THERE are many techniques available to measure the abundance of animal populations (e.g., Caughley 1977; Caughley and Grigg 1981; Southwell 1989; McCallum 2000; Buckland et al. 2001). A key point emphasised by each of these authors is that when choosing the most appropriate method(s) for measuring the abundance of animal populations, the manager or researcher must consider the ecological question(s) being asked. This in turn will determine what technique(s) will be most appropriate, what data are likely to be collected for analysis, and how these data will address the ecological question being asked. For the larger macropods, particularly *Macropus* spp., many of the techniques used to measure the abundance, and associated issues, have been reviewed (see Southwell 1989). Despite this, the applicability of these techniques has rarely been compared, particularly with respect to the observed variability in temporal counts.

The ecologically sensitive habitat used in this study is Epping Forest National Park. It is considered ecologically sensitive because it is the only remaining habitat occupied by the critically endangered northern hairy-nosed wombat, *Lasiorhinus krefftii*. Epping Forest NP is a small parcel of protected semi-arid savannah in central Queensland. Wombats are currently restricted to about 300 ha of the 3300 ha of this reserve. Best described as a combination of open-woodland and grassland, Epping Forest NP has distinct summer wet and winter dry seasons (Fig. 1a). Rainfall occurs primarily from November to March with a mean annual rainfall of 671 mm (s.d. ± 228). This region is also characterised by a high drought frequency, and the study (1993 - 1996) was conducted in four years of below average rainfall (annual mean 334 ± 123 mm).

One of the key threatening processes identified in the Recovery Plan for *L. krefftii* (Horsup 1999) is the potential for competition with the eastern grey kangaroo, *Macropus giganteus*. Ongoing estimation of the size of the *M. giganteus* population therefore forms part of risk management strategy for the conservation of *L. krefftii*. Because of the ecological sensitivity of Epping Forest NP, methods of estimating abundance of macropods need to have minimal impact on the overall survival of wombats. They also need to be reliable and repeatable. To establish the best method for surveying *M. giganteus* in the presence of *L. krefftii*, population densities were estimated in two ways: by modified line-transect counts (Burnham et al. 1980; Coulson and Raines 1985; Southwell 1989; Buckland et al. 2001), and by the measurement of rates of accumulation of faecal pellets (Coulson and Raines 1985; Johnson and Jarman 1987; Johnson et al. 1987; Osawa 1989; Southwell 1989).

Details of the modified line-transect counts are described by Woolnough and Johnson (2000). A modification of the line-transects was necessary because of the low numbers of recorded observations of kangaroos, thereby violating the minimum sample sizes needed for line-transect analysis using the Distance method (see Buckland et al. 2001). In brief, counts were conducted from a vehicle by two observers during the hour prior to sunset along a 6.6 km transect passing through the entire range of *L. krefftii*. By using the existing network of tracks for the survey-transect, an unavoidable, but acceptable, level of bias was introduced to the counts (e.g., Burnham et al. 1980; Coulson and Raines 1985; Southwell 1989; Buckland et al. 2001). Direct counts were conducted for a minimum of four days per sampling period. An effective strip width of 180 m was set to encompass 96% of all macropod sightings (*n* = 185), creating an effective survey area of 118.8 ha or about 40% of all *L. krefftii* habitat. Bimonthly surveys were conducted from May 1993 to June 1996.
with the exception of the sampling periods January/February 1994 and March/April 1996.

Faecal pellet accumulation was measured on 56 circle-plots of three metre radius placed at 50 m intervals along seven 400 m transects, distributed evenly throughout the habitat of L. krefftii. All pellets accumulated between bimonthly sampling periods were counted and removed from each plot. A published measure of defecation rates of M. giganteus (89.5 defecations/24h, 5.5 pellets per defecation, Johnson et al. 1987) was used to convert pellet accumulation rates to estimates of population density. Bimonthly surveys were conducted at the same times as the direct counts, but beginning in September 1993. Data were not collected using this method in November/December 1993 and March/April 1996.

