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# "I just want to count them! Considerations when choosing a deer population monitoring method"

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Effective management of any population involves decisions based on the levels of abundance at particular points in time. Hence the choice of an appropriate method to estimate abundance is critical. Deer are not native to Australia and are a declared pest in some states where their numbers must be controlled in environmentally sensitive areas. The aim of this research was to help Australian land managers choose between widely used methods to count deer. We compared population estimates or indices from: distance sampling, aerial surveys, spotlight counts, and faecal pellet counts. For each we estimated the labour input, cost, and precision. The coefficient of variation varied with method and time of year from 8.7 to 36.6%. Total labour input per sampling event varied from 11 to 136 h. Total costs of vehicles and equipment per sampling event varied from AU$913 to $2966. Overall, the spotlight method performed the best at our study site when comparing labour input, total cost and precision. However, choice of the most precise, cost effective method will be site specific and rely on information collected from a pilot study. We provide recommendations to help land managers choose between possible methods in various circumstances.

Of the 18 species of deer introduced into Australia only six survive in free roaming wild populations (Bentley 1998, Jesser 2005). Most deer populations have been restricted in distribution for almost a century but many are now increasing in number and distribution (Moriarty 2004, Jesser 2005). Few introduced species (or group of species) in Australia divide community attitudes as much as deer. In Tasmania, Victoria and NSW they are classified as Game and protected through legislation whilst in other states they are either declared pests or have no legal status. In Queensland, wild deer were protected in legislation from 1863 until 1994. They then had no legal status until 2009 when they were declared pests. The importance of deer to many people as either a valued resource or a declared pest implies a management imperative, yet there is a dearth of information in the peer reviewed literature relating to these species in Australia (McLeod 2009).

Effective management of any species usually involves making decisions from knowledge of their population abundance or trends in abundance (Sinclair et al. 2006) and managers often perform counts of the population to estimate these parameters. Obtaining estimates of abundance that are useful to management requires the best choice of method (Sinclair et al. 2006).

Often researchers will start with a decision to either estimate absolute or relative abundance (Sinclair et al. 2006). For deer species worldwide popular methods for estimating absolute abundance include line transect distance sampling (Focardi et al. 2002, Jathanna et al. 2003, Acevedo et al. 2008, Ariefiandy et al. 2013), aerial surveys (Fafarman and DeYoung 1986, Potvin and Breton 2005, Daniels 2006, Kantar and Cumberland 2013), thermal imaging (Belant and Seamans 2000, Focardi et al. 2001, 2013, Smart et al. 2004, Daniels 2006, Collier et al. 2013), camera surveys (Roberts et al. 2006, Curtis et al. 2009, McCoy et al. 2011, Dougherty and Bowman 2012), population manipulation indices (Conner et al. 1986, Sinclair et al. 2006), and faecal pellet counts ( Marques et al. 2001, Campbell et al. 2004, Smart et al. 2004, Mandujano et al. 2013, Alves et al. 2013). Popular methods of estimating relative abundance for deer include spotlight counts (Belant and Seamans 2000, Focardi et al. 2001, Collier et al. 2007, Acevedo et al. 2008, Garel et al. 2010) and faecal pellet counts (Forsyth et al. 2007, Acevedo et al. 2008, 2010, Ariefiandy et al. 2013).

Data on the performance of various methods is, however, for most managers in Australia based on research conducted in other countries with different climates and habitats. Also, as little research has been conducted on the ecology of deer species in Australia, it is unknown if their behaviour in this environment will impact on the success of methods used elsewhere. We tested four of the most widely used survey methods for deer using the same population of deer within the same time period and in the context of the resources available to Australian land managers.

Taking into consideration the steep terrain of our study area, the target species wild red deer *Cervus elaphus*, the relatively high density of the deer, and available resources (labour, finance and equipment) we chose distance sampling, aerial survey (mixed distance sampling/mark–recapture), spotlight counts and faecal pellet indices to estimate relative abundance. To help land managers choose appropriate methods to suit their needs we provide a comparison of these four methods for the estimates or indices obtained, labour input, cost, and precision at our study site.

## Material and methods

### Study area

This research was conducted in the Cressbrook Dam catchment (27°25′8″S, 152°19′5″E) between October 2010 and October 2012. Cressbrook Dam is located approximately 55 km northeast of the major provincial city of Toowoomba in southeast Queensland in the warm/humid zone of subtropical Australia (Australian Bureau of Meteorology 2012). Cressbrook Dam catchment reserve (Fig. 1) is managed by the Toowoomba Regional Council (TRC) and comprises approximately 4893 ha (M. McDermid, TRC, pers. comm.). The reserve area is fenced to exclude domestic livestock (i.e. cattle and horses), but not to exclude or contain wild animals (i.e. deer, kangaroos, wallabies, feral pigs and wild dogs).

