial
surveys of areas with low harvest or of habitat unsuitable for fixed-wing surveys but
feasible for helicopter surveys.

Ground surveys

Ground survey techniques including surveys on foot and by vehicle are often assumed
to more accurate and precise than aerial survey techniques despite few tests of this
assumption (Southwell 1989). In particular, vehicle surveys along tracks are likely to
be biased (Caughley & Sinclair 1994). Recent work on kangaroo populations of
known size has confirmed that walked line transect counts are reasonably accurate
over a wide range of conditions (Southwell 1994). However, ground survey is too
costly and labour intensive to use as a regular monitoring tool on a broad-scale. Most
state kangaroo management programs use ground counts in small, key areas, as both a
check on aerial survey estimates and a way of estimating kangaroo density in habitat
unsuitable for aerial survey.

Foot surveys have been conducted over a large area of the eastern highlands providing
population estimates for eastern grey kangaroos, wallaroos and whiptail wallabies
(Southwell et al. 1997). Vehicle surveys have been used to determine the distribution
and ratio of the two grey kangaroo species (Caughley et al. 1984, Cairns & Gilroy

Indirect monitoring methods

Harvest statistics potentially offer continuous indirect monitoring of kangaroo
populations between surveys and in areas where surveying is either not feasible or
infrequent. These statistics include catch per unit effort, sex ratio, average carcass
weights, skin sizes and simply the numbers of animals harvested. These could indicate
population size or trend, or harvest rate (Kirkpatrick and Amos 1985, Pople 1996),
and this is the focus of current research. Models predicting population rate of increase from rainfall and other covariates may also supplement direct monitoring.

The non-commercial harvest of kangaroos for damage mitigation provides another index of population size. It serves to identify areas where landholders perceive that kangaroo densities are sufficiently high as to pose some threat to agricultural industries.

**KANGAROO SURVEYS AS PART OF A BROADER FRAMEWORK FOR MONITORING BIODIVERSITY**

The value of kangaroo monitoring to biodiversity monitoring goes beyond monitoring other species such as emus and feral goats. Comparisons of large herbivore population dynamics between areas allows an assessment of varying environmental impacts such as drought, effects of different management regimes such as harvesting and National Park management, and longer-term environmental change. Kangaroos are likely to respond to various types of environmental change, including a shift in productivity (Ealey 1967, Caughley 1987), changes to landscape structure (Hill 1981) changes in predation by dingos (Newsome et al. 1989, Pople et al. 2000) and even foxes (Banks 200?). There is a reasonable understanding of the population dynamics of kangaroos. This allows detection of unusual patterns in population fluctuations. Therefore kangaroos should be useful surrogates for detecting environmental change.

In their review of existing biodiversity monitoring programs Woinarski et al. (2000) identified four important features that were shared by existing programs for monitoring exploited native species that rendered them particularly suitable for incorporation in a framework for monitoring biological diversity in the rangelands. In order to demonstrate the potential use of current kangaroo monitoring programs in this broader framework, we will briefly examine them with respect to these four important features.

1. **Systematic placement of sampling units so that patterns of distribution and abundance can be related to spatial patterns of landscape change**

The systematic placement of transect lines for fixed-wing surveys across the sheep rangelands is ideal for investigating spatial patterns and changes in those patterns. The use of monitor blocks in Queensland makes detection of broad-scale landscape change potentially less sensitive because the overall survey area is not evenly sampled, but there are advantages (Clancy 1999). Precision of population estimates declines with area for a given sampling effort (Caughley 1979), so that regional estimates from statewide fixed-wing surveys often have poor precision with which to examine temporal patterns of abundance. In contrast, individual monitor blocks often have relatively higher precision.

Spatial modelling of data can be used to identify factors determining abundance (e.g. Short et al. 1993, Cairns et al. 1992), but can also be used to improve precision of population estimates and derive small-scale abundance estimates by integrating under the fitted spatial density surface (Hedley et al. 1999, Thomas et al. 2002).
Due to the legislative requirements for monitoring of commercially harvested kangaroo species at both state and commonwealth levels, there is strong political and bureaucratic support for these monitoring programs. All states now have long-term datasets for examining both kangaroo population dynamics and broad-scale distribution patterns. Placement of transect lines and monitor blocks is fixed, which is appropriate for monitoring trends. Trend monitoring is aided by rigid standardisation of potential confounding variables such as survey height, speed, time of day, time of year and observer experience.

