Review of eastern grey kangaroo counts and derivation of sustainable density estimates in the Australian Capital Territory

Eastern grey kangaroos at the Pinnacle Nature Reserve, Canberra, April 2014

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Summary

The Territory and Municipal Services Directorate of the Australian Capital Territory Government commissioned Kurahaupo Consulting to review (a) the current methods used to derive the target densities set for eastern grey kangaroos in the conservation culling program in Canberra Nature Park. The program is run in accordance with government policy set out in the ACT Kangaroo Management Plan (KMP), and (b) the methods used to count eastern grey kangaroos in the Nature Reserves of Canberra Nature Park. Both the counting and estimation of target densities are conducted by the Environment and Sustainable Development Directorate (ESDD), a separate arm of the ACT Government. Therefore, we obtained relevant documentation from ESDD and interviewed staff from this Directorate on their methods and rationale for current practices for managing the kangaroos.

Objectives

- To review the rationale for determining the target population sizes or densities of eastern grey kangaroos desired in the ACT to achieve a grazing regime that conserves native animals that rely on the conditions of the ground-layer vegetation in habitats used by kangaroos.
- To review the methodology used to estimate the numbers or densities of eastern grey kangaroos in the ACT to validate the culling regime applied to achieve the desired target population sizes.

Key conclusions and recommendations

1. The logic and evidence underpinning the KMP is valid but the conservation culling components of the plan are properly adaptive and will be refined as the results of current research and monitoring reduce uncertainty about key parameters such as target densities.

2. Unmanaged kangaroo populations reduce the biomass of ground-layer vegetation which has adverse impacts on some other native species. Therefore culling kangaroos is a valid management action. The current management ensures sustained populations of kangaroos at densities that purport to allow more vegetation and more secure populations of threatened native species.

3. There is published evidence that the current target density of kangaroos (set by modelling at 1 per hectare) does benefit other native plants and animals but managers recognise there are gaps in understanding the details of how temperate grassland ecosystems work as components of it (mostly kangaroo

numbers) are manipulated. Current projects conducted by ACT staff and PhD studies underway at ANU should fill some of these knowledge gaps.

4. One key question is whether the density of 1 kangaroo per hectare is the ‘correct’ target for all times, all nature reserves and under all environmental and biological conditions. We suspect it will be too high (100 large herbivores per km^2 is still a very high density relative to other systems and species, and certainly constitutes no threat to the sustainability of the kangaroos). The results of an ACT project currently being conducted will will help identify whether the average density set is the best or at least within the optimal range of densities.

5. Each nature reserve is a sort of habitat island with a variety of assets and threats, with varying degrees of connection between the reserves. The KMP might be supported with a set of individual site plans, with kangaroo management as but one action within each plan. Site-specific monitoring will allow management to be fine-tuned.

6. ACT managers have two options to lead to this site-based approach. They can nominate a number of nature reserves to be managed to allow the rare native species to be maintained with resilient populations and achieve it as efficiently as possible (cost minimisation). Or they can set a fixed annual budget and determine how many nature reserves can be effectively managed within the budget (benefit maximisation).

7. The methods being used to count kangaroos and estimate densities are sound, but we recommend the following four changes. (i) direct and sweep counts need more replication, (ii) uncertainties in components of direct, sweep and pellet count methods should be addressed in analyses, (iii) a team of trained professionals (i.e. staff and/or contractors) should be the core for all counts, although we acknowledge the wider social and public relations benefits of including volunteers, and (iv) the counts should be conducted as close as possible to the intended cull. Further, consideration should be given to conducting a second post-cull count perhaps six months later, at least in a subset of reserves.

8. Sweep counts have several potentially significant problems, including traffic problems if kangaroos flee the counters. We recommend ACT consider either replacing this method with direct or walked-line transects, or if this is not possible to use core trained staff as above.

9. It would be valuable to conduct a trial to compare the costs, accuracy, and precision of the four counting methods across different habitat types and kangaroo densities.

10. The methods used to conduct kangaroo counts should be described in standard operating manuals that can be updated as required. This would

ensure continuity for a program that will have to be sustained long after current staff have left.

11. Publication of research by ACT staff and others should be facilitated because this work is potentially of high standard and of interest to a wider audience, as well as providing ACT decision-makers and other stakeholders with the confidence of peer review.

Introduction

The Territory and Municipal Services Directorate of the Australian Capital Territory (ACT) Government commissioned Kurahaupo Consulting to review (a) the current methods used to derive the target densities set for eastern grey kangaroos (*Macropus giganteus*) in the ACT Kangaroo Management Plan (KMP) (ACT 2010), and (b) the methods used to count eastern grey kangaroos. The authors visited the ACT in early April 2014 to discuss the terms of reference for this report, gather relevant data, and visit the places where the KMP is applied.

Objectives

- To review the rationale for determining the target population sizes or densities of eastern grey kangaroos desired in the ACT to achieve a grazing regime that conserves native animals that rely on the conditions of the ground-layer vegetation in habitats used by kangaroos.

- To review the methodology use to estimate the numbers or densities of eastern grey kangaroos in the ACT to validate the culling regime applied to achieve the desired target population sizes.

In this report we have deconstructed these objectives into four questions and assess how well the current practice achieves them:

Why should kangaroos be controlled in the ACT?