Cressbrook Dam is located in part of the mountain chain that forms the Great Dividing Range of eastern Australia. Elevation in the study area varies from 280 m to 607 m a.s.l. (Toowoomba Regional Council 2009). Topography in the Cressbrook Dam catchment varies from relatively gentle slopes in the lower elevations around the dam foreshore to steep gullies, ridgelines and hills at higher elevations.

Approximately 82% of the 4,893 ha, (4016 ha) is dry sclerophyll forest. In 2009 approximately 15% (730 ha) was open grassland but this reduced to about 7% (352 ha) in early 2011 when the water reservoir filled rapidly after heavy rains (M. McDermid, pers. comm.). Conversely, the reservoir water level covered approximately 3% (147 ha) in 2009, but this increased to nearly 11% (526 ha) in early 2011 and was maintained at this area for the balance of the study (M. McDermid, pers. comm.). Approximately 1400 ha of dry sclerophyll forest in the northeast part of the catchment reserve had access restrictions during the course of the study.

Red deer were originally released in southeast Queensland in 1873 close to the Cressbrook Dam catchment (Bentley 1998, Jesser 2005). Deer flourished in the region and have built up to a herd estimated at between 10 000 and 15 000 (Moriarty 2004, Jesser 2005). Deer numbers locally in the Cressbrook Dam catchment reserve currently comprise a high density population (Finch 2003, Amos et al. 2011). Red deer at the study site display a similar life cycle to where they originated in the Northern Hemisphere, but timing of events is six months advanced. Thus the rut (mating season) is still in Autumn, but this occurs at the study site in late March through April rather than late September through October as in Scotland (Clutton-Brock et al. 1982). Toowoomba Regional Council staff conducted a management cull of deer in the Cressbrook Dam catchment reserve between July and September 2011 removing 85 animals.

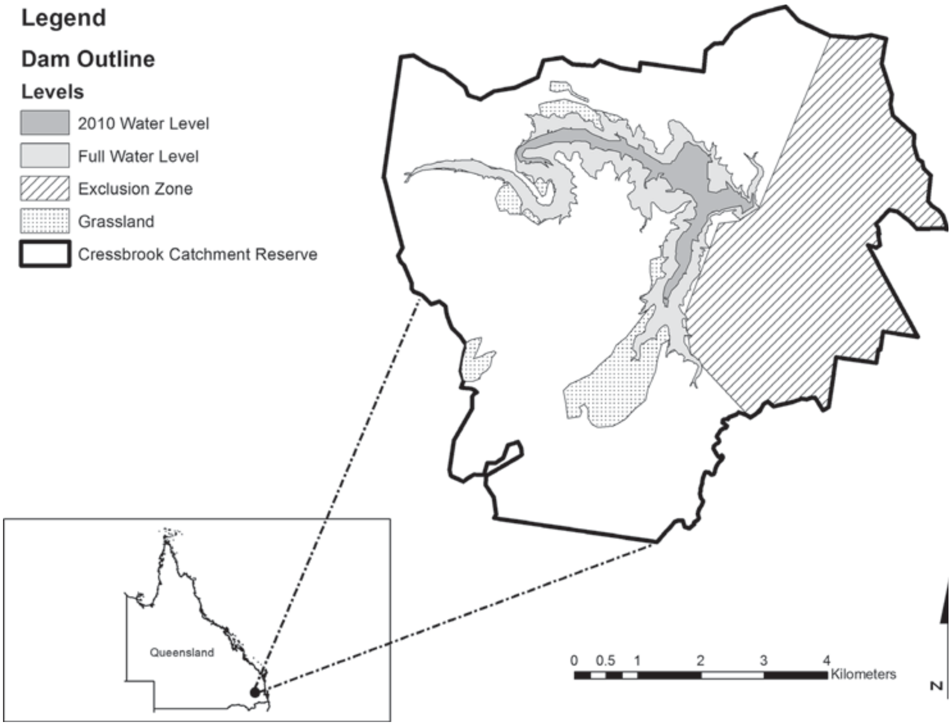

Figure 1. Location of Cressbrook Dam and surrounding catchment reserve. Dam water levels for 2010 and post January 2011 are shown, as well as the grassland area and exclusion zone.

### *Ethics approval*

This research had The University of Queensland animal ethics approval (SAS/239/09 UQ) and Queensland government Eco-access permit (WITK05993409).

### *Distance sampling*

Distance sampling from walked line transects has been used extensively in a variety of circumstances to count deer and has generally been regarded as providing reliable estimates (Mandujano and Gallina 1995, Focardi et al. 2002, Jathanna et al. 2003, Acevedo et al. 2008, Ariefiandy et al. 2013). Distance sampling was conducted following standard methodology (Buckland et al. 2001). A single observer traversed a transect on foot recording the distance and compass bearing to the centre of target animal groups. Distance was measured with a laser rangefinder and compass bearing with a magnetic compass. Observers carried binoculars with a magnification of 8 or 10 times to aid counting at longer distances. Observers noted the species and group number of the target animals whilst traversing the transects at a speed of approximately 2.4 km $h^{-1}$. A pilot study (Amos 2010) suggested sampling should be conducted in spring (September to November) when deer groups were the largest and easiest to detect. Transects were undertaken within 2 hours of sunset to avoid possible complications with morning fog but when deer were active after resting in the middle of the day.