In theory, comparisons can be made of the trends of kangaroo populations in different areas. Obviously comparisons would need to account for environmental variation between areas. Even within areas, trend monitoring will be complicated by process error in fluctuating environments (McCallum 2000). Long-term data are therefore important for trend monitoring. An annual survey frequency should be adequate to monitor the fluctuations in populations of large long-lived vertebrates, where maximum rates of increase will be relatively low. Spurious trends could be detected with less frequent sampling because the environmental variation (process error) would be harder to model. Droughts and floods have major influences on vertebrate populations in arid Australia (Stafford-Smith and Morton 1990). An adequate time series must obviously include these extremes, preferably more than once.

Since the primary aim of the kangaroo monitoring is to derive population estimates from which to set harvest quotas, the processes for analysis and presentation of data are well developed (Southwell 1989). The general public more readily understands estimates of absolute density than changes in an index. Absolute density also allows direct comparisons between areas, which is less likely to be true for an index. Systematic arrangement of sampling units allows presentation at a range of spatial scales (regional, state and continental), but again, precision will be relatively poor at fine scales.

Other large conspicuous species such as emus and bustards, and feral herbivores such as goats, pigs, donkeys and horses are also counted during aerial surveys, allowing patterns of distribution and trends in their abundance to be determined. These are not counted routinely in all states and some historical data are limited to presence-absence. A broader range of species is not counted partly for fear of comprising the counts of kangaroos. The use of tape recorders rather than pencil and paper could overcome this problem. Correction factors are poorly developed for some species recorded on fixed-wing surveys and the repeatability of the estimates is unknown. Kangaroo survey parameters such as height and strip width are also not ideal for some species such as pigs.
CASE STUDIES

The following set of empirical case studies from Queensland are intended to demonstrate the potential application of this monitoring as part of a broader biodiversity monitoring program.

Case Study I: Range expansion of eastern grey kangaroos

The western boundary of the distribution of *Macropus giganteus* has been recorded as moving inland at a rate of ~4-5 km year\(^{-1}\) (Caughley et al. 1984). Cairns and Coombs (1992) using harvest data and Cairns and Gilroy (2001) using vehicle surveys, have tracked this expansion in New South Wales in recent years. It has now extended to the western extremities of the main aerial survey areas of Queensland and New South Wales. Future surveys outside this area may detect further range expansion. What is of interest here is the change in populations behind the dispersing front in Queensland. The simplest model is one of logistic growth, but there is likely to be some degree of overshoot. Caughley (1976) described the latter for an ungulate eruption with a concomitant decline and fluctuation in pasture biomass. From a biodiversity monitoring perspective, it is the knock-on effects that are important. What would manifest under domestic stock grazing and a fluctuating environment is difficult to predict.

Figure 1 shows the change in the ratio of red kangaroos to grey kangaroos within the core survey area over 1980-2001 (Fig. 2). The ratios have been determined from surveys by fixed-wing aircraft across the entire area (1980-1992, 2001) and helicopters in monitor blocks (1991-2001) (see Pople and Grigg 1997, Lundie-Jenkins et al. 1999 for details). The ratio has generally declined over the period, resulting from a decline in grey kangaroos from mid 1980s to the mid 1990s. Red kangaroos were generally stable over this period.

This can be contrasted with changes in the same ratio on the western edge (using one degree blocks) of the core area using fixed-wing data, and the ratio based on the three western helicopter blocks centred on Julia Creek, Windorah and Hungerford (Fig. 2). The fixed-wing data suggest an increase in grey kangaroos relative to reds in the west. However, the helicopter data parallels that for the entire core area.

Aerial surveys were also conducted west of the core area in 1980-2, 1984 and 2001. The ratios of greys to reds based on these data suggest an increase in greys relative to reds (Fig. 3), matching that found just inside the core area. The harvest in this area shows a similar pattern for the same years, but also shows considerable fluctuation in the relationship in the intervening years.

While the range boundary for eastern grey kangaroos has not been stable, the relative population size behind this boundary has also changed. On average, eastern greys are becoming more common at the western edge of their range. This only becomes clear when viewed over a long period of roughly 20 years, because populations fluctuate in response to a variable environment (Fig. 4) and reds and greys do not fluctuate in concert (at least not on such a broad scale as this). Even then, more formal analyses are needed to account for both observation and process error in these data. Whether
grey kangaroos have reached a dynamic equilibrium (i.e. no further long-term trend) is still unclear although some predictions could be modelled using the existing data.