The direct count method estimates of M. giganteus densities during the study ranged from 0.4 (± 0.6) to 16.9 (± 12.3) animals km⁻² (Fig. 1b). A similar range of 2.3 to 13.6 macropods km⁻² day⁻¹ was observed using the indirect faecal pellet counts (Fig. 1c). The observed seasonal differences in the macropod population estimates are discussed by Woolnough and Johnson (2000).

To compare the two population estimate techniques Spearman’s Rank coefficient was used. No significant differences were found between the two population estimates throughout the study period (rₛ = 0.556, d.f. = 12, P > 0.05, Fig. 1b, 1c). This suggests the two methods gave similar estimates of the density of M. giganteus at Epping Forest NP.

For an ecologically sensitive habitat like Epping Forest NP, the indirect faecal accumulation method has many advantages over the direct count. Some of these advantages are general to faecal counts (e.g., Caughley 1977; Coulson and Raines 1985; Southwell 1989) and others specific to more ecologically sensitive habitats. These advantages include:

1. Reducing potential impact on L. krefftii behaviour, since faecal accumulation can be measured during day-light when the nocturnal wombats are not active (Woolnough et al. 1998). Evening emergence by wombats can occur in the same hour before sunset when direct counts of macropods are generally conducted, particularly in the winter months. Minimising the potential impact of human interference is particularly important from an endangered species management perspective.

2. Not having to see the kangaroos, particularly when they are at lower density in the drier months (see Woolnough and Johnson 2000).

3. This method is easily repeatable and is less dependent on weather. Note that faecal pellet degradation was found to be slow at Epping Forest NP. Some faecal pellets persisted up to 18 months (Woolnough 1998). Naturally, some limited losses of faeces would potentially occur through attacks on fresh faeces by dung beetles or trampling of fresh faeces by kangaroos (Southwell 1989).

4. Surveys can be carried out in a defined time period (e.g., an afternoon or a day).

5. Minimal experience required to count faecal pellets.

Like all techniques aimed at estimating abundance, there are some limitations of both techniques. For the indirect technique, the main problem is that the estimation procedure tends to overestimate population density at low densities, since Johnson et al.’s (1987) data on defecation rates were collected from a population in more mesic habitat, which is therefore likely to facilitate greater rates of pellet production than at Epping Forest NP. A separate issue for the indirect technique is that counting faecal pellets is tedious compared to direct observations. Ideally, this should not influence the way data are collected but in reality it is an issue that needs to be considered when implementing routine monitoring strategies for management purposes. For the direct counts, observations need to be repeated over several days (minimum of four) to increase accuracy and minimise the effects of environmental variability (e.g., weather conditions) and animal behaviour (Southwell 1989). This inevitably means that this type of survey needs to be incorporated with other work to justify time spent in the field.

In summary, the indirect faecal accumulation method may be more appropriate for the ecologically sensitive habitat of L. krefftii. The direct count method provides an equally reliable population estimate, and in different circumstances (e.g., larger survey area) may be more appropriate. By using the two methods in tandem, one method essentially acted as a cross-check for the other. Both survey methods confirmed that the density of M. giganteus during the study period was low. Such densities are not likely to represent a competitive threat to L. krefftii (Woolnough and Johnson 2000). However, the numbers of kangaroos will fluctuate through time, and a reliable and relatively cheap method is required to monitor their abundance. In this respect, the faecal count survey method would be ideal.
Fig. 1. Bimonthly rainfall and abundance of *M. giganteus* during the study period (May/June 1993 to May/June 1996). Rainfall (a) was recorded at the nearest weather recording station (Clermont Post Office). *M. giganteus* abundance was measured by direct observations, ± standard deviation, using line-transect methodology (b) and indirect observations using faecal pellet accumulations (c). An asterisk indicates that no data were available for the sampling period.
ACKNOWLEDGEMENTS
This project was generously funded by the Commonwealth Department of Environment and Heritage’s Endangered Species Program, Queensland Parks and Wildlife Service and an Australian Postgraduate Award. Valued contributions to this study were made by Chris Johnson, Bill Foley and Alan Horsup. I thank Stephen Jackson and Laurie Twigg for improving this manuscript and the many volunteers that assisted with data collection.

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