Has the last 15 years of kangaroo management in the ACT achieved its key objectives?

Luke O'Loughlin*, Miles Keighley & Claire Wimpenny

Background Buru / Eastern Grey Kangaroo are managed in the grassy ecosystems around Canberra (Ngunnawal Country) to achieve 2 key objectives:

(1) maintain kangaroo populations at sustainable target densities

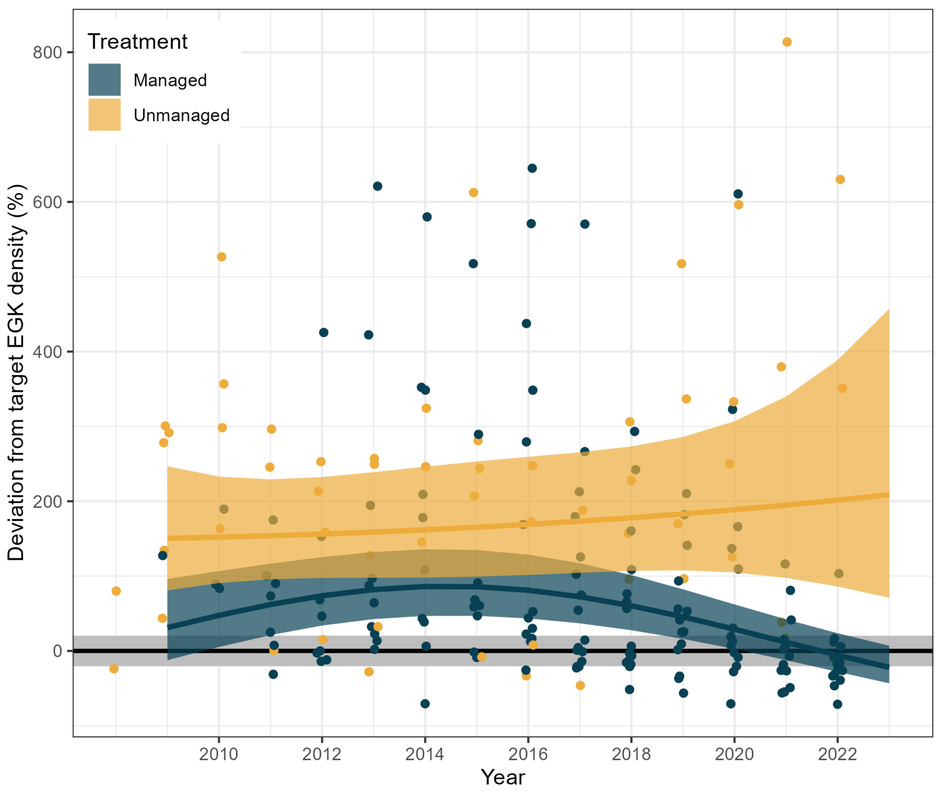
(2) minimise the negative effects the species by maintaining grass height within a target range

We use annual monitoring of **kangaroo numbers** and **grass condition** to *trigger* management actions……

……but are those management actions *resulting in* **kangaroo numbers** and **grass condition** that we want ???

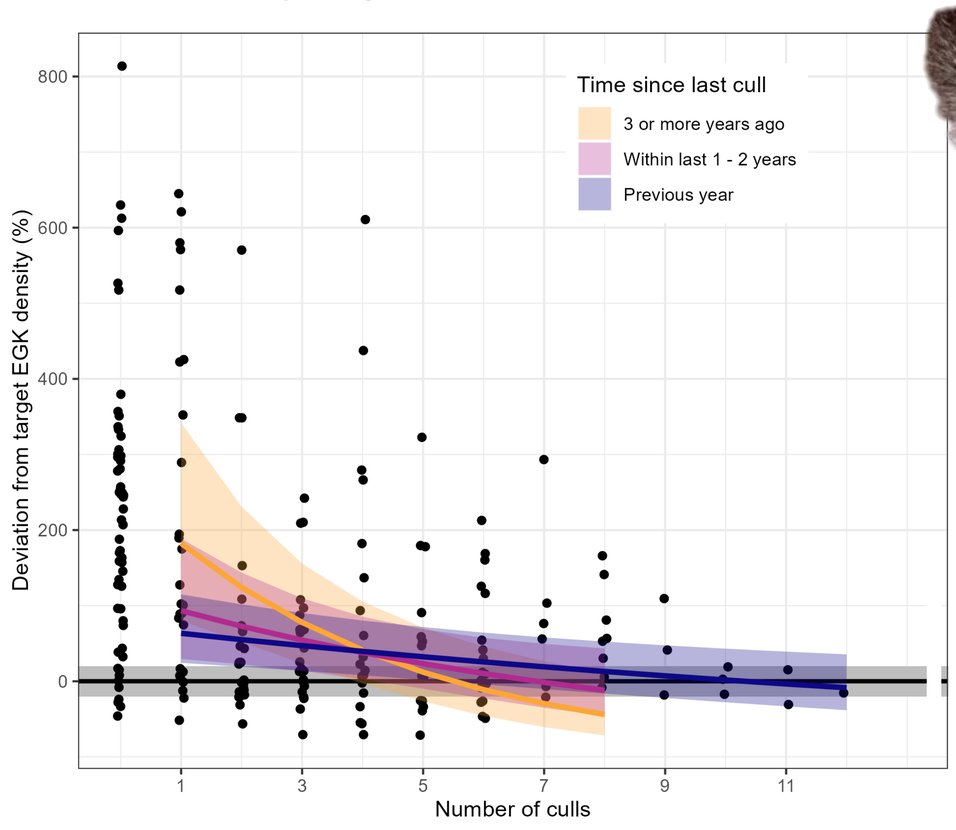
Results Objective 1

How closely does the kangaroo **density achieved** by management match the **density targets?**



- Average **Unmanaged** population densities have been consistently 150-200% greater than targets
- Average **Managed** population densities were around 100% greater than targets, and have now declined overtime to be within targets (0 deviation)

What aspects of **management actions** best predict that **density targets are achieved?**