There were between 15 and 21 transects sampled each year that varied from 0.5 to 4.5 km in length and covered the accessible area of the catchment reserve (Supplementary material Appendix 1 Fig. A1). Transects were located far enough apart to avoid the possibility of double counting or flushing animals on another transect, whilst providing a good coverage of the survey region. Multiple transects were sampled on the same afternoon using multiple trained observers. A sampling event consisted of sampling 10 to 21 of the 21 transects each afternoon for four consecutive afternoons. Transects were located on low use vehicle tracks not open to the public.

Data were analysed using Distance 6.0 release 2 (Thomas et al. 2010). As detection probability for individual vegetation types (forest or grassland) was similar between years, data were pooled by vegetation type for all years. The grassland data were truncated at 500 m and the forest data at 160 m to eliminate outliers (Buckland et al. 2001). For each vegetation type the detection function and cluster size were calculated from the pooled data but density and encounter rate were calculated for each year. Cluster size was estimated as the mean of observed clusters. When transects were resampled within a sampling event, individual transect data were pooled and the line length multiplied by the number of visits. We used the uniform key with cosine adjustments, half normal key with cosine adjustment, half-normal key with Hermite polynomial adjustments, and hazard rate key with simple polynomial adjustment models as recommended in Thomas et al. (2010). The selection of the best model and adjustment term were based on Akaike's information criterion (AIC), goodness of fit, and visual inspection of the histogram (Buckland et al. 2001). Results for different vegetation type by year were combined together to get an overall estimate. Standard error overall for each year was calculated by summing the square of the standard error for estimates of deer for each vegetation type, then taking the square root as the overall result.

### *Aerial survey*

An aerial survey using mark–recapture distance sampling methods was conducted as a single sampling event in October 2011 following the methodology of Fewster and Pople (2008). Eight east/west transects 1 km apart were flown with a helicopter over the study area (Supplementary material Appendix 1 Fig. A2). The helicopter was flown at 61 m (200 ft) above the ground at 93 km $h^{-1}$ (50 knots). Two independent observers sat on the left of the aircraft simultaneously recording sightings whilst one observer searched from the right of the aircraft. Independence between observers was maintained by turning off electronic communication between observers and by the noise of the helicopter with doors removed. Observers searched for deer clusters in five distance classes defined by aluminium poles extending perpendicularly on either side of the helicopter with intervals 0–20, 20–40, 40–70, 70–100 and 100–150 m perpendicular to the transect line.

Data was analysed using Distance 6.0 release 2. First a mark–recapture distance sampling (MRDS) model was built to analyse the double sightings from independent observers on the left hand side of the aircraft. The best model using different covariates for cluster size, observer, and distance, was determined by the use of AIC (Laake et al. 2008). Detection probability on the transect line ($g(0)$) was calculated from this model. A conventional distance sampling (CDS) analysis was then run in Distance 6.0 release 2 using results from 1 observer on each side of the aircraft with the detection probability on the transect line included as a multiplier in the analysis. The same models as for distance sampling above were utilised.

### *Spotlight counts*

Spotlight counts were recorded from a motor vehicle driven at 8 km $h^{-1}$ (5 mi $h^{-1}$). A single sampling event consisted of three consecutive nights sampling and the deer/night result for that sampling event was taken as the mean of the three nights sampling (Sinclair et al. 2006). Spotlighting occurred approximately 1–2 h after dark using 100 watt spotlights. The survey team consisted of four people inside a vehicle – a driver, a scribe, and two observers using spotlights – one on each side of the vehicle. Spotlight counts were carried out yearly between October 2010 and October 2012. The spotlight transect was 5.9 km long before January 2011. After flooding rains in January 2011 it was re-designed to 4.4 km due to track closures. The spotlight transects covered grassland areas in the southern portion of the catchment reserve (Supplementary material Appendix 1 Fig. A3).

The spotlight transect area was calculated by taking distance measurements of the approximated visible spotlight range with a laser rangefinder every 100 m along the spotlight transect. Distance measurements were taken either side of the track at right angles to the direction of travel and GPS locations were also recorded at the same location. This data was combined to construct an average spotlight area polygon in ArcMap 10.1 (ESRI). This polygon had an area of 130.3 ha for the 2010 transect and 83.2 ha for the 2011 and 2012 transects. Both estimates of abundance (no. deer $km^{-2}$) and indices of abundance (no. deer km$^{-1}$) were calculated for the spotlighting method.