If kangaroos are to be controlled in the ACT, then what target density (or densities, or range of densities) should be set?

How should the population size or density of kangaroos in reserves be estimated, and how often?

And, is the formula used to calculate how many kangaroos should be culled when the target density is exceeded valid?

In answering these questions we have the information in the KMP which is based on evidence published or known before 2010. There is also some information published since 2010, and information from projects in progress but not yet published. These latter sources may of course already indicate changes required when the KMP is revised.

Background

Kangaroos are now an iconic, and common native marsupial in the ACT. They have always been present in the major natural areas to the west of the Murrumbidgee River but were extirpated to the east of the river as these areas were developed by European pastoralists farming sheep. Changes in land and farming practices resulted in eastern grey kangaroos naturally re-establishing within the perimeters of Canberra in 1976.

There are 34 discrete Nature Reserves (and more likely to be added in future) that comprise the Canberra Nature Park. These reserves support a diverse suite of native plants and animals including 19 species listed as threatened under Commonwealth and ACT legislation (ACT 2010), and include two endangered ecological communities; natural temperate grassland and yellow box – red gum grassy woodland.

Eastern grey kangaroos are the dominant vertebrate herbivore (see below) in most of these reserves and are managed under the Kangaroo Management Plan (2010) (hereafter KMP). The overall objective of the KMP is to maintain the presence of eastern grey kangaroos while reducing any environmental (i.e. particularly to the other native plants and animals), economic and social impacts.

Results

Why should kangaroos be controlled in the ACT?

The KMP sets out the three biological or biodiversity reasons that might justify controlling kangaroo numbers – kangaroos reduce the biomass of the vegetation, they alter the composition of the vegetation, and these impacts have adverse affects on other native fauna of value. If this chain of logic is correct then the KMP is a valid management approach based on the judgement that retaining other native fauna (especially rare and endangered species) is more valuable than allowing high densities of the eastern grey kangaroo to naturally reach a ‘food-limited’ density, i.e. to exist on a ‘marsupial lawn’ with the biodiversity consequences of that state. The KMP and a series of research projects (some in progress) detail this chain of logic. We summarise what is known, or remains to be demonstrated, to give our assessment of the justification for control of the kangaroos.

Eastern grey kangaroos are clearly currently the dominant grazer at sites within Canberra Nature Park at which culling of this species is being considered. However, this has not always been the case and may not be the case in the future. The impacts, and hence management of other mammalian herbivores, are outside the scope of our review, but should be considered in the broader context of these reserves. European rabbit (*Oryctolagus cuniculus*), brown hare (*Lepus europaeus*), fallow deer (*Dama dama*), swamp wallaby (*Wallabia bicolor*), red-necked wallaby (*Macropus rufogriseus*), and euro (*M. robustus*) may be present in some of the reserves. Culling eastern grey kangaroos may increase food availability or otherwise make habitat more suitable for some of these species, or conversely taller grass might disadvantage species such as rabbits.

4.1.1 Do kangaroos affect the biomass of vegetation?

The KMP is based on the presumption that kangaroos have a direct effect on the amount of vegetation, or at least some components of it, and the more kangaroos the greater this effect. However, this is not the case in all places so we briefly explore the published literature to see when kangaroos do and do not act in this way.

The best described kangaroo-vegetation system comes from the series of studies undertaken in the arid rangeland, including Kinchega National Park, in western NSW (Caughley et al. 1987). Here the system of red (*Macropus rufus*) and western grey (*M. fulginosus*) kangaroos and ground-layer vegetation biomass is largely driven by erratic rainfall (annual mean = 236 mm but highly variable between years with a CV of 45% and variable over short distances). Vegetation biomass increases soon after rain and kangaroos respond to more food (actually a threshold biomass of over 200 kg/ha) by breeding and increasing in numbers. When the vegetation biomass falls below 200 kg/ha kangaroo numbers decline. Kangaroos have little effect at any density on the flush of vegetation after rain falls but they may (depending on their density at the time since their numbers are sometimes not synchronised with the rain fall event) reduce the peak vegetation biomass that might occur or drive the vegetation to an even lower state in droughts. The feedback loops (more vegetation-more kangaroos, less vegetation-fewer kangaroos, and a loop within the pasture itself that slows growth as biomass increases in this system ensures centripetality – a tendancy towards a stable state but not one that is never reached as a new external event (erratic occurrence of rain) resets the system. Caughley et al. (1987) were generally skeptical about the merits of culling kangaroos in national parks to conserve biodiversity values when these dynamics applied, although they did concede that controlling kangaroos to reduce competition with sheep or simply to harvest meat were legitimate management actions.

So, is the advice given in this seminal book relevant to the kangaroos in the Nature Reserves in Canberra? If the eastern grey kangaroos in Canberra do not affect ground-layer vegetation biomass as for the rangeland species of kangaroos, then there is no justification (on biodiversity grounds alone) for controlling their numbers.

The systems are different. Rainfall in Canberra is higher (650 mm) with a much more even annual distribution (CV = 27%) and more even monthly distribution than that at Kinchega (e.g. McIntyre et al. 2010). Rainfall is most variable in March, and in April 2014 when we visited the sites it had been wet and the vegetation was abundant and green (see frontpiece). Under these circumstances plant growth is still driven by rainfall (and season via a strong temperature effect and a rain-temperature interaction (Fletcher 2006)), but as rain is less erratic pasture biomass is more constant and reaches higher levels (means of 569 ± 44 kg/ha with maximums of 2352 kg/h in 2007 (McIntyre et al. 2010) than in the arid rangelands (less than 10 kg/ha in droughts and over 800 kg/h in wet periods) (Robertson 1987).