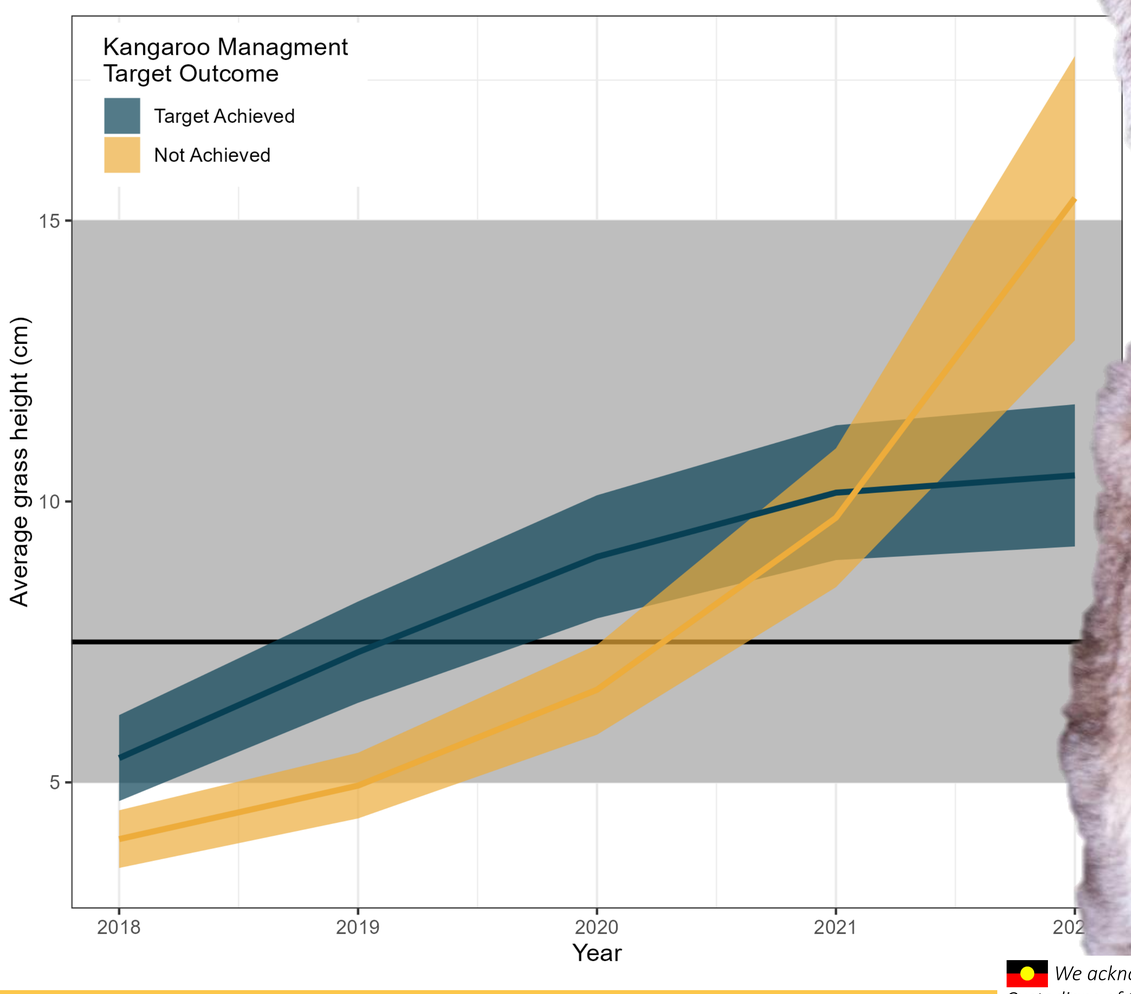


- **Achieving density targets** (low deviation from targets) was a product of **frequency** and **timing**
- More culls = higher likelihood achieving targets
- No annual gaps in culls = most important for the first **4 culls.**

Results Objective 2

Does achieving target kangaroo densities influence **grass height?**

- Average grass height where kangaroo density **targets have been achieved** has been consistently within desirable range
- Average grass height where kangaroo density **targets have NOT been achieved** was lower in 2018-2020 and outside of the desirable range in drought years
- In 2021-2022, most areas have kangaroo densities within targets, with the few areas where they are not within target, being *on average* comprising tall invasive grasses



Conclusion Kangaroo management in the ACT has been effective at achieving its two key objectives – especially in recent years. Achieving these outcomes is the result sustained management effort to reduce overabundance.

We acknowledge the Ngunnawal People as the Traditional Custodians of the land we completed this work. We pay our respects to Elders past, present and future, and acknowledge their continuing culture and connection to Country.

Acknowledgements *Many thanks to the countless folks who have worked with the ACT Government to count kangaroos, manage kangaroos, and measure grass since 2008*

From: [redacted]
Sent: Fri, 15 Dec 2023 17:25:51 +1100
To: Driver, Kyeelee
Subject: RE: Follow up - ACT kangaroo management

You don't often get email from [redacted]. Learn why this is important

Caution: This email originated from outside of the ACT Government. Do not click links or open attachments unless you recognise the sender and know the content is safe. Learn why this is important

Kyeelee this is gold, thank you very much.

Have a good break, I'll let you know how the review is coming along in the new year.

Sarah

From: Driver, Kyeelee <Kyeelee.Driver@act.gov.au>
Sent: Friday, December 15, 2023 12:10 PM
To: [redacted]
Subject: Follow up - ACT kangaroo management

OFFICIAL

Hi Sarah,

Once again thank you for taking the time to seek my feedback on kangaroo management in the ACT. Please see below links/information on the *Animal Welfare Act 1992* and the *ACT Wellbeing Framework.*

- Animal Welfare Act 1992 (the Act)

  In 2019 the Act was amended to reflect that the main objects of the Act *are to recognise that—*

a) animals are sentient beings that are able to subjectively feel and perceive the world around them; and

b) animals have intrinsic value and deserve to be treated with compassion and have a quality of life that reflects their intrinsic value; and

c) people have a duty to care for the physical and mental welfare of animals.

In amending the Act to recognise 'sentience' the 'Explanatory Statement' stated:

- *....animal welfare encompasses all aspects of animal health and wellbeing, and all people have a responsibility to take reasonable measures to protect the welfare of animals in all human-animal interactions.*
- *Animal welfare in a modern context describes how an animal is coping both mentally and physically and recognises that animals are sentient beings that have the capacity to feel and perceive things. Achieving good animal welfare relies on recognising the five freedoms of animals, which are set out in the Strategy, and encompass at a high level*

the freedom from hunger and thirst, freedom from discomfort, freedom from pain, injury or disease, freedom to express natural behaviour, and freedom from fear and distress. It also relies on recognising that animals deserve having a life worth living, in terms of both physical and mental wellbeing.

