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Using faecal pellet counts along transects to estimate quokka (*Setonix brachyurus*) population density

Matt W. Hayward[A,B,C,D], *Paul J. de Tores*[B], *Michael J. Dillon*[C], *Barry J. Fox*[A]
and Peter B. Banks[A]

[A]School of Biological, Earth and Environmental Science,
University of New South Wales, Sydney, NSW 2052, Australia.
[B]Department of Conservation and Land Management, Wildlife Research Centre,
PO Box 51, Wanneroo, WA 6946, Australia.
[C]Department of Conservation and Land Management, Dwellingup Research Centre,
Banksiadale Road, Dwellingup, WA 6213, Australia.
[D]Corresponding author. Current address: Terrestrial Ecology Research Unit, Department of Zoology,
Nelson Mandela Metropolitan University, Port Elizabeth 6031, Eastern Cape, South Africa.
Email: hayers111@aol.com

Abstract. A study was conducted to determine the validity of using transect counts of faecal pellet groups to estimate population densities of a threatened, macropodid marsupial – the quokka (*Setonix brachyurus* (Quoy & Gaimard, 1830)). Mark–recapture estimates of population density were regressed against counts of faecal pellet groups at six sites with and three sites without fox control within the northern jarrah forest of Western Australia. Significant linear relationships were found between population density and pellet counts for all sites ($r^2 = 0.56$, $P < 0.02$) and when all unbaited sites were excluded ($r^2 = 0.98$, $P < 0.01$). We suggest that this method could be used for broad-scale monitoring of this threatened species.

Introduction

Faecal pellet counts have been extensively used to study the relative or actual abundance of a wide range of mammalian species (Krebs *et al*. 1987, 2001; Fuller 1991; Lehmkuhl *et al*. 1994; Hone and Martin 1998; Langbein *et al*. 1999; O'Connor 1999; Plumptre 2000; Weckerly and Ricca 2000). Macropodid marsupials that have been studied in this way include the swamp wallaby (*Wallabia bicolor*) (Floyd 1980), the red-legged pademelon (*Thylogale stigmatica*) (Vernes 1999), the parma wallaby (*Macropus parma*) (Maynes 1974; Read and Fox 1991), the red-necked wallaby (*M. rufogriseus*) (Johnson and Jarman 1987), the eastern grey kangaroo (*M. giganteus*) (Coulson 1985; Perry and Braysher 1986; Johnson and Jarman 1987), and the western grey kangaroo (*M. fuliginosus*) (Arnold and Maller 1987).

Advantages of faecal pellet counts over standard mark–recapture methods as estimators of population size are their reduced labour intensity, their cost effectiveness, and that they can be used for rapid assessment over larger areas. Additionally, faecal pellet counts minimise the disturbance and threat of injury to captured animals often associated with trapping.

This study reports on the use of faecal pellet counts to estimate population densities of the quokka (*Setonix brachyurus* (Quoy & Gaimard, 1830)). The quokka is a vulnerable, medium-sized, macropodid marsupial that is endemic to the south-western corner of mainland Australia and two offshore islands. The quokka is found in a variety of habitats, ranging from heaths and shrublands on the mainland coast and both offshore islands (Storr *et al*. 1959; Storr 1965) to *Agonis linearifolia*-dominated swamps in the jarrah (*Eucalyptus marginata*) forest (Storr 1964; Hayward 2002), and swamp shrublands, swordgrass-dominated understorey and regrowth areas of the karri (*E. diversicolor*) forest (Christensen *et al*. 1985). The understorey structure of all these habitats is very similar, however, consisting of dense, low vegetation (Hayward 2002) and the quokka's restriction to them provided an opportunity to investigate the use of faecal pellet counts as a method of both determining the presence of the species and estimating population density. More importantly, this technique provided an opportunity to trial a cost-effective method of estimating abundance, as quokkas are extremely trap wary and estimates of population sizes derived through trapping are time consuming, expensive and difficult (Sinclair 1999; Hayward *et al*. 2003).