### *Faecal pellet index*

We conducted the faecal pellet index as described by Forsyth (2005). Sixty random sites were computer generated – thirty sites each for both the grassland and dry sclerophyll forest vegetation types (Supplementary material Appendix 1 Fig. A4). Each site represented the start of a 150 m transect with a random direction of travel. Plots one m in radius were checked every five m along the transect line to count faecal pellets. All intact deer faecal pellets inside the plot were counted. This method does not rely on assumptions for deer defecation rate or faecal pellet decay rate, so these parameters were not calculated. Sampling was conducted in August/September in 2010 and 2011. Data were entered into spreadsheet and the index was then calculated as the mean number of pellets per transect overall and for each vegetation type. 95% confidence limits were obtained by using the free POPTOOLS (<www.cse.csiro.au/poptools/download.htm>) add in and calculating the mean of 10 000 bootstrap samples from the total number of pellets for each transect and then analysing the bootstrap samples with a Monte Carlo analysis. Overall results for the two years were compared with a student's *t*-test and a general linear model was used to examine the fixed effects of year, vegetation type and their interaction.

### Inter-method comparisons

As the accuracy of the estimate by any given method compared to the actual abundance is unknown, one way to compare the various methods is to compare the precision or sampling error of the methods. To do this we compared the relative precision of each method via the coefficient of variation as defined in Buckland et al. (2001) – the ratio of the standard error to the estimator expressed as a percentage of the estimate. We derived a pooled relative precision estimate as above for all years for each method by first pooling the standard deviation (root mean square) for each method and combining with the mean estimator and mean number of observations. An average labour input was calculated for a single sampling event for each method. We also projected the relative precision for all methods for varying levels of labour input by first estimating the projected sample size for the labour input. The projected sample size was estimated by multiplying the actual mean sample size of the method by the projected labour time and then dividing by the actual mean labour input for that method. The projected sample size was then combined with the mean estimator and pooled standard deviation to derive the projected relative precision. The varying levels of labour input for the projected relative precision for comparing methods were set as 24, 36, 48, 72 and 96 h which corresponded to 0.5×, 0.75×, 1×, 1.5 × and 2 × the mean sampling effort from distance sampling. Some extra levels of labour input were added at 6 and 12 h for aerial survey since this method had such a low field labour input.

To calculate the cost of labour a rate of AU\$30 h$^{-1}$ was used. Assumptions for comparison of vehicle and equipment costs are listed in Supplementary material Appendix 1 Table A1. Equipment costs for the faecal pellet index were negligible so these were not included.

## Results

### Distance sampling

We observed 2870 deer in 479 groups whilst distance sampling. (Table 1). The grassland model (uniform model with cosine adjustment) fitted the grassland observations well (Kolmogorov–Smirnov test: $D = 0.076$, $p = 0.33$) although there was some evidence of evasive movement of the deer prior to detection was noted in the perpendicular distance histograms at approximately 190 to 250 m (Fig. 2a – Grassland). The forest model (half normal with cosine adjustment) however did not fit the observations well (Kolmogorov–Smirnov test: $D = 0.155$, $p < 0.01$) and there was a spike at zero (Fig. 2b – Forest). Grouping the data into distance classes did not improve the model. Detection probability varied between the vegetation types (grassland ~ 0.5, forest ~ 0.4). Encounter rate had the greatest effect on variance in the grassland (60 – 82% of variance). Cluster size had the greatest effect on variance for the forest in 2010 (50% cluster size vs. 35% encounter rate) whereas in 2011 and 2012 encounter rate had the greatest effect on variance (82 and 75% respectively). Deer densities were estimated to be lower in the forest (23.7–29.3 deer km$^{-2}$) than grass-

Table 1. Statistics relative to October distance sampling and aerial surveys at Cressbrook Dam. Distance sampling and aerial survey estimates showing strata, year, sample size (n), encounter rate (n/L, cluster km$^{-1}$), effective strip width (ESW, m), detection probability (*P*), expected cluster size (*E*(s)), estimated population abundance ($\hat{N}$), and 95% confidence intervals (95%CI). %CV denotes the coefficient of variation for the column on its left.