- The amendments aim *to give effect to this contemporary understanding of animal welfare and to recognise sentience and that animals have a right to both mental and physical wellbeing. The concept of animals as sentient beings reflects that animals have the ability to subjectively feel and perceive the world around them and are capable of experiencing both positive and negative states*.

- ACT Wellbeing Framework

  The ACT Wellbeing Framework categorises areas (domains) that have been identified as consistently contributing to the overall quality of life for Canberrans. Many of the domains have close connection with each other. 'Wellbeing Impact Assessments' are embedded into ACT Government Budget and Cabinet processes.

  To my mind kangaroo management in the ACT may impact the following 'domains':
  - Climate and Environment (Healthy and resilient natural environment; Connection to nature) – *Conservation*
  - Safety (Road safety) – *Human safety/ Animal welfare*
  - Health (Mental health, Healthy lifestyle) – *Animal welfare/ Conservation*
  - Governance and institution (Trust in government, Feeling that voice and perspective matter) - *Animal welfare/ Conservation*
  - ? Social connection (Levels of volunteering?) - *Animal welfare/ Conservation*
  - ? Identity and belonging (Connection to Canberra, Valuing Aboriginal and Torres Strait…) - *Animal welfare/ Conservation*

Please do not hesitate to contact me if you have further questions.

Wishing you a safe and (almost if you have to work) relaxing Christmas/ New Year period.

Regards,

Kyeelee

Dr Kyeelee Driver BVSc | Acting Chief Veterinary Officer
T 02 6207 2357 | M [redacted] | Kyeelee.driver@act.gov.au
Biosecurity and Agriculture Policy| Environment, Planning and Sustainable Development Directorate | ACT Government
GPO Box 158 Canberra ACT 2601 | www.environment.act.gov.au

I acknowledge the Ngunnawal people as traditional custodians of the ACT and recognise any other people or families with connection to the lands of the ACT and region. I acknowledge and respect their continuing culture and the contribution they make to the life of this city and this region.

From: [redacted]
Sent: Thursday, December 14, 2023 9:00 AM
To: Driver, Kyeelee <Kyeelee.Driver@act.gov.au>
Subject: ACT kangaroo management

Hi Kyeelee

I hope you are well. I'm carrying out the external review of the ACT kangaroo management plan, at the request of the Conservator.

I am hoping to line up a time to talk to you (online, via zoom) about some aspects of the plan and its operation.

Do you have a spare hour either tomorrow at 4pm, or Monday avo next week, or anytime on Tuesday next week?

Many thanks
Sarah

Professor (Wildlife Conservation) Charles Darwin University
Honorary Professor, The Australian National University
Principal Research Fellow, University of Queensland
Biodiversity Councillor
[redacted]

From: [redacted]
Sent: Mon, 18 Dec 2023 19:23:47 +1100
To: Wimpenny, Claire; Keighley, Miles
Subject: RE:

Great, thanks Claire. Let catch up tomorrow at 2 then?

I also thought the PCS folks should be consulted. Are they around this week?

From: Wimpenny, Claire <Claire.Wimpenny@act.gov.au>
Sent: Monday, December 18, 2023 7:15 PM
To: [redacted]; Keighley, Miles <Miles.Keighley@act.gov.au>
Subject: RE:

OFFICIAL

Hi Sarah,
Yes, I could do either tomorrow afternoon anytime between noon and 4.45pm or Wednesday 1-3pm. You will see I have sent Mark and Sal a meeting invite for Wednesday afternoon, that looks like the only free hour in their calendars that day. I agree that you should definitely talk to them. The only other people on that internal list that I think are a strong maybe are the PCS staff? But maybe ask Mark and Sal what they think.
That's completely fine if you want to push back the date for the draft and also the final report if required. What dates will work for you? After this week [redacted] and I imagine Sal/Mark and others that will read the draft will be similar, so we could make the draft due then if that suits? I'm just conscious of not pushing it into any upcoming commitments you might have? Based on the original dates, I was planning to review your draft [redacted]. Still happy to do that if you want to get it wrapped up earlier. Let's chat about it tomorrow/Wed.

Thanks so much for the list of questions, that's really helpful. I can dig out some relevant information before we chat.

And just a heads up on the AWAC sub-committee – I'm meeting with them again this Wednesday to chat through some questions they have about the current kangaroo management programs, then they are keen to talk to you, so probably early Jan if that suits?

Regards,

Claire Wimpenny

Senior Ecologist
Office of Nature Conservation | Environment, Heritage and Water Division | Environment, Planning and Sustainable Development Directorate (EPSDD) | ACT Government
Phone +61 2 6205 8252 | Email claire.wimpenny@act.gov.au
480 Northbourne Avenue, Dickson ACT 2602| GPO Box 158 Canberra ACT 2601 | www.environment.act.gov.au

From: [redacted]>
Sent: Monday, 18 December 2023 6:25 PM
To: Wimpenny, Claire <Claire.Wimpenny@act.gov.au>; Keighley, Miles <Miles.Keighley@act.gov.au>
Subject:

Hi Claire, Miles

Can we line up a time to talk either tomorrow avo after noon, or on wed after 11.30. Maybe wise to schedule 2 hours if poss. I'm also going to attach a list of the things I am hoping to talk about, in case there's anything that would benefit from a heads up. Claire – one thing id like to talk about is pushing out the date for when I send you a draft. Im aiming to have the bulk of the review down on paper by Friday, but there will be some loose ends and I'd like the time to polish it up a bit. I don't imagine anyone is going to be reading this doc until early Jan?? I have found the interviews – which have been so very valuable – do chew up a lot of time.

Below is a table with the people I have talked (or will have, by Wednesday). Are there any important omissions? (Including anyone who will feel offended if left out).