Methods

Within the northern half of the Jarrah Forest biogeographical zone of south-western Australia (Thackway and Cresswell 1995), 10 populations of quokkas were believed to exist in the early 1990s (Hayward

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et al. 2003). Each of these sites occurred in the swampy, upper reaches of creek systems vegetated by *Agonis linearifolia*-dominated shrublands. Eight of these were trapped by MWH for 2.5 years from spring (November) 1998 and population sizes were estimated using the Jolly–Seber mark–recapture technique in Program MARK (White and Burnham 1999), while two sites at the extremities of the study region were excluded owing to logistical constraints (Hayward *et al.* 2003). One of these excluded sites (Gervasse), however, was trapped annually by Department of Conservation and Land Management staff, allowing one of us to estimate its population size using similar mark–recapture techniques (PdeT, unpublished data). Trapping to determine estimates of the population sizes of the quokka in mainland Western Australia was considered necessary to ascertain its status (vulnerable according to IUCN criteria: Hilton-Taylor 2000) as well as to attach radio-telemetry equipment for home-range and habitat-use studies (Hayward *et al.* 2004, 2005) in order to gather information to allow effective conservation management of the species.

Trapping was conducted seasonally (autumn, winter, spring, summer) at the Chandler, Hadfield, Kesners, Rosella Road and Victor Road sites (Table 1). Trapping was discontinued early at three sites (Hoffman, Holyoake and Wild Pig) because no captures or evidence of quokka presence were found (Hayward *et al.* 2003). Traps consisted of a pair of large and small cage traps, baited with apples and 'universal bait' respectively, placed inside and between 50 and 100 m outside the swamp along its length (Hayward *et al.* 2003). Trapping was conducted for up to 51 consecutive days when trying to confirm the presence of a quokka population at a site, but from autumn 1999 until spring 2000 trapping was conducted for eight consecutive days each season at each of the known quokka population sites, except Gervasse (Table 1).

Population density was then calculated for each site by dividing the number of individuals estimated using mark–recapture techniques by the area of swamp vegetation at the site (Table 1; population estimates from Hayward *et al.* 2003). The area of swamp vegetation was calculated using aerial photograph interpretation and MapInfo computer software (1985–99 MapInfo Corporation Inc., Troy, New York, USA) (Hayward 2002; Hayward *et al.* 2005).

Prior to the cessation of trapping and the subsequent population estimates, faecal pellet count transects were undertaken at all nine sites. All pellet counts were conducted in mid to late winter 2000 when cold temperatures minimised pellet decay. Transects were similar in length (30–50 m) and extended from the swamp edge to the centre. Quasi-representative sampling was carried out with a minimum of 10 transects walked at each site and additional transects were walked at larger sites. Counts of clusters of faecal pellets were made by searching only on distinctive quokka runways within transects (see discussion for confirmation of this technique). The dense vegetation within the swamps meant that only pellets in the immediate vicinity of the observer were counted. Only fresh faecal pellet groups were counted and were identified by their soft exterior and green colour when broken apart. Older pellets had a hard, black exterior and the dried vegetable matter inside was grey. The same observer (MWH) undertook all transects.

At each site, the faecal pellet group count was divided by the number of transects conducted to obtain a pellet count value, which was used as the independent variable in regressions against population density using Statview Version 5.0 (SAS Institute Inc. 1998). The Cook–Weisberg test for heteroskedasticity was used in the Intercooled Stata 7.0 statistical package (StataCorp 2001, Boston, MA, USA). The intercept of the regression was not forced through the origin because populations may exist at low density but not be detected by scat counts (resulting in a positive intercept of the y-axis) and/or low-density populations may not be detected by trapping (resulting in a negative intercept of the y-axis).

Results

Faecal pellet counts and site-specific variables are shown in Table 1. The Gervasse site had the highest population estimate and the Victor Road site had the highest pellet count. The three sites where quokkas are now thought to be extinct (Hoffman, Holyoake and Wild Pig) (Hayward *et al.* 2003) had pellet counts of zero. The linear regressions derived from these data show strong and significant relationships between population density and faecal pellet counts (Table 2). The most powerful relationship occurs when unbaited sites are excluded from the analysis ($r^2 = 0.98$, $n = 6$, $P < 0.01$). Fig. 1*a* shows the relationship between the faecal pellet counts for all sites and their population density ($r^2 = 0.56$, $n = 9$, $P = 0.02$) (Table 2).