| | | | | | | | | | | | | 95% CI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strata | Year | n | n/L | %CV | ESW | *P* | %CV | *E*(s) | %CV | $\hat{N}$ | %CV | Lower | Upper |
| Forest | 2010 | 75 | 0.8 | 13.1 | 70.9 | 0.44 | 8.4 | 4.6 | 15.7 | 1025 | 22.1 | 664 | 1583 |
| | 2011 | 104 | 1.1 | 23.8 | 70.9 | 0.44 | 8.4 | 3.7 | 7.1 | 1176 | 26.2 | 675 | 2049 |
| | 2012 | 92 | 0.8 | 22.1 | 70.9 | 0.44 | 8.4 | 4.3 | 9.3 | 951 | 25.4 | 566 | 1597 |
| Grassland | 2010 | 38 | 1.5 | 25.4 | 265.6 | 0.53 | 3.4 | 15.4 | 20.3 | 325 | 32.7 | 165 | 640 |
| | 2011 | 49 | 3.2 | 30.0 | 265.6 | 0.53 | 3.4 | 6.6 | 13.5 | 140 | 33.1 | 64 | 310 |
| | 2012 | 72 | 3.2 | 33.6 | 265.6 | 0.53 | 3.4 | 8.6 | 22.8 | 182 | 40.8 | 78 | 425 |
| Overall | 2010 | | | | | | | | | 1350 | 18.5 | 942 | 1935 |
| | 2011 | | | | | | | | | 1316 | 23.7 | 833 | 2079 |
| | 2012 | | | | | | | | | 1133 | 22.3 | 735 | 1746 |
| Aerial survey | 2011 | 28 | 0.4 | 24.6 | 70.8 | 0.40 | 14.4 | 5.6 | 22.1 | 1284 | 36.6 | 632 | 2608 |

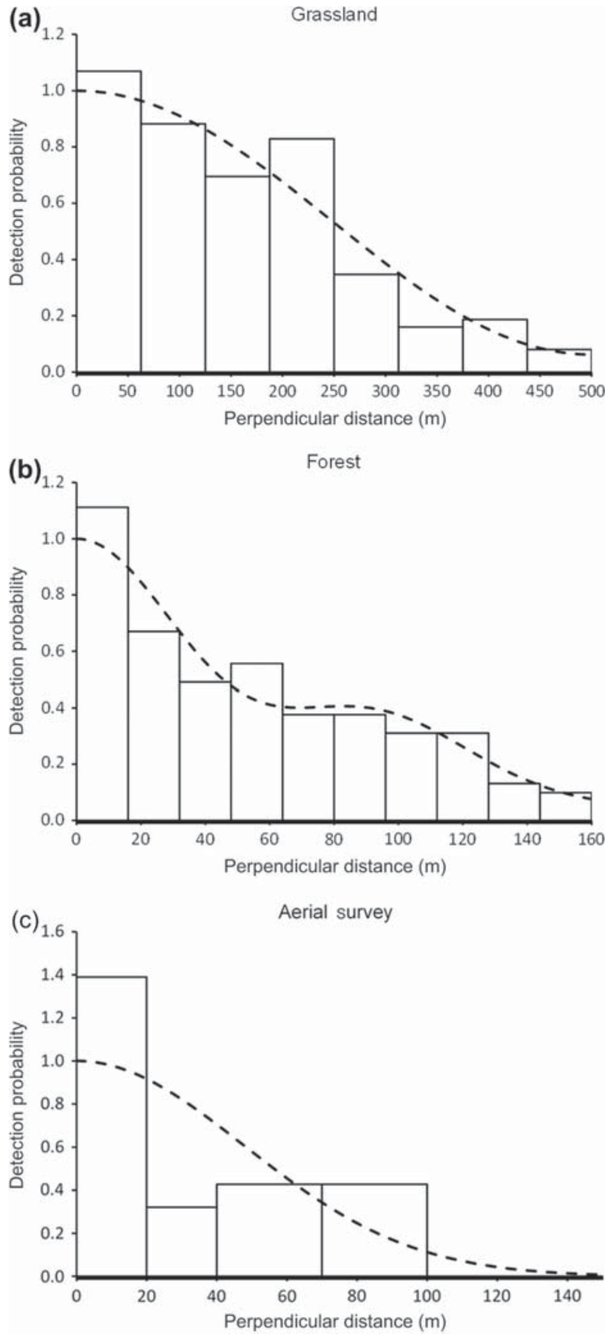

Figure 2. Histograms of perpendicular distances and detection probability (broken lines) for distance sampling in grassland and forest vegetation types (pooled for October 2010, 2011 and 2012) and for aerial survey (October 2011).

land areas (39.8–51.7 deer $km^{-2}$). Population estimates more than halved for the grassland from 2010 ($\hat{N} = 325$) to 2011 ($\hat{N} = 140$) but this did not change the estimated density (Table 2) as the area of grassland in the Cressbrook Dam catchment reserve also halved due to rises in the dam water levels. Given the effective strip width of the grassland model of 265.6 m we calculated the coverage of the grassland transects in 2010 to be approximately 300 ha and in 2011 and 2012 to be approximately 230 ha due to rises in the dam water level. We calculated the coverage of the forest transects with an effective strip width of 70.9 m to be approximately 234 ha for all years.