The KMP and the research on pastures on which it relies (e.g. Fletcher 2006, 2007 at three sites selected to span the local range of climatic variation in grassland habitats, viz. Tidbinbilla, Gudgenby and Googong; and Neave & Tanton 1989 at Tidbinbilla) show that, unlike the arid rangeland case, kangaroos do have a significant affect on grassland biomass in temperate areas under some circumstances. The modelled outcomes in Fletcher (2006) showed more kangaroos equals less grass[1] and vice versa, although this relationship was at times completely overwhelmed by weather. This is inevitable in any vegetation-herbivore system because the plants can respond (grow or die) much faster than the herbivores breed or die. Conversely, the herbivores can overshoot their food supply and be left with too many mouths to feed when the vegetation is in natural decline, e.g. in a drought. The experimental data reported by Neave & Tanton (1989) show (among other things) that the height of most vegetation was significantly reduced when kangaroos were present. The conclusion is from both empirical data and the model derived from them that the temperate system differs from the semi-arid system studied at Kinchega. Kangaroos in the more stable temperate system do, on average over time, have a large effect on the biomass of grasslands.

Following the publication of the KMP in 2010, the only additional published evidence that eastern grey kangaroos affect grass biomass in the Canberra Nature Park is that of McIntyre et al. (2010). They described an experiment being conducted at Mulligans Flat that aims to evaluate how various (but unstated) eastern grey kangaroo densities affect a variety of variables, including plant biomass. Further studies were conducted in 14 Nature Reserves (Anon undated) in 2012/13 to assess the ground-layer vegetation biomass under three herbivore regimes (eastern grey kangaroos and rabbits excluded, kangaroos only excluded, and kangaroos and rabbits at ambient densities with that for kangaroos being measured). The sites have a range of kangaroo densities between 0 and 3.2 kangaroos/ha (mean = 1.2) so encompass the range of interest for setting target densities (0.6 – 1.5/ha). The results from these studies, when published, will provide empirical data on the relationship between kangaroo density and plant biomass to inform the modelled relationships from Fletcher (2006).

We conclude that culling kangaroos to reduce their density allows more vegetation (mostly grass) and therefore the KMP's logic is correct for this first step of the chain.

4.1.2 Does fewer kangaroos change native plant biodiversity?

Ground-layer vegetation can be reduced to 'marsupial lawns' when kangaroo densities are consistently high (McIntyre 2005). While these lawns are interesting, and not without value in their own right (and presumably favour some native plants and animals), they do not favour most native species. For example, Neave & Tanton (1989) showed differences in the cover of grasses and herbs at sites with and

[1] Eastern grey kangaroos diet is mostly grass (Jarman & Phillips 1989)

without kangaroo grazing at Tidbinbilla – most species decreased at grazed sites but one grass was favoured.

The evidence that more or less kangaroo grazing advantages or disadvantages native plants over exotic plants is unclear. For example, Table 3.3 in the KMP lists nine threatened plant species from the ACT of which only two (*Thesium australe* and *Leucochrysum albicans* var. *tricolor*) are speculated to be at risk from herbivory – neither are grasses so the threat from kangaroos is moot. Neave & Tanton (1989) show some are advantaged by grazing and some not. A more detailed analysis to discriminate kangaroo effects from other factors (perhaps by concentrating on grass species rather than all species) would be required to answer this question.

The current project (Anon undated) has measured several indices of species richness at plots on 17 sites with and without kangaroos (and under the herbivore experimental regime noted above) and may help answer the question of how kangaroos managed to a target density change native plant biodiversity.

We conclude that kangaroos do change plant diversity but the details are unclear.

4.1.3 Does more 'grass' and more diverse flora favour valued native fauna?

Showing a direct cause and effect relationship, or at least diagnosing a single cause (such as kangaroo density-related grazing) becomes more contentious as propinquity widens along the trophic levels in a system. Before the KMP was published several papers noted that a simple reduction in height of the vegetation made areas unsuitable for some invertebrates and birds such as stubble quail (*Coturnix pectoralis*) and Richard's pipit (*Anthus novaeseelandiae*) (Neave & Tanton 1989).

As with the flora, there are several threatened animal species in the Canberra area that are thought to be adversely affected by kangaroo grazing (KMP 2010). If we go back to the various recovery plans for these species the 'usual suspects' are listed rather than much evidence of a 'culprit'. For example, the plan for the grassland earless dragon (*Tympanocryptis pinguicolla*) says "the main factors involved in the decline are thought to be …" and goes on to list a page of possible threats (Robertson & Evans 2010). This lack of specific diagnosis is common in threatened species plans and reflects, in part, the difficulties noted in the first sentence of this section.

Since the KMP was published there have been attempts to improve these threat diagnoses. For the grassland earless dragon, Dimond et al. (2012) suggested that the degree of cover during droughts – and by implication the effect of grazing during droughts – was a key factor in the decline of this species. The project underway (Anon undated) is also measuring reptile abundances and species composition across a gradient of kangaroo densities – results are pending.