There are more people I would like to talk to, but we are running out of time. However, I would like to have an hour with Sally and Mark – is that possible this Wednesday as well?

sarah

Monday 4th December 2023, 5:30pm - 480 Northbourne Avenue, Ground Floor, Room 00.025	
Organisation	**Name**
Woodlands and Wetlands Trust/Ginninderry Conservation Trust	[redacted]
Mt Taylor Parkcare Group	
Friends of Aranda Bushland	
Mt Ainslie Weeders	
Friends of Grasslands	
Friends of Grasslands	
Friends of Mt Majura	
Friends of Mt Majura	

Tuesday 5th December 2023, 5:30pm - 480 Northbourne Avenue, Ground Floor, Room 00.031	
Animal Protectors Alliance	Sch 2.2(a)(ii)
Animal Protectors Alliance	
Animal Liberation ACT	
Animal Liberation ACT	
Save Canberra's Kangaroos	
Save Canberra's Kangaroos	
Animal Defenders Office	
ACT Wildlife	
Individual Meetings - Sarah contacted directly	
RSPCA	
RSPCA	
Individual Meetings - Sarah contacted directly	
Organisation	
Rural Landholder	
Rural Landholder	
Sch 2.2(a)(x)	
Rural Landholder	
Rural Landholder	
Sch 2.2(a)(x)	
Ecologists - Sarah contacted directly	
Ecologist	
Ecologist	
Ecologist	
Ecologist	
Ecologist	
ACT gov staff	
ONC Macropod Team	Claire Wimpenny
	Miles Keighley
Cull effectiveness evaluation	Luke O'Loughlin
Offsets	Brett Howland
Offsets	Steph Pulsford
Veterinarian	Kyeelee Driver
Shooting Contractor	Sch 1 1.14

contents to any other person.

From: Keighley, Miles
Sent: Mon, 18 Dec 2023 22:59:48 +0000
To: Smits, Jennifer; Wimpenny, Claire; Sarah Legge
Subject: RE: Guest ArcGIS online for Sarah Legge

Thanks heaps for setting this up Jen,

I've added two maps to the group which I hope will be informative for Sarah:

- *HerbageMass_Monitoring Map wData* shows HM monitoring polygons and plot locations as well as their grass height relative to the 5-15 cm thresholds.
- *CNP/Offsets Monitoring results* shows results for various monitoring programs, including more detailed results from herbage mass monitoring at the plot scale. Not all layers have symbology set up in an informative way so if there's something you'd like presented differently, we can change it.

Cheers,
Miles

From: Smits, Jennifer <Jennifer.Smits@act.gov.au>
Sent: Monday, December 18, 2023 1:38 PM
To: Keighley, Miles <Miles.Keighley@act.gov.au>; Wimpenny, Claire <Claire.Wimpenny@act.gov.au>;
Subject: RE: Guest ArcGIS online for Sarah Legge

OFFICIAL

Ok, Sarah I have sent you an email to set a password.

Miles, can you please add any data and maps to this new AGOL Group: EHW EGKCNSMP Review 2023 that you want to share with Sarah.

https://actgov.maps.arcgis.com/home/group.html?id=1838ee6556cb4889a0f9fbf4665eaca0#overview

Miles I have made you a group manager so you can add other people and other data.

Jen

From: Keighley, Miles <Miles.Keighley@act.gov.au>
Sent: Monday, December 18, 2023 11:40 AM
To: Smits, Jennifer <Jennifer.Smits@act.gov.au>; Wimpenny, Claire <Claire.Wimpenny@act.gov.au>;

Subject: Guest ArcGIS online for Sarah Legge

Hi Jen,

As discussed, could we set up Sarah (cc'd here) with a guest ArcGIS Online account? This is so that she can view 'Monitoring Map 2023' which has the herbage mass monitoring unit polygons. The map is currently part of the Herbage Mass Working Group, but I think the monitoring map is all she needs from there, so maybe we can set up a separate group called *EGKCNSMP Review 2023* with this map and potentially others that she might need.

Claire and Sarah, Jen needs to know how long access will be required for. Would you be able to suggest an end date?
Are there any other maps or spatial data you'd like access to for the purpose of the review Sarah?

Cheers,
Miles

Miles Keighley (he/him)

Ecologist
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Phone +61 2 6205 8252 | Email miles.keighley@act.gov.au
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Conservation Research Website | EPSDD Environment Science Platform | View our story map collection here!

I acknowledge the Ngunnawal people as traditional custodians of the ACT and recognise any other people or families with connection to the lands of the ACT and region. I acknowledge and respect their continuing culture and the contribution they make to the life of this city and this region.

From: Wimpenny, Claire
Sent: Tue, 19 Dec 2023 07:14:18 +0000
To: [redacted]
Cc: Keighley, Miles
Subject: docs
Attachments: Kangaroo Density Estimation Trial 2.doc, EGK Limited Area Culling Trial Research Report final draft.docx, Morgan and Pegler 2010 Culling roos to simulat predation Macropods Ch30.pdf, Kangaroo cull summary 2009 to 2023 Update of Figure 33.xlsx

OFFICIAL

Hi Sarah,
Here are some of the docs you are looking for.
I can't find anything about looking at the replication of sweep and direct counts but it was definitely done in response to the 2014 review recommendations. I'll ask Mel when she's back. Actually, is there anything you would like to chat to Mel about? She has been away for the last couple of months but will be back in Jan.
I have most of the rural cull records, just missing a couple of years, so I will send that in the next few days. Also, did you want the number of PY killed in the conservation cull? The attached file just has adults but I can add PY to it without too much trouble.

Miles – I found a digital copy of the Morgan and Pegler paper so could you please just have a look for this one at DOB:

- Fletcher D 2006b. What process limits the high-density populations of eastern grey kangaroos at Gudgenby and other local sites? in *Caring for Namadgi: Science and People*, ed. National Parks Association of the ACT (National Parks Association of the ACT, Canberra.):pp. 61–77.