## Aerial survey

The MRDS analysis estimated a detection probability on the transect line of $g(0) = 0.76 \pm 0.05$. The CDS analysis gave an overall deer population estimate of 1285 deer in the Cressbrook Dam catchment reserve (Table 1). The model fit could not be evaluated as with data from exact distances, but visual estimation of the model fit suggests it is a poor fit due to a spike at zero distance (Fig. 2c – Aerial survey). Encounter rate (45.0%) and cluster size (36.3%) were the greatest contributors to variance. Given the effective strip width of 70.8 m, we calculated the aerial survey coverage to be approximately 202 ha.

## Spotlight counts

The spotlight estimates for 2010 and 2012 were more than double the 2011 estimate (Table 2). The spotlight indices with standard error (in parentheses) were 31.3 (3.2), 10.7 (1.9), and 25.6 (2.3) deer/km for 2010, 2011 and 2012 respectively. The trends for the spotlight indices closely followed the trends of spotlight abundance.

## Faecal pellet index

Faecal pellet indices for 2010 and 2011 did significantly differ between years at the $P = 10\%$ level ($t = 1.89$, DF = 116, p = 0.061) and grassland sites had higher indices than forest sites for both years (F = 6.76, DF = 1, p = 0.011) (Fig. 3). There was no significant effect of vegetation type on the year that faecal counts took place (F = 0.00, DF = 1, p = 0.956).

## Inter-method comparisons

Estimates of abundance from the distance sampling, aerial survey and spotlighting are summarised in Table 2 for comparison.

The aerial survey method estimate of 1285 deer was comparable to the distance sampling estimate for 2011 of 1316 deer (Table 1). The distance sampling covered a much wider strip in the grassland than the aerial survey, but results were similar in the forest. The detection probability for aerial surveys was again similar to the distance sampling for the forest. The variance was greater for the aerial survey compared to overall results for distance sampling.

Spotlighting estimates for 2010 were more than triple and 2012 more than double distance sampling estimates for the grassland. Only the 2011 spotlight estimate was comparable to distance sampling estimates for the grassland.

The faecal pellet index indicated a decline in relative deer abundance from 2010 to 2011(Fig. 3) but this trend was not shared with overall distance sampling (Table 2). However, the faecal pellet index indicated a lower relative abundance in the forest in both years, which was similar to distance sampling.

Spotlighting had the highest relative precision for any single sampling event (Table 3), but high precision was not

Table 2. Estimates of wild red deer abundance. Spring estimates of population density (deer km$^{-2}$) in the grassland and overall at Cressbrook Dam between October 2010 and October 2012. Figures in brackets denote the 95% confidence intervals.

| | Grassland | | | Overall | | |
|---|---|---|---|---|---|---|
| Method | 2010 | 2011 | 2012 | 2010 | 2011 | 2012 |
| Distance sampling | 44.6 (22.6–87.7) | 39.9 (18.0–88.1) | 51.6 (22.1–120.7) | 28.4 (19.8–40.8) | 30.1 (19.1–47.6) | 25.9 (16.8–40.0) |
| Aerial survey | | | | | 29.4 (14.5–59.7) | |
| Spotlighting | 141.7 (114.7–168.7) | 56.6 (36.5–76.7) | 135.7 (112.7–158.8) | | | |

as consistent for this method as for the distance sampling and faecal pellet index methods. The faecal pellet index method was the most labour intensive method, while the aerial survey was the least labour intensive (Fig. 4). When comparing estimates of pooled relative precision and mean field labour input, spotlighting performed well against other methods for the level of precision versus the labour input (Table 4). Spotlighting was predicted to be the most efficient method from projected precision estimates (Fig. 5).

Total estimated costs for the faecal pellet index and distance sampling methods were more than double the costs of the other methods (Fig. 6). Distance sampling had the highest relative equipment costs (Fig. 6).

## Discussion

As expected, there were tradeoffs associated with cost, labour input, and precision for the methods used in this research. Both distance sampling and faecal pellet indices indicated a lower density of deer in the forest compared to the grassland. Distance sampling, spotlighting and faecal pellet indices showed similar trends for the grassland from 2010 to 2011 (Table 2, Fig. 3). However, this trend agreement between years was not shared for distance sampling and faecal pellet index for the forest and overall and cannot be adequately explained. Possibly the rate of decay of faecal pellets was different in the two years due to the high rainfall in January 2011 compared to 2010 when conditions were very dry and stable. Also the increased vegetation cover in 2011 made the counting harder, and more pellets may have been overlooked. Distance sampling for the grassland showed a slight increase from 2011 to 2012 which was in agreement with spotlighting. Spotlighting results in 2011 were likely to be negatively affected by spotlight culls of deer in the preceding months. As distance sampling (Table 1) indicated a relatively stable population over the whole study area for the study duration, it is hard to predict which of the methods were most useful for estimating trends in deer abundance.