Case Study II: Irruptive wallaroo populations?

Dingo control and provision of artificial water appear to have allowed wallaroos to occur away from their more typical habitat of rocky hills and occupy open plains and downs in the Pilbara (Ealey 1967), in western NSW and central-western Queensland (Pople 1989). In the Pilbara, wallaroos increased to such high densities that considerable effort was spent on their control (Ealey and Richardson 1960).

In central-western Queensland, wallaroo numbers are highest within the Blackall survey block. The densities shown in Figure 5 are likely to underestimated by a factor of 2-3 (Clancy et al. 1997), so the densities are certainly high. The wallaroo population has fluctuated in a roughly similar fashion to red and eastern grey kangaroo in the district up until 1998. However, in recent years wallaroo numbers have increased dramatically and at far higher rates than reds or greys.

This recent increase follows good rainfall in the late 1990s in western Queensland (Fig. 4), but this does not explain the disparity between the species. In the Pilbara, the increase in wallaroos and decline in red kangaroos and sheep was attributed to a change from a pasture dominated by chenopod shrubs to one dominated by less palatable spinifex as a result of overgrazing by sheep. Wallaroos, given adequate water, can persist on such poor quality food. Newsome (1994) suggested that dingo control was a further factor. This does not explain why wallaroos would be advantaged over red kangaroos, unless they are more vulnerable.

A similar argument could be made for the Blackall district. Perennial grasses generally dominate pastures there, but these become less palatable through the winter and spring dry. It is possible these have become more dominant, restricting increases in more palatable winter feed for red and grey kangaroos. Another factor is the relatively heavy harvesting of red and grey kangaroos in the district (Pople 1996). Wallaroos are also harvested, but the offtake is >90% male and the harvest rate is lower (Pople 1996). An increase in and improved coordination of baiting programs for dingoes in the Blackall district may also have influenced the dynamics of wallaroo populations to a greater extent than their congeners.

Case Study III: Kangaroo population dynamics on Currawinya National Park

Removal of domestic stock from National Parks may lead to increases in kangaroo numbers through competitor release. Caughley (1987) offered this as an explanation for the higher abundance on Kinchega National Park compared with the adjoining sheep grazing property. Edwards (1989) reported kangaroo densities for Sturt national Park and surrounding properties, suggesting that this was not always the case. He also pointed out the confounding factors of harvesting on sheep properties and large fences that possibly restrict kangaroo dispersal on parks such as Kinchega.

Currawinya National Park had stock removed in 1990. The Park forms part of a helicopter monitor block just north of Hungerford in southwestern Queensland (Fig. 2). Helicopter surveys began in 1991. Between 1980 and 1992, a single transect line
was flown through the Park during regular surveys by fixed-wing aircraft. Therefore, there are population estimates for kangaroos prior to and following the removal of sheep, and population estimates on adjoining properties (Off-Park) over the same period. Trends in kangaroo numbers are shown in Figs 6 and 7. Eastern grey kangaroos were generally at higher densities Off-Park, but there has been a relative increase following removal of sheep. Red kangaroos are less clear-cut. Sampling intensity was halved in 2002 and so should be considered as an outlier. The data are also confounded by harvesting Off-Park that increased in intensity in the early 1990s.

Case Study IV: Trends in emu numbers

A comparison of bird atlases compiled in 1977-1981 and 1998-2001, suggests that emus have declined across most of the semi-arid and arid regions in eastern Australia and certainly in the area monitored by aerial surveys (Barrett et al. 2002). The decline was a ≥ 20% drop in the reporting rate between the two atlases. The authors qualify their identification of 28 decliner species and 32 increasers by listing a number of factors that will influence changes in reporting rate and changes in distribution. These include changes in observer behaviour, survey methodology, agricultural land use and climatic conditions. Reporting rates were adjusted for differences in survey methodology and effort. Barrett et al. (2002) also describe the conditions prior to the second atlas as being either wetter (recent) or similar (longer term) to conditions prior to the first atlas, particularly in the eastern semi-arid regions.