The only unbaited but extant population (Victor Road) is somewhat anomalous in that it has a much greater pellet count value than population density (Fig. 1*a*). This is a result of this datapoint violating the least-squares assumption (Cook–Weisberg heteroskedasticity test, $P < 0.01$) according to diagnostic plots of leverage versus the square of the normalised residuals. Despite not being forced through the origin, the slope crosses the y-axis within the 95 percentile confidence interval (CI at $y = 0$ is –1.8–2.0 for all sites (Fig. 1*a*) and –1–0.6 for all baited sites (Fig. 1*b*)).

Table 1. Population estimates and densities (from Hayward *et al.* 2003) and faecal pellet counts of quokkas in the northern jarrah forest
At least 10 transects were walked at each site. Larger sites had additional transects

Site	Population estimate	Swamp area (ha)	Population density (no. ha^{-1})	Pellet count	No. of transects	Pellet count value	Fox baiting
Chandler	10	11.4	0.88	1	11	0.09	Yes
Gervasse	49[A]	10.4	4.70	5	10	0.50	Yes
Hadfield	29	6.8	4.26	4	10	0.40	Yes
Hoffman	0	8.0	0.00	0	10	0.00	No
Holyoake	0	2.6	0.00	0	10	0.00	No
Kesners	36	12.4	2.90	4	12	0.33	Yes
Rosella Road	1	15.3	0.06	1	15	0.07	Yes
Victor Road	9	8.2	1.19	6	10	0.60	No
Wild Pig	0	9.9	0.00	0	10	0.00	Yes

[A] PJdeT, unpublished data.

Table 2. Regression equations and statistics for the faecal pellet group counts compared with population densities
PCV = pellet count value

Regression	Equation	r^2	Count	*P*
All sites	Density = 0.2 + 6.0PCV	0.56	9	0.02
Excluding Victor Road	Density = –0.1 + 9.9PCV	0.98	8	<0.001
Excluding unbaited swamps	Density = –0.2 + 10.1PCV	0.98	6	<0.001

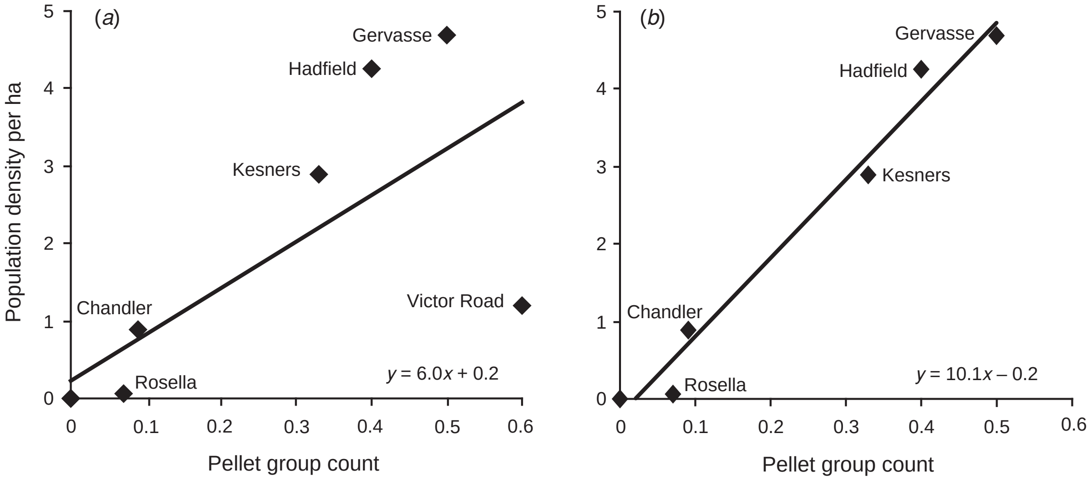

Fig. 1. Regression plot showing population density per hectare against faecal pellet count value for (*a*) all sites and (*b*) unbaited sites. The regression equations are shown in Table 2.

Discussion

Although faecal pellet counts have been thought of as difficult to apply across a range of habitats (Langbein *et al.* 1999), this technique provides a basis for broad-scale surveys of quokkas in any densely vegetated areas throughout their range and has also been used in the karri forest and south coast (MWH, unpublished data). In fact, the only area where this technique may not work is on Rottnest Island, where over-browsing by quokkas has opened up the vegetation (Storr 1963; Pen and Green 1983). This technique is far less onerous in time, effort and consequently money than the current preferred practice of trapping for quokkas, although it could be used in conjunction with trapping and DNA techniques. It also causes far less stress to the animals and therefore may be considered more ethical (Monamy and Gott 2001).