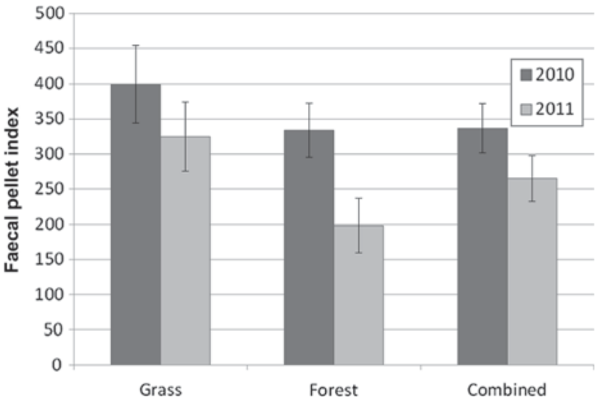

Figure 3. Faecal pellet indices of wild red deer abundance within the Cressbrook Dam catchment reserve for spring 2010 and spring 2011 showing standard error.

We found that distance sampling gave repeatedly precise estimates, and the aerial survey gave reasonable precision for the small labour input. We would recommend the distance sampling method to gain an estimate of absolute deer abundance if sufficient labour was available. If labour was limiting, the terrain and vegetation cover suitable and funds available, we would recommend aerial survey. The population estimates from these two methods were comparable to each other, and also comparable to an earlier estimate by Finch (2003) in the same study area using the Index–manipulation index method.

Of the methods we trialled, the spotlight method performed the best when comparing total expense, total labour cost and precision. However, the small spotlight sample size and sampling on sequential nights may have tended to underestimate the 'true' variability in population size. This method is mostly used to provide an index of abundance (Focardi et al. 2001, Collier et al. 2007, Acevedo et al. 2008, Garel et al 2010) and we found that absolute abundance estimates from this method were generally not comparable to those from distance sampling. This is somewhat expected as the two methods were conducted at different times of the day, and deer generally move out from the forest into the grassland in the evening leading to higher spotlight estimates.

The usefulness of spotlighting to monitor deer populations is very controversial. Garel et al. (2010) recently described spotlighting as 'reliable' from a long term study of red deer in a forested environment in northeastern France. The findings of Garel et al. (2010) indicate that spotlighting is useful for monitoring abundance annually. In contrast Collier et al. (2013) questioned the usefulness of spotlighting in any circumstances following study of white-tailed deer *Odocoileus virginianus* in South Carolina, USA. Those authors found

Table 3. Relative precision (CV%) results from spring estimates. Relative precision (CV%) for all methods used to estimate deer abundance within the Cressbrook Dam catchment reserve from 2010 to 2012 showing estimates from spring sampling.

| Year | 2010 | 2011 | 2012 |
|---|---|---|---|
| Distance sampling | 18.5 | 23.7 | 22.3 |
| Aerial survey | | 36.6 | |
| Spotlight count | 9.7 | 18.1[a] | 8.7 |
| Faecal pellet index | 10.4 | 12.3 | |

[a] sampling occurred after spotlight cull of deer.

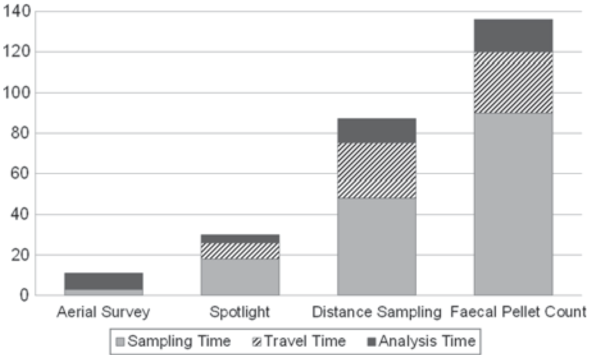

Figure 4. Total labour estimate per sampling event comparing all methods used to monitor wild red deer abundance in the Cressbrook Dam catchment reserve between 2010 and 2012.

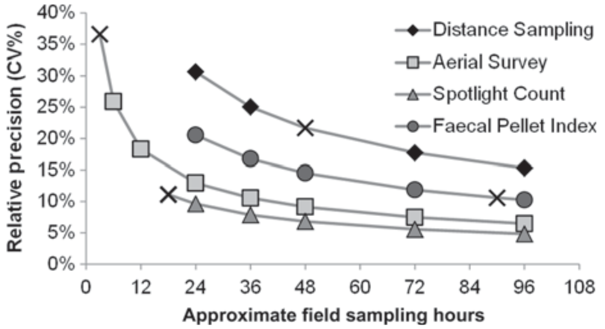

Figure 5. Projected relative precision for varying levels of field labour input from pooled spring estimates and indices of wild red deer abundance in the Cressbrook Dam catchment reserve. X denotes the actual pooled relative precision realised from the actual mean field sampling labour input for each method.

that spotlighting had such a highly variable detection probability that it was unlikely to provide abundance data useful for management decisions. Although we also experienced variable detection probability using this method, trends between years generally agreed with distance sampling estimates for the grassland. Given the level of precision at our study site and low overall costs, we would recommend this method to gain an index of relative abundance for red deer in open woodland and grassland habitats in Australia. However, low detection rates in dense vegetation would likely make this method more unsuitable in forest areas.