Figure 8 shows changes in the abundance of emus using aerial survey data for the core area in Queensland. Fixed-wing counts have been corrected for visibility bias using a factor developed by Caughley and Grice (1982) using double counting in Western Australia. Helicopter estimates were made using line transect methods, so effectively apply survey-specific correction for visibility bias. The fixed-wing estimates describe an average population density much lower than the helicopter estimates, suggesting the correction factor is too conservative, although a direct comparison between the two methods needs to be made as has been done with kangaroos (Pople et al. 1998). Nevertheless, no decline is apparent for emus in this area. Their fluctuations are also consistent with rainfall over the period (Fig. 4). This is supported by similar data in the South Australian pastoral zone where an increase has occurred over 1978-2002, but with considerable fluctuations in between. Clearly, such process variation needs to be considered when attempting to detect trends. The contrast between the bird atlas trends and those described by regular aerial survey, and between the two aerial survey methods, suggest survey methodology needs careful examination to avoid spurious trends.

CONCLUSIONS

It is apparent from the preceding discussion and case studies that, even in their current form, the broadscale programs for monitoring kangaroos in the rangelands are valuable, not simply for detecting changes in the distribution and abundance of kangaroo species, but also for indicating patterns of landscape change at a range of scales. The considerable historical databases of kangaroo densities allow an examination of long-term trends and provide a basis for exploring issues of surrogacy with respect to broader biodiversity monitoring. Given our current state of knowledge on the factors influencing the dynamics of kangaroo populations, these surveys can be
interpreted with some confidence in relation to patterns of landscape change at both national and regional scales. Whilst interpretation at the national scale may be complicated to some extent by jurisdictional differences in such things as methodologies and frequency of surveys, the combined spatial and temporal coverage appears sufficient to examine the impacts of landscape disturbances associated with climate change, tree clearing and the proliferation of artificial waterpoints. At the regional scale, kangaroo monitoring techniques are sufficiently robust to enable the results to be interpreted in terms of factors influencing regional landscapes such as grazing pressure, harvesting rates and protected area management. More detailed examination of the relationships between kangaroo populations and elements of their environment will improve the ability of these monitoring techniques to detect changes in patterns in other components of the biodiversity.

Woinarski et al. (2000) noted that aggregation and meta-analysis would increase the quality of interpretation of data such as those derived from broad-scale kangaroo monitoring. This would in turn strengthen the application of these surveys in assessing the condition and trends in biological diversity in the rangelands. Current research work coordinated by the University of Queensland and funded by the ARC Linkage program is attempting to complete these types of analysis on the long-term kangaroo monitoring datasets compiled by the state wildlife agencies. Although the primary focus of the project is to provide tools to enhance the capacity of wildlife agencies to understand and hence manage kangaroo populations, the outcomes from the project will almost certainly improve the usefulness of existing kangaroo monitoring programs for monitoring and interpreting environmental change at a range of temporal and spatial scales. A secondary and potentially more useful outcome of this project may be a more standardised approach to the collection, collation, analysis and reporting of the data from kangaroo surveys across the various agencies. Woinarski et al. (2000) considered that a facility for taking existing information and providing integrated analysis across jurisdictions was the absolute minimum that could legitimately justify description as a national framework.

We consider that considerable progress has been made towards integrating the information derived from several state kangaroo monitoring programs, albeit for the rather narrow goal of sustainably managing kangaroos. It would not require a significantly more sophisticated approach to this process to enable the surveys to be integrated into a national framework for monitoring biodiversity in the rangelands. Current research towards the development of improved temporal and spatial models of kangaroo populations will clarify questions of surrogacy. In doing so, it should significantly enhance the usefulness of broadscale kangaroo monitoring as one element of a national biodiversity monitoring system.

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References


Ealey and Richardson 1960


**Figure legends**

Fig. 1. Map of Queensland depicting core area of the state (shaded area) where aerial surveys are regularly conducted.

Fig. 2. Changes in the ratio of eastern grey kangaroo density to red kangaroo density in the core area (Fig. 1) and western part of the core area of Queensland between 1978 and 2000 as determined from aerial surveys.

Fig. 3. Comparative changes in the ratio of eastern grey kangaroos to red kangaroos in the western region of Queensland between 1978 and 2000 as indicated by aerial surveys and harvest offtake.

Fig. 4. Comparative changes in the average densities of eastern grey kangaroos, red kangaroos and common wallaroo in the Blackall survey block between 1990 and 2000 as determined from aerial surveys.

Fig. 5. Average densities of eastern grey kangaroos and red kangaroos on Currawinya National Park and neighbouring pastoral properties between 1990 and 2000 as determined from aerial surveys.

Fig. 6. Trends in the average density of emus in central western Queensland as determined from aerial surveys.

Fig. 7. Standardised rainfall for the core survey area in Queensland (Fig. 1) over 1979-2000.
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