A third study (Manning et al. 2013) asked whether ambient vegetation biomass indices or kangaroo grazing affected reptile abundance. They concluded that decreasing grazing effectively increased small skink abundance in grasslands with high biomass, but the addition of cover (woody debris) was required in areas with low vegetation biomass caused by high kangaroo densities. This suggests to us that predation on the reptiles (by cats, foxes or birds) is mediated by the degree of cover which is affected by kangaroo grazing. Managing both herbivory and predation may be required to protect rare reptiles.

Howland et al. (unpublished manuscript in review) studied reptile diversity and abundance in 19 reserves with different kangaroo densities. Some reptile species were favoured by low kangaroo densities, others by moderate kangaroo densities, while high kangaroo densities favoured no reptiles. They recommended managing different reserves for different kangaroo densities (from low to intermediate) to favour different suites of reptiles – see also our recommendations.

Barton et al. (2011) showed that reducing the grazing by kangaroos increased the abundance and diversity of beetles, while adding woody debris to sites further improved the status of beetles. They speculated that this increase in invertebrate biomass would advantage insectivores such as the endangered reptiles.

We conclude that the threats to native fauna are likely to be multi-factored but that one remedy is to increase the biomass of ground-layered vegetation by reducing mammalian herbivory, and the dominant herbivore in the system is likely to be eastern grey kangaroos – although rabbits may from time to time rival them.

What target densities should be set?

4.2.1 Canberra Nature Reserves and kangaroo densities in context

Three main species of Australian kangaroos (*M. rufus*, *M. fulginosus* and *M. giganteus*) prefer rangeland, grassland and open woodland habitats and have adapted to cope with both regular and erratic rainfall biomes across temperate and arid systems found over much of Australia. Eastern grey kangaroos are so well adapted they that they can sustain extraordinarily high densities when food is abundant – at least compared with kangaroos in the rangeland and exotic wild and feral ungulates in Australia (Table 1).

The densities of eastern grey kangaroos in ACT Nature Reserves and adjacent national parks, where they are not culled, varies from zero (Environment & Sustainable Development 2103; D. Fletcher pers. comm.) through to 2 animals/ha (Namadgi National Park in 1996 and several reserves in Canberra Nature Park), up to a maximum of 4.5 animals/ha (Jerrabombera East in 2013), to 5.1/ha at Tidbinbilla (Fletcher 2007). The modal density is around 3 animals/ha (ACT 2010, App. 5 and ACT unpubl. data).

Table 1. Some densities of unharvested/culled large herbivores measured in Australian habitats used by kangaroos

Species	**Density (animals/ha)**	**Place, habitat type**	**Reference**
M. giganteus	4 – 7	Wilsons Promintory VIC., coastal temperate modified grassland	D. Forsyth (unpubl. data)
M. giganteus	0.87 – 4.53	Canberra nature reserves in 2013	ACT (unpubl. data)
M. rufus *M. fulginosus*	0.1 – 0.38 0.05 – 0.18	Kinchega National Park, arid rangeland in dry and wetter periods	Bayliss (1987)
Capra hircus	0.09	Oxley NP NSW, woodland, dry forest	Bayne et al. (2000)
Sus scrofa	0.02 0.018	Sunny Corner NSW, grassland, woodland Namadgi NP	Saunders & Kay 1991) McIlroy & Saillard (1989)
Camelus dromadarius	0.29	Australian range, arid habitats	Ninti One (2013)

4.2.2 Target densities in ACT reserves

The KMP sets a density of 1 eastern grey kangaroo/ha, weighted for the proportions of grassland, woodland and forest in each reserve, as the target for management. The model on which it is based (Fletcher 2006) gives a range of between 0.6 to 1.5 eastern grey kangaroos/ha as that allowing ‘conservation of grassy ecosystems’.

The KMP refers to this target density as a ‘carrying capacity’. Wildlife managers and farmers have always confused themselves with this term (Sinclair et al. 2006) and this confusion is not helped by the set of definitions in the KMP. Since we do not really know what maximum density of kangaroos could be sustained (or the average over time) in these temperate ecosystems (K = the ecological carrying capacity) and thus at what density maximum sustained yeilds would apply, we think the term ‘target density’ better (and more simply) describes the aims of the KMP.

Field evidence to validate this target density is currently unavailable. Most of the experimental work (e.g. Barton et al. 2011) has compared the impacts of low densities of kangaroos (i.e. up to 1/ha inside leaky large exclosures), with ambient densities (up to 2.5/ha in adjacent areas). This may or may not be sufficient to identify any thresholds in the kangaroo-vegetation relationship – if such breakpoints do occur. Eventually target densities might be fine-tuned for each reserve and outcomes compared across reserves, e.g. in an adaptive management experiment, as attempted in the Howland et al. (unpublished manuscript in review) study on the impacts of kangaroo densities and grassland biomass on reptile diversity and abundance.