Regards,

Claire Wimpenny

Senior Ecologist
Office of Nature Conservation | Environment, Heritage and Water Division | Environment, Planning and Sustainable Development Directorate (EPSDD) | ACT Government
Phone +61 2 6205 8252 | Email claire.wimpenny@act.gov.au
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ACT Government

ESTIMATING KANGAROO DENSITY:

A COMPARISON OF METHODS FOR EASTERN GREY KANGAROOS IN THE PERI-URBAN ENVIRONMENT

DRAFT

ENVIRONMENT, PLANNING AND SUSTAINABLE DEVELOPMENT DIRECTORATE

JANUARY 2017

CONTENT

EXECUTIVE SUMMARY

INTRODUCTION

The Eastern Grey Kangaroo (*Macropus giganetus*, hereafter 'kangaroo') is the largest indigenous mammal in the ACT, both individually (males up to 100 kg) and in terms of their biomass (up to 25 tonnes per hectare). As the overwhelmingly dominant herbivore in lowland grassy ecosystems, kangaroos occupy a central place in the ecology of such ecosystems due to a strong preference for feeding on grass and other monocotyledonous species (Billing, 2007; Davis et al., 2008; Jarman and Phillips, 1989). Kangaroos may be 'ecosystem engineers' based on the definition by Jones *et al*. (1997) and Wilby *et al*. (2001) based on their ability to modify habitat both for conspecifics and other species. In the broader landscape, kangaroos are preyed upon by dingoes (*Canis lupus*), wedge-tailed eagles (*Aquila audax*, Fuentes et al., 2007) and introduced red foxes (*Vulpes vulpes*; Fletcher, 2006; Jarman and Wright, 1993; Robertshaw and Harden, 1989). Their carcasses provide food for a diversity of scavengers (Barton et al., 2013a; Barton et al., 2013b; Barton et al., 2011).

In the modified and highly fragmented areas of kangaroo habitat found within Canberra Nature Park, many natural processes surrounding kangaroo ecology are impeded or do not occur. Whilst the number of kangaroos killed as a result of vehicle collisions likely greatly exceeds 4,000 annually (based on the number attended by rangers, ACT Government unpublished data), the absence of natural predation allows populations to increase by as much as 40% each year in some areas. Kangaroos graze selectively and, in places, heavily enough to have a negative effect on biodiversity by modifying the habitats of birds (Neave and Tanton, 1989), reptiles (Dorrough et al., 2012; Howland et al., 2014; Manning et al., 2013), invertebrates (Barton et al., 2011) and plants (McIntyre et al., 2014; Meers and Adams, 2003; Neave and Tanton, 1989). In the absence of landscape connectivity, even a short period of overgrazing by kangaroos can result in a permanent loss of native species from isolated grassy ecosystems. The impacts of Eastern Grey Kangaroos in lowland grassy ecosystems are thus managed annually by assessing annually determined population density relative to site-specific target densities set based on vegetation assessment and site-specific conservation objectives. The policy for kangaroo management in the ACT is detailed, alongside the relevant literature, in the ACT Kangaroo Management Plan (KMP; ACT Government, 2010).

Kangaroo density in the ACT is estimated, where feasible, in discreet areas referred to as a kangaroo management units (KMU). Kangaroo management units comprise any area of actual or potential kangaroo habitat within some form of movement barrier (e.g. suburb boundaries, waterbodies, high speed roads) and may include a variety of land tenures (e.g. nature reserve, rural lease, horse paddock). The presumed stability of populations within a KMU is supported by observations of high site fidelity by kangaroos fitted with GPS collars within Canberra Nature Park (ACT Government, unpublished data). Accurate estimates of kangaroo density within individual KMUs is critical to calculating the number of kangaroos to be removed each year through culling (ACT Government, 2016). A number of methods of estimating wildlife density across such small scale sites (often < 1,000 ha), including that of kangaroos specifically, have been identified in the scientific literature including both direct counts and those involving some form of sampling approach (Coulson and Raines, 1985; Perry and Braysher, 1986). The relative suitability of a given technique within any one site however depends on a number of factors, including site area, vegetation density, it's isolation from adjoining areas of habitat and the behaviour or 'flightiness' of the kangaroos themselves. Whilst each of the methods utilised by the ACT Government in counting kangaroos are supported by the literature, the suitability and precision of these methods within the specific areas being counted has not been assessed (Parkes and Forsyth, 2013). As such, we undertook to perform our own assessment of the practicality, accuracy and precision of four kangaroo estimation techniques across a range of sites and kangaroo densities typical of those routinely assessed within the ACT. In particular, two 'sampling' methods – namely faecal pellet counts (Perry and Braysher, 1986) and walked line transect counts undertaken according to the 'Distance sampling' technique

(Buckland et al., 2007; Buckland et al., 2001; Thomas et al., 2010), were compared to the direct and sweep 'total count' methods, which are considered an accurate assessment of kangaroo density on small sites (Coulson and Raines, 1985).

METHODS

SITES

Kangaroo density was estimated by a 'total count' method (direct or sweep count, see below) as well by both the 'faecal pellet' and 'distance sampling' approach (Caughley, 1977). Sites assessed were chosen based on their being considered suitable for estimating abundance using multiple count methods. The characteristics of each site are summarised in Table 1 and maps of the study sites are shown in Figure 1. All counts were undertaken in the winter or early spring of 2014 and animals were counted only if they were 'independently mobile', i.e. young in the pouch were not considered in population estimates. The timing of counting reflected a period of relatively stable population dynamics for Eastern Grey Kangaroos in the temperate zone, after the majority of young kangaroos permanently leave the pouch (around November) and before the die-off of largely sub-adult kangaroos as a result of food limitation in late winter and early spring (Fletcher, 2006).

DIRECT COUNTS

Direct counts are the most accurate and straightforward of the count techniques used by ACT Government for estimating kangaroo density in Canberra Nature Park. They involve a small number of observers, usually working in 2-3 groups of 1 or 2 people each, following a pre-defined 'recipe' for navigating the KMU to count every kangaroo quickly and with minimal disturbance to animal groups. The formulation of a count 'recipe' involves a number of visits during different weather conditions and at different times of year, to gain an understanding of the preferred routes and both grazing and resting areas typically used by kangaroos. Knowledge of where different groups are likely to move to if disturbed helps to divide the KMU into sections, one of which is counted by each observer. Minimising movement between sections assists with observers being able to keep track of counted and uncounted animals throughout the count period (Figure 2). Ideally, counting procedures are overseen by an additional person located at a vantage point (e.g. on top of a hill) who assists with coordination of the count overall, and who tracks the movement of any displaced kangaroos to ensure they do not get missed or counted twice. The counting operation is largely dependent on communication between groups via VHF radio and the use of detailed maps marked with grid references. The observers' knowledge of the site, the topography (e.g. any 'false peaks' on hilly areas or low lying areas not visible from marked tracks where kangaroos may hide) and any relevant features in the landscape is also necessary for accuracy and to aid communication between groups. Minimising the time spent counting the site is largely beneficial in avoiding confusion caused by kangaroos moving between count sections, and so opportunities for increased efficiency should be incorporated into the count 'recipe' for future years. Four repeat counts were undertaken for this study and the mean and standard error of the four counts is reported.