We believe this model is adequate in estimating quokka population density from faecal pellet group counts and provides a reliable technique for managers when undertaking broad-scale assessment of population density. Although often robust to violations of least-squares assumptions (Cochran 1947), the heteroskedasticity exhibited in the model with all sites included suggests that some caution should be applied when using the model and interpreting results. These violations were probably caused by differences in behaviour between baited and unbaited populations, because quokkas threatened with high levels of predation rarely depart from the *Agonis* swamp (and therefore deposit more faeces inside the swamp) than do those with reduced threat (Hayward 2002; Hayward *et al.* 2004, 2005).

Potential sources of error in using faecal pellet counts to estimate abundance include incorrect identification of faecal pellets (i.e. pellets attributed to the wrong species), lack of detection of faecal pellets and variation in faecal pellet deposition and decay (Read and Fox 1991; Hone and Martin 1998; Bulinski and McArthur 2000; Buckland *et al.* 2001). This study was undertaken in the northern jarrah forest where three other macropodid marsupials occur in partial sympatry with the quokka: the western grey kangaroo (*Macropus fuliginosus*), the western brush wallaby (*M. irma*) and the tammar wallaby (*M. eugenii*). It is possible to differentiate macropodid scats on the basis of their size and shape (Triggs 1996), but we were not comfortable in our ability to differentiate them on these features alone. We believe faecal pellets of adult male quokkas are indistinguishable from those of sympatric wallabies and subadult kangaroos. However, only the quokka makes characteristic ‘runways’ (~15 cm × 20 cm) through the densely vegetated swamps (White 1952; Storr 1964; Christensen *et al.* 1985). Consequently, faecal pellets found within these runways cannot be confused with those of any other species of macropodid because these other species are much larger than

15–20 cm high and do not inhabit the densest parts of the swamp (MWH, personal observations). The scats of the tammar wallaby (*Macropus eugenii*) and quokka could also be confused because of their overlapping geographical range (Alacs *et al.*, unpublished data). However, the closest populations of tammar wallaby are restricted to the Perup Forest Block, several hundred kilometres to the south, to Garden Island south of Perth, and to a small translocated colony yet to become established in mining-rehabilitation areas near Dwellingup that has shown no evidence of dispersal (P. Mawson, personal communication). Other long-term monitoring in the northern jarrah forest (PJdeT, unpublished data) indicates that the tammar wallaby is absent from sites investigated in this study. The woylie or brush-tailed bettong (*Bettongia penicillata*) has also recently been reintroduced into the region (de Tores 1999). Its preference for open habitats, the effect of its diet on scat characteristics (Christensen 1980; Start *et al.* 1995) and the absence of trapping records during this study (Hayward 2002) indicate that its scats are unlikely to be confused with those of the quokka. We therefore believe that faecal pellets consistent with the known physical appearance of quokka faecal pellets and observed within characteristic quokka runways can be confidently identified as quokka scats.

The probability of overlooking scats is influenced by the vegetation of the site (Bulinski and McArthur 2000), but the uniformity of habitat structure surveyed in this study (Hayward 2002) meant that these errors were likely to affect all sites similarly. The potential bias associated with pellet decay and decomposition rates (Perry and Braysher 1986; Lehmkuhl *et al.* 1994; Hone and Martin 1998; Vernes 1999; Buckland *et al.* 2001) was assumed to apply consistently across all sites owing to the short time frame (two months) in which this study was conducted. The uniformly dense habitat structure meant that variation in pellet decay through localised differences in insect activity, which could potentially be caused by shady patches, or variations in moisture and humidity were minimised also. The cold temperatures during the survey period further minimised this. Nonetheless, pellet decay and decomposition should be incorporated into pellet count studies in the future.

We recommend that managers carefully consider the purpose of any survey and monitoring program and assess the relative merits of trapping and faecal pellet counts before committing to any particular technique or combination of techniques. The accuracy of the faecal pellet count model may be improved by incorporating the principles of Distance sampling (Buckland *et al.* 2001). This will necessitate estimates of faecal pellet deposition and decay rates.

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