The current target density of 1 kangaroo/ha seems to be a high herbivore density. The consequences of setting a lower target density as a precautionary measure are (a) a higher initial cull would be required at most sites, but (b) a smaller ongoing cull would be required to maintain the target population size – with cost and animal-welfare advantages (see Todd et al. 2008) for an analysis of such a case for overabundant koala (*Phascolarctos cinereus*) populations subject to fertility control . However, we are not in a position to recommend this until a series of kangaroo density versus ground-cover biomass relationships under at least the two extremes of rainfall across seasons are described. If this was possible it is likely that reserve and condition-specific target densities would be indicated, but the cost to achieve these might be high. The target density of 1/ha appears to be about 25 – 33% of the density reached at *K* in the Canberra nature reserves. Theory suggests the harvests required to keep the populations at this proportion of *K* will be less than maximum sustained yield and that food availability will not be limiting eastern grey kangaroos.

In general setting target densities based on a herbivore-vegetation relationship depends on the form of that relationship. If the relationship is linear then any target could be justified. If the realtionship is curved or with thresholds (see Fig. 8.6, p. 226 in Fletcher 2006) then the target to achieve some level of resource condition is determined by the herbivore density at which the resource begins to respond (e.g. see Choquenot & Parkes (2001) for a discussion of the ways to model thresholds in pest management).

We conclude that 1 kangaroo/ha is a reasonable starting target for management, but it is unlikely to be the optimal target for all reserves under all circumstances. Our suggestion to begin site-specific planning may allow an adaptive approach to be made to fine-tune this 'average' target density.

4.2.3 Required density reductions

The obvious required reduction in kangaroos is, as in the KMP, simply the difference between the estimated population size (see below) and the population at the target density weighted by habitat types. The KMP recommends accounting for any expected population growth between the count and the cull – but see our point below.

Counting kangaroos

4.3.1 Timing of counts relative to culling

Kangaroos are culled during the March-July shooting season. The counts of eastern grey kangaroos used to determine the required density reductions should be conducted as close as possible to the culls so as to minimise potential population chage (e.g. due to natural recruitment of mortality) between count and cull. Currently, counts of eastern grey kangaroos used to determine the required density reduction in Canberra Nature Park have sometimes been conducted in spring and sometimes in summer. We suggest that the Canberra Nature Park culls be scheduled for say a 4-week period within this shooting season in a way that allows all the counts to be conducted as close as possible to the culling season such that the estimated number of animals to be culled is as accurate as possible. For example, the counts could be conducted in February and March (when nearly all young born in the previous year have emerged from the pouch) with a view to starting culling in May.

4.3.2 How many counts annually?

A target density of 1 kangaroo/ha has been stipulated for kangaroo management units (KMUs) in Canberra Nature Park. Kangaroo counts are currently conducted once annually. Above we recommended that the counts be conducted as close as possible to when culling occurs. Hence, assuming the counts are accurate and that the cull target is attained, the population would be at the target density immediately after the cull. During the remainder of the year the population could be expected to increase (through births but also potentially immigration) if conditions (e.g. high per capita food availability) are good but could, more rarely, decrease (through deaths and emigration) if conditions are poor. These possibilities are currently addressed by allowing for *expected* population kangaroo growth in deciding the cull target (see 'Calculation of the number of kangaroos to cull' document). It is unclear to us how the expected annual population growth rate is estimated and applied to each culled population. A more transparent way of addressing this issue is to conduct a second annual count six months after the first count, and use the mean of this and the pre-cull count as the annual density. Conducting a second count would obviously have financial implications.

4.3.3 Training observers

Kangaroo surveys are currently conducted by staff, contractors and volunteers with a wide range of experience, training and likely skill. The accuracy of counts would almost certainly be improved if greater emphasis was placed on the selection and training of people collecting these data. We acknowledge that conducting field work is costly but using poorly trained staff, contractors and volunteers could substantially affect estimates of kangaroo population size, particularly in sweep counts which often require a large number of people to follow detailed instructions and to respond in real-time to changing circumstances during the sweep. Volunteers with a bias could also deliberately bias the sweep counts (e.g. by deliberately undercounting kangaroos). This potental bias applies mostly to the two ‘total count’ methods (direct and sweep counts) as the two ‘sampling’ methods (pellet counts and walked line transects) are conducted entirely by trained staff.

We suggest that serious consideration be given to having a core team of staff/contractors that conduct all kangaroo counts (i.e. volunteers are not used). The core group should receive regular training and only people that meet minimum competency standards can undertake surveys. We note that replacing sweep counts with walked line transects would reduce the need for large numbers of people to undertake field work, and hence the cost of field work.

Methods to count kangaroos

Five methods have been used to count the number of kangaroos: (i) direct (or vantage point counts); (ii) sweep (or drive) counts; (iii) walked line transect counts; (iv) pellet counts; and (v) driven line transect counts. The reason for using different count methods is that each method has advantages and disadvantages that vary with site features such as vegetation height and density, topography, size, personnel availability and skill level, and cost. We address each method in turn.

A trial to compare the costs, accuracy and precision of the methods, particularly the four methods that count kangaroos, is recommended.

4.4.1 Direct (vantage point) counts

Direct counts are used in small reserves in which it is thought that all kangaroos present can be counted from a vantage point by one or more persons. This method should be termed ‘vantage point count’ (Ratcliffe 1987, Mayle et al. 1999) rather than ‘direct count’ because the latter applies to any method in which the number of animals is directly rather than indirectly counted (Thompson et al. 1998). Hence, vantage point counts, walked line and driven transects and sweep counts are all ‘direct count methods’ and pellet counts are an ‘indirect count method’. Vantage-point counts are the most preferred method for counting kangaroos within Canberra Nature Park because they are cheap and are thought to provide an accurate and easy-to-compute method for estimating kangaroo abundances in small reserves with vantage points (e.g. ridge or roadside) that enable all kangaroos thought to be present to be seen.