SWEEP COUNTS

Sweep counts were based on the 'drive count' method previously described by Raines (1982) and Coulson and Raines (1985). Briefly, sweep counts involved a number of people forming a line which stretched across the width of one end of the site to be counted. The count began when the line of observers began walking across the site as a line, maintaining visibility to the person on either side. Observers counted any kangaroos which passed through the line between themselves and the person on their left, noting the direction of movement such that kangaroos passing through the line multiple times (i.e. those which moved from the counted area behind the line back into the area to be counted; Figure 3) could be subtracted at the end. The person in the furthest right position also recorded any animals which passed

on their right between themselves and the KMU boundary (usually a road or suburb boundary). The spacing between people in the counting line was allowed to vary as necessary to allow the maintenance of visible contact between participants regardless of changes in vegetation density and topography.

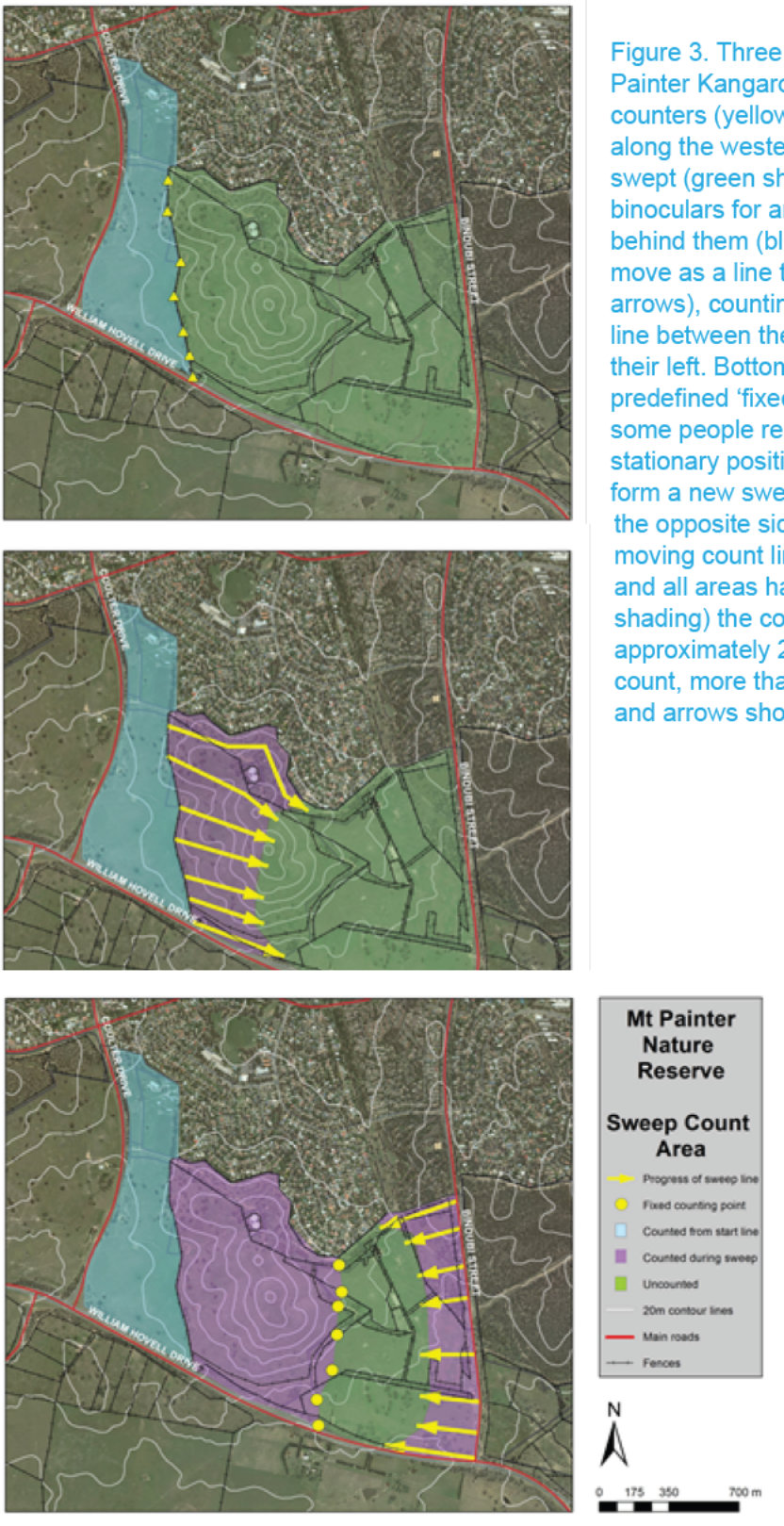

Figure 3. Three stages of a sweep count at Mt Painter Kangaroo Management Unit. Top: counters (yellow triangles) position themselves along the western border of the area to be swept (green shading) and check with binoculars for any kangaroos in the leased land behind them (blue shading). Middle: counters move as a line through the reserve (yellow arrows), counting kangaroos which cross the line between themselves and the person on their left. Bottom: as counters reach the predefined 'fixed positions' (yellow circles), some people remain in place counting from stationary positions and the remaining people form a new sweep count line beginning from the opposite side of the site. When the new moving count line meets the stationary line, and all areas have been counted (purple shading) the count is complete. Note that approximately 24 people are required for this count, more than is indicated by the triangles and arrows shown.

Table 1. List of sites (kangaroo management units, KMU) included in the methods trial and a description of their vegetation, topography and levels of public use.