We obtained consistently high precision from the faecal pellet index which is used elsewhere in Australia to monitor changes in Sambar deer *Cervus unicolor* relative abundance (D. Forsyth pers. comm.). We found this method extremely labour intensive in subtropical grassland with dense vegetation cover and the deer densities we encountered. However, this method was most likely designed with lower deer densities in mind, as bootstrapping in the analysis made no difference to 95% confidence intervals as compared to those derived without bootstrapping.

When comparing all methods, regardless of whether an estimate of absolute or relative abundance, we found the spotlight method to be the most efficient in terms of labour and equipment costs compared with precision. However, because consistently high precision was only obtained by methods utilising a relatively high labour input, we conclude that there are no short cuts to monitoring populations of wild red deer in a context such as we encountered in the Cressbrook Dam catchment reserve. Each method has desirable and undesirable traits, and choosing a method for any given study site will involve a thorough evaluation of the methods available (Acevedo et al. 2008).

We advocate the use of a pilot study to obtain an estimate of the variability of deer sighting over time and space before conducting counts using any particular method. A pilot study is particularly useful in determining if the sampling method is suitable for the study site, and may indicate the sampling effort required to achieve the survey goals. We used a pilot study effectively for the distance sampling method (Amos 2010) to determine the transect line length as described in Buckland et al. (2001) to achieve reasonable precision.

Not all methods could be trialled at exactly the same time due to high labour requirements for some methods. Some methods may have also negatively affected results for other methods if conducted at the same time by inducing deer avoidance due to high personnel presence. This timing of events introduces some extra variation into the comparison of the experiments, but all estimation methods were undertaken as temporally and spatially close to one another as logistically possible, hence this variation was minimised.

Finally, researchers and land managers must be aware that our comparison of these methods was conducted in a region where deer densities are high by world standards. For example some European red deer densities have been reported in the range of 1.7–7 deer km$^{-2}$ (Georgii 1980, Kamler et al. 2008, Jerina 2009), 14 deer km$^{-2}$ (Clutton-Brock et al. 1982) and 25–26 deer km$^{-2}$ (Lovari et al. 2007). A recent

Table 4. Mean sampling time and associated statistics for spring estimates of absolute and relative abundance. Mean field sampling hours (*t*) per sampling event, mean sample size (n), mean estimator (E), pooled standard deviation (SD) and pooled relative precision (CV%) for all methods used to estimate deer abundance within the Cressbrook Dam catchment reserve from 2010 to 2012 showing estimates from spring sampling.

| Method | *t* | n | E | SD | CV% |
|---|---|---|---|---|---|
| Distance sampling | 48 | 143 | 1266 | 3287 | 21.5 |
| Aerial survey | 3 | 28 | 1284 | ,487 | 36.6 |
| Spotlight count | 18 | 3 | 115 | 22 | 11.1 |
| Faecal pellet index | 90 | 60 | 301 | 247 | 10.6 |

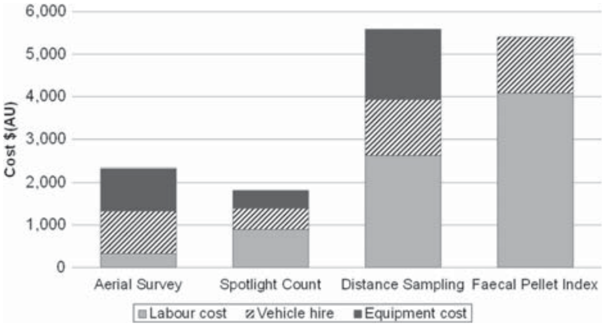

Figure 6. Total cost of methods used to monitor wild red deer abundance in the Cressbrook Dam catchment reserve 2010 and 2012 with labour input valued at \$30 h$^{-1}$ (Australian dollars).

study in a Mediterranean climate classified red deer density as low between 0.04–20.0 deer $km^{-2}$ and high between 20.01–66.77 deer $km^{-2}$ (Acevedo et al. 2008). Our density estimates from distance sampling methods in the Cressbrook Dam catchment reserve estimated wild red deer density to be approximately 25–30 deer $km^{-2}$.Hence all our analyses must be evaluated in that context and may not be applicable in other locations with a lower deer density, or in different terrain types.

## Conclusions

This research highlights the importance of assessing the available methods for estimating deer abundance prior to choosing a monitoring method. Our study will help Australian land managers and researchers make informed decisions regarding method choice for monitoring deer populations in the future.

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Supplementary material (available online as Appendix wlb.00080 at <www.wildlifebiology.org/readers/appendix>). Appendix 1