Direct counts involving 1−3 people were used in three KMUs in 2013; Crace, Dunlop and Mulanggari. Our visit to Mulanggari KMU (7 April 2014) suggested that direct counts are a cost-effective method for estimating kangaroo abundances there. To our knowledge there are no published studies evaluating this method for eastern grey kangaroos. Direct and sweep counts conducted by ACT are always replicated to achieve a mean count as follows. At least three replicate counts are required if the team of counters has not previously used the method on the site, and the result is accepted only if (i) there is no suspicion of over- or under-counting when the data are perused, and (ii) the counts are consistent, with the highest and lowest count being within 10% of the mean count. Two replicate counts are required if the team has previously used the method at the site and met points (i) and (ii) above. For sites with at least three replicates the operational details are changed (e.g. the sweep direction is changed) until the rules are met. Potential sources of variation include the observer (likely to vary with individual experience and inherent ‘skill’) and the time (some kangaroos may be lying down) and date (the number of kangaroos present may vary with time) of the sampling. We suggest that a minimum of four (but preferably more) direct counts be conducted in sites at which this method is used, and that a mean and 95% confidence intervals be reported for these four samples.

4.4.2 Sweep (drive) counts

Sweep counts are more commonly referred to as drive counts in the literature (e.g. Coulson & Raines 1985; Southwell 1989), but the term ‘sweep’ reflects the local preference as care is made to avoid forcing the kangaroos ahead of the observers. This method was used in at four KMUs in 2013: Gungaderra, Mt. Painter, The Pinnacle, and Mulligans Flat Woodland Sanctuary. Sweep counts can provide a very accurate estimate of population size when animal movement is restricted to within a small area (Southwell 1989). Coulson & Raines (1985) evaluated the accuracy of sweep counts of eastern grey kangaroos on 266-ha Rotamah Island, Victoria. The abundance estimated in one sweep count (547) was well within the 95% confidence intervals of estimates from walked line transects (Coulson & Raines 1985).

The sweep counts conducted in Canberra Nature Park involve one or more lines of people moving through the site and counting kangaroos as they pass back through the line(s), and are used in areas considered too large, too heavily forested, or where the topography is too complex for vantage point counts to be effective. Mixed count methods are used in some reserves. For example, sweep counts are used in the heavily wooded part of Gungaderra reserve and vantage point counts in the more open grassland part of the reserve. Our visits to all four sites (7 and 8 April 2014) at which sweep counts were used in 2013 indicated some of the difficulties associated with this method. The main difficulty with this technique is ensuring that all kangaroos present in the reserve prior to the count are counted, although one factor in selecting the mathod for a reserve is the degree of isolation of the population – by major roads and suburbs. There are two main potential problems with sweep counts in terms of accuracy. First, there is potential for kangaroos to ‘leak’ out of the reserve ahead of the line(s) and hence not be counted. Second, observers in the line may lose position and/or otherwise be spaced such that not all kangaroos moving through the line are counted. Kangaroos that have moved behind the line of people counting them are recorded in one column (‘positives’) seperately from those that move in the opposite direction back through the line (‘negatives’).

A key issue with sweep counts is the arbitrary nature of deciding whether the count was successful (and hence used in subsequent analyses) or unsuccessful (and hence discarded). The ACT managers are aware of this issue and attempt to deal with it by applying the ‘rules’ and criteria described above, and on the absence of ‘incidents’ relating to the intactness of the line of counters and ‘leakage’ of kangaroos.

Either 2 or 3 sweep counts were conducted at each site during late 2013, and these were often on the same day (i.e. morning and afternoon). These 2 or 3 counts were used to estimate the mean population size and its 95% confidence interval. It does not seem sensible to estimate a 95% confidence interval from only 2 or 3 sweep counts: as for direct counts, we suggest a minimum of 4 (and preferably more) sweep counts be conducted. It would be desirable to replicate the counts on at least different days (rather than morning and afternoon of the same day) so that any daily variation in the number of kangaroos present in the reserve is captured. We note daily variation is unlikely to be an issue in most reserves that are more-or-less isolated by suburbia.

The large number of people (e.g. about 50) required for some sweep counts has meant that they are conducted by a mix of ACT Parks staff, contractors and volunteers. The accuracy of sweep counts are likely to be significantly affected by the wide variation in observer experience and ability (including ability to follow instructions), particularly on larger KMUs where there is greater potential for leakage and animals moving through the line to be missed.

A potentially significant risk with sweep counts is kangaroos being pushed out of the site onto roads and colliding with vehicles. This has not yet happened and without directly observing sweep counts we cannot assign a likelihood of this occurring. Measures are taken to minimise this risk by (a) not sweeping towards a road and by sweeping inwards toward the center of the reserve, (b) where the sweep is beside a road two people move ahead of the count line along the road edge to encourage the kangaroos to move away from the road and in the path of the sweep line, and (c) an experienced wildlife ranger patrols roads during the count to radio through to the sweep leader if any kangaroos approach or cross the road. However, the risk of vehicles colliding with kangaroos must be explicitly considered in the decision to conduct sweep counts (rather than some other count method) at a site and in the planning of the conduct of the sweep count. The current briefing document for sweep count observer (which is given to each participant) states that ‘If it appears that kangaroos are likely to go onto a road, stop the line and report.’ However, other risk-reduction options are possible, including (but not limited to): temporary road signs, temporary reduced speed limits, and temporary road closures.