Site Name	Area	Description
Dunnarts Flat	112 ha	Small area contained within a 'leaky' kangaroo exclusion area of Goorooyarroo Nature Reserve. Animals are known to leave readily through gaps in the fence during sweep counts. Vegetation is approximately 50% open grassland and 50% woodland with reasonably dense understory. The topography is gently sloping for the most part. Limited public visitation.
Farrer Ridge	202 ha	KMU comprises almost entirely of Nature Reserve. Surrounded by high speed (80 km/h) roads on two sides and a suburb to the north. Mostly wooded with limited mid-story. Some open areas under powerlines. Gentle topography for the most part. Regularly used by the public for walking dogs.
Gungaderra	342 ha	KMU comprises almost entirely of Nature Reserve, although some areas are grazed by cattle for fire hazard reduction. Surrounded by high speed (80 km/h) roads on two sides and suburb on two sides. Mostly open and grassy with a small area of dense woodland. Intermediate topography. Little use by the public.
Mulanggari	184 ha	KMU comprises almost entirely of Nature Reserve, although some areas are grazed by cattle for fire hazard reduction. Surrounded by high speed (80 km/h) roads on two sides and a town centre to the north. Mostly open and with scattered trees. Generally flat with few hills. Little use by the public.
Jerrabomberra East	233 ha	KMU comprises Nature Reserve in ACT as well some privately owned areas and adjacent NSW land. Included due to highest recorded kangaroo density in ACT. Almost exclusively grassland. KMU is continuous with other suitable habitat however kangaroos are rarely observed to use areas outside of the KMU – likely due to perceived predation risk (culling) or avoidance of cattle. Area is mostly flat with one central hill. Little use by the public.
Wanniassa Hills	496 ha	KMU comprises Nature Reserve, horse paddock and some privately owned land. Bordered by high speed roads and suburbs. Area has complex topography and is wooded with variable mid-story. Reasonable public use for jogging and walking dogs.

avoid kangaroos being 'spooked' ahead where the site was open or flat. Observers wore high visibility vests to aid with maintaining constant visual contact with the people on either side, although this was removed for brief periods where people were required to be less conspicuous to allow kangaroos to pass calmly through the counting line.

Due to the close proximity of many urban sites to suburbs or high speed roads, the 'drive count' method was modified such that two lines counted toward the centre of the count area, rather than one counting line continuing the full way through the site and risking herding kangaroos outside the KMU boundary. In practice, the more complex end of the reserve was undertaken initially using all available counters (to allow closer spacing) and then at an appropriate point a subset of these counters formed a fixed counting line (with maximum possible spaces between individuals) which remained stationary whilst continuing the count as previous (i.e. counting to their left). The remaining counters were ferried to the far end of the site where they formed a new counting line spanning the width of the area. This line moved from the far end of the site back toward the stationary line, recording animals in the same way as previously, and when the moving and stationary count lines met the count was considered complete (Figure 3).

Sweep counts generally involved a minimum of 20 people, largely community volunteers, in addition to 2-4 'team leaders' who were experienced in the method and who coordinated their section of the counting line. As many people as possibly carried VHF radios to aid communication along the line, although the majority of communication occurred between team leaders to ensure the channel was free to report and quickly rectify any incidents which may nullify the count or be of a safety concern for people or animals. At some sites, it was also found to be beneficial having experienced supervisors navigating the site in vehicles to check the relative distances between observers at either end of the line. More recently, the use of smart phone apps such as 'Glympse' have also been employed to allow team leaders at different positions along the line to visualise the relative position of themselves compared to other parts of the line to assist in keeping the counting line straight. Major problems result from counts where individual counters lose visual contact with the people to either side of them. This can result in either large gaps in the line – allowing kangaroos to pass through without detection; or else overlaps in the line where kangaroos effectively pass through two lines of counters (one stretching left and one stretching right in an effort to rejoin one another) and subsequently get counted twice (Figure 4).

Four repeat counts were undertaken for this study (two counts per day over two days) and the mean and standard error of the four counts is reported.

FAECAL PELLET COUNTS

The faecal pellet count method used in this report was comparable to that used previously in the ACT by Perry and Braysher (1986) with some modifications. Briefly, up to 16 paired 100 m transects 80 m apart were placed randomly within vegetation strata (based on canopy cover; Wimpenny et al., 2015) such that sampling was representative of the vegetation across the site. Faecal pellets were cleared from 15 quadrats (1 m radius) at 6 m intervals along each 100 m transect on Day 1 of the survey period. On approximately Day 21, quadrats were revisited and any new pellets deposited were counted to determine the number of pellets deposited per hectare per day within each vegetation strata. Heavy rain events prompted the process to be re-started since the movement of pellets across the ground can have substantial impacts on density estimations. An identical procedure was undertaken within sites of known kangaroo density to give a temporally relevant defecation rate (pellets per kangaroo per day) to allow for changes in mean defecation rate as a result of climate-driven food availability. Defecation rates were found to differ markedly between sites within years (301 - 980 pellets per kangaroo per day) and thus this data was rejected and the published defecation rate of 493 based on direct observations (Johnson et al., 1987) was applied instead. The number of kangaroos per vegetation strata was thus estimated and extrapolated across the site to give a total population estimate for the KMU. Density was estimated as the mean ± the