4.4.3 Walked-line transect counts

Walked-line transect counts have been widely used to estimate the abundance of kangaroos (e.g. Coulson & Raines 1985; Southwell 1994; Clancy et al. 1997; le Mar et al. 2001; Glass 2013). Studies evaluating the accuracy and precision of walked line transect estimates of eastern grey kangaroo abundance in populations of known size indicate that the method is accurate and has reasonable (i.e. ≤ 20%) precision (Southwell 1994, Glass 2013). Importantly, the assumptions underpinning the method, the field procedures for collecting data, and methods for analysing the data, are all well described and widely accepted in the scientific community (Buckland et al. 2001, 2014; Thomas et al. 2009, 2010).

Walked-line transects were conducted in the two largest KMUs, Callum Brae-Isaacs-Hume (2033 ha) and Goorooyarroo (1391 ha), and also at Mulligans Flat Woodland Sanctuary (487 ha), Googong (c. 700 ha but not a cull site) and Wanniassa Hills (498 ha). The methods used to collect and analyse the walked line transect count data (described in Fletcher 2013) seemed highly appropriate. We were encouraged to see that KMUs had been stratified by vegetation type (from aerial photographs) and that sampling was conducted systematically (i.e. along parallel equally-spaced transects) and with the required transect length being calculated in advance, with the aim of obtaining estimates of abundance with precision ≤ 15% (although this may not always have been achieved). The two observers conducting the field work were ‘experienced’ (Fletcher 2013). It is good that the most recent version of program DISTANCE (Version 6.0. Release 2, which has some major analytical advantages over previous versions) was used to analyse the walked line transect data.

Walked-line transects may be considerably cheaper than sweep counts and have a much lower risk of pushing kangaroos onto adjacent roads and hence colliding with vehicles. In view of the limitations and risks of sweep counts (see above), we suggest that walked-line transects be considered for all kangaroo management units in which sweep counts are conducted.

4.4.4 Pellet counts

Pellet counts have been widely used to estimate large herbivore abundances (Marques et al. 2001), including eastern grey kangaroos (Coulson & Raines 1985, Johnson & Jarman 1987, Johnson et al. 1987) and the method can be partitioned into three aspects: (a) pellet accumulation rate estimation, (b) defecation rate estimation, and (c) analysis. When defecation rate is estimated for the population of interest (rather than using an estimate from captive animals) then the method has been shown to be reasonably accurate (Johnson & Jarman 1987).

Pellet counts were used to estimate kangaroo abundances in three KMUs in late 2013: Mt Majura, Kama Nature Reserve and Jerrabomberra East (a planned reserve). Kama Nature Reserve and Jerrabomberra East Reserve are research sites at which kangaroos are not subject to culling: density estimation at those sites is for research purposes. Pellet counts rather than the more preferable direct counts (i.e. direct, sweep and walked line transects) were used at Mt Majura because thick vegetation meant that most kangaroos could not be observed, and at Kama Nature Reserve (155 ha) and Jerrabomberra East (97) because of their connectivity to adjacent rual lease habitats mean animals easily move in and out of the reserve and pellet counts would better represent ‘average kangaroo usage’ than direct counts (Fletcher 2013). We believe that walked line transects could be conducted at Kama Nature Reserve and Jerrabomberra East, and that repeat sampling be conducted on different days and perhaps different times of the day (e.g. midnight, dawn, dusk and mid-day). A methodology for conducting walked-line transects in a smaller area (76 ha) with high densities of eastern grey kangaroos was successfully implemented in part of Wilsons Promontory National Park by Glass (2013). Walked-line transects could also be conducted at night with spotlights (with star pickets with reflectors placed out before the count was conducted).

The size (3.1 m^2) and number (n = 240) of quadrats used to estimate pellet crops at the sites within the Canberra Nature Park seem appropriate in the sense that the estimates of mean pellets had moderate precision (ranging from 13% to 32%). The 21-day accumulation period seems appropriate, any longer and pellets deposited at the start of the interval might have decayed by the end of the interval, and any shorter may decrease the precision of the estimates. It is assumed that observers can differentiate eastern grey kangaroo pellets from those of other macropods. Although swamp wallaby (*Wallabia bicolor*) is currently present at low density relative to eastern grey kangaroos at Mt Majura, if eastern grey kangaroos were culled there then the relative density of swamp wallaby would increase. The absolute density of swamp wallaby might also increase if culling of eastern grey kangaroos increased food availability for the former and the pellets of juvenile feral pigs and some deer can sometimes be mistaken for kangaroo pellets.

Defecation rate can either by estimated empirically or assumed equivalent to other studies (e.g. from captive animals). The latter is likely to be substantially biased because defecation rate will vary with factors including such as season, sex-age class of the population and food availability (Johnson & Jarman 1987, Southwell 1989). Research has indicated that the daily defecation rate of eastern grey kangaroos in Mulligans Flat Woodland Sanctuary and Goorooyarroo KMU varied over short periods (Howland 2008). Empirical estimation of defecation rate, as is currently done by ACT Parks, is therefore preferred. The current approach of using a population of known size (i.e. fenced with open grassland habitat) with apparently similar food availability to the Mt Majura, Kama Nature Reserve and Jerrabomberra East survey areas is appropriate, with the following two caveats. First, there needs to be standardised replication (e.g. n = 4 or 6) of the direct counts used to estimate the number of kangaroos present over the 21-day sampling period (see above). Second, the pellet quadrats should be randomly or systematically located (see above).

The third and final aspect of pellet counts is the analysis. The analyses estimating the number of kangaroos present in Mt Majura, Kama Nature Reserve and Jerrabomberra East from pellet counts are appropriate but should be improved by addressing the following issues. First, uncertainty in the number of kangaroos present in the population of 'known' size should be propagated into the analysis of defecation rate such that the estimate of daily defecation rate has a standard error and 95% confidence interval that is contributed to by the numerator and denominator. Second, the uncertainty in the defecation rate addressed in the previous point needs to be properly accounted for in the estimated number of kangaroos. Current measures of uncertainty (i.e. standard errors and 95% confidence intervals) surrounding the estimated mean abundances of eastern grey kangaroos are overly conservative (narrow) because uncertainty in the estimated defecation rate (from both variation in the direct count and the rate of pellet accumulation) is not considered. This is a straightforward issue to address.

4.4.5 Driven-line transects

The driven-line transect method has only been used once in the Canberra Nature Park before being replaced with walked line transects. There are two key problems with this method. First, sampling along roads is ‘convenience sampling’ (i.e. not a random or systematic sample of the area because roads tend to be on flat areas and on ridges) and hence could provide a highly biased estimate of kangaroo abundance (Marques et al. 2013). Second, kangaroos would be expected to use roads less than surrounding areas because they learn to avoid cars on roads and also because there would be less forage and/or protective shelter there relative to surrounding areas (the former would be the case for gravel roads); kangaroos may also hear the vehicle approaching and move away before they are observed from the vehicle, violating a key assumption of walked-line transect. Marques et al. (2013) proposed a method by which some of these problems could be overcome, but this used GPS telemetry data from a sub-sample of kangaroos and hence would be logistically and financially difficult to use regularly. We believe that walked- line transect should always be used in preference to driven-line transects.

Key conclusions and recommendations

1. The logic and evidence underpinning the KMP is valid but the conservation culling components of the plan are properly adaptive and will be refined as the results of current research and monitoring reduce uncertainty about key parameters such as target densities.

2. Unmanaged kangaroo populations reduce the biomass of ground-layer vegetation which has adverse impacts on some other native species. Therefore culling kangaroos is a valid management action. The current management ensures sustained populations of kangaroos at densities that purport to allow more vegetation and more secure populations of threatened native species.

3. There is published evidence that the current target density of kangaroos (set by modelling at 1 per hectare) does benefit other native plants and animals but managers recognise there are gaps in understanding the details of how temperate grassland ecosystems work as components of it (mostly kangaroo numbers) are manipulated. Current projects conducted by ACT staff and PhD studies underway at ANU should fill some of these knowledge gaps.

4. One key question is whether the density of 1 kangaroo per hectare is the ‘correct’ target for all times, all nature reserves and under all environmental and biological conditions. We suspect it will be too high (100 large herbivores per km^2 is still a very high density relative to other systems and species, and certainly constitutes no threat to the sustainability of the kangaroos). The

results of an ACT project currently being conducted will will help identify whether the average density set is the best or at least within the optimal range of densities.

5. Each nature reserve is a sort of habitat island with a variety of assets and threats, with varying degrees of connection between the reserves. The KMP might be supported with a set of individual site plans, with kangaroo management as but one action within each plan. Site-specific monitoring will allow management to be fine-tuned.

6. ACT managers have two options to lead to this site-based approach. They can nominate a number of nature reserves to be managed to allow the rare native species to be maintained with resilient populations and achieve it as efficiently as possible (cost minimisation). Or they can set a fixed annual budget and determine how many nature reserves can be effectively managed within the budget (benefit maximisation).

7. The methods being used to count kangaroos and estimate densities are sound, but we recommend the following four changes. (i) direct and sweep counts need more replication, (ii) uncertainties in components of direct, sweep and pellet count methods should be addressed in analyses, (iii) a team of trained professionals (i.e. staff and/or contractors) should be the core for all counts, although we acknowledge the wider social and public relations benefits of including volunteers, and (iv) the counts should be conducted as close as possible to the intended cull. Further, consideration should be given to conducting a second post-cull count perhaps six months later, at least in a subset of reserves.

8. Sweep counts have several potentially significant problems, including traffic problems if kangaroos flee the counters. We recommend ACT consider either replacing this method with direct or walked-line transects, or if this is not possible to use core trained staff as above.

9. It would be valuable to conduct a trial to compare the costs, accuracy, and precision of the four counting methods across different habitat types and kangaroo densities.

10. The methods used to conduct kangaroo counts should be described in standard operating manuals that can be updated as required. This would ensure continuity for a program that will have to be sustained long after current staff have left.

11. Publication of research by ACT staff and others should be facilitated because this work is potentially of high standard and of interest to a wider audience, as well as providing ACT decision-makers and other stakeholders with the confidence of peer review.

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