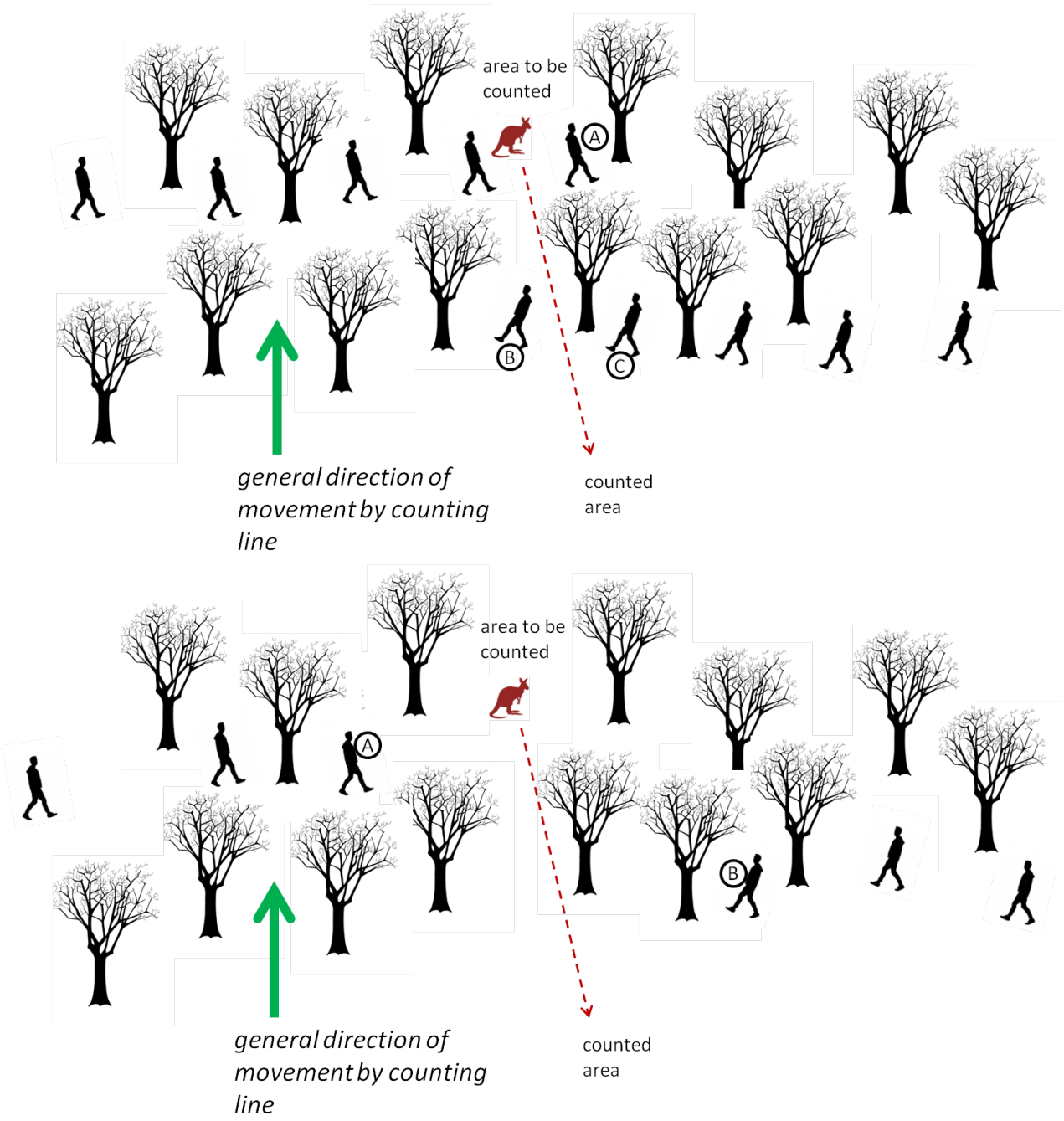

Figure 4. Two scenarios to avoid during a sweep count. Top: two individuals in the counting line ('A' and 'B') have lost visual contact and are moving perpendicular to the general direction of movement (right and left respectively) to try and locate one another. As a result of 'A' being further forward than 'B', the two lines cross and a kangaroo could potentially pass through both lines getting counted on the left of both person 'A' and person 'C'; resulting in an over-count. Bottom: individuals 'A' and 'B' have lost visual contact and 'B' can no longer knowingly count any kangaroo which crosses between himself and 'A'. Kangaroos could pass through this gap undetected resulting in an under-count.

standard error based on the variability in the number of pellets accumulated along transects (CHECK) within the same vegetation type. The error introduced by the use of a single published defecation rate is not reflected in our measurements.

WALKED LINE TRANSECT 'DISTANCE' SURVEYS

Distance sampling estimates population density by calculating a 'detection function' to account for the decreased likelihood of observing an object as its distance from a point or line increases. In this sense, it provides an estimate of both the animals which were observed, and those which were not. The assumptions behind the model rely on all animals on the transect line being detected (i.e. the probably of seeing an animal at zero distance is 100%, or 1; Figure 5), animals are detected before any 'reactive' movement resulting from the observers presence, and that the transect lines are located randomly relative to the distribution of animals across the landscape (Buckland et al., 2007; Marques et al., 2013). In our application of this method a kangaroo group was the counted object and a separate calculation for average group size (adjusted according to the distance at which it was observed) was part of the analysis in the Distance program (Thomas et al., 2010). As such, observers recorded the distance and bearing to each kangaroo group from his or her position on the transect. Kangaroo group size and the location of the observer on the transect at the time of the observation (i.e. the UTM grid coordinates) were also recorded. Distance, bearing and group size measurements were made with a laser rangefinder accurate to ± 1 m for the southern hemisphere (TruPulse 360R or Newcon 4000 CI), grid coordinates were recorded on a handheld GPS (Garmin GPSMap 62s), and data was recorded into a hands-free voice recorder (Olympus VN-711PC) and later transcribed.

An analysis of data collected according to similar methods in 2013 indicated that approximately 40 km of transects should be surveyed on an average site to achieve a coefficient of variation of less than 15% (p 242, Buckland et al., 2001), which was nominated as our minimum desired accuracy level. Transects covered the full extent of the site (i.e. started at the very edge of a KMU and ended at the very edge of a KMU, rather than at a perimeter fence or similar; Figure 6), were parallel and orientated north-west to south-east to avoid surveyors experiencing impaired visibility as a result of walking into the winter morning sun in either direction. Transects were often quite close to one another (< 50 m) in small reserves, so to avoid error introduced as a result of counting animals which were 'flushed' from a previous transect no two transects closer than 600 m were surveyed on the same day. Groups of transects to be walked as a 'group' on one day were colour coded on maps provided to surveyors. Surveys were undertaken within three hours of first light to limit detection bias resulting from the increased likelihood of kangaroos laying down or retreating to more heavily wooded areas towards the middle of the day. Where large groups of kangaroos were observed at distance (> 10 animals), group sizes less than 10 were recorded arbitrarily to achieve the same total during data entry to better reflect group sizes likely to have been observed should kangaroos have been recorded from a closer vantage point. Coupled with a policy to not record kangaroo groups estimated to be > 200 m perpendicularly from the transect line, these two modifications to the method described by Buckland *et al.* likely reduced the need to truncate data prior to analysis (Buckland et al., 2001).

Post-stratification of kangaroo groups by vegetation type (Wimpenny et al., 2015) was undertaken after the grid position of the group was calculated based on its distance and bearing from the recorded grid coordinates of the observer. This was similar to the method used by Aars *et al.* (2009) but overcame the need to fit transect lines within small patches of consistent vegetation strata which was not feasible at this scale. Stratified data was used for multiple-covariate distance sampling (MCDS) analysis in program Distance 6.2 (Thomas et al., 2010) to allow different detection functions to be estimated for different vegetation types (Figure 5). The 'best' model for each survey was chosen based on an information theoretic approach using AIC , or was the average of two or more models where Δ AIC < 2 (Anderson, 2008).