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Eastern Grey Kangaroos (*Macropus giganteus*) (Jemma Cripps).

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Contents

1. Executive summary

Aerial surveys conducted in September 2017 were used to estimate the kangaroo population in 58 Victorian Local Government Areas (LGA). These estimates exclude LGAs located entirely (or almost entirely) within highly urbanised parts of the Melbourne metropolitan area. The estimates also excluded thickly forested parts of Victoria due to the unreliability of kangaroo detection in those areas. Ground surveys were also conducted in the west of the state to estimate the relative proportions of Eastern and Western Grey Kangaroos in areas where their ranges overlap. These proportions were then applied to the aerial survey data to provide separate estimates for both Eastern and Western Grey Kangaroos.

Analysis of the combined aerial and ground survey data estimated that the overall kangaroo population in Victoria was 1,442,000 (95% confidence interval; 976,000 – 2,132,000). That estimate includes the three major kangaroo species occurring in Victoria, Eastern Grey Kangaroo (1,359,000), Western Grey Kangaroo (70,000) and Red Kangaroo (13,000). It should be noted that these estimates exclude the heavily forested areas of the state and hence, are a conservative estimate of kangaroo abundance in Victoria. The estimate for Red Kangaroos is also unreliable due to the relatively low precision of the abundance estimate.

Population estimates in each LGA were based on kangaroo densities estimated for seven regional strata, reflecting the likely regional variation in kangaroo densities across Victoria. The Central stratum had the highest density of Eastern Grey Kangaroos (48.5 kangaroos/km^2), much greater than the next highest density in the Gippsland stratum (10.7 kangaroos/km^2). The Upper Wimmera stratum had the lowest density of kangaroos (1.7 kangaroos/km^2). The population estimates for each species in each LGA included in the survey can be found in Tables 6 to 8.

1.1 Recommendations

- The precision of abundance estimates at the LGA level would be increased by flying more aerial survey transects, especially in the Mallee, Otway and Gippsland strata. Extra survey effort in the Mallee stratum would also serve to increase the precision of Red Kangaroo abundance estimates, which had the lowest precision of all species and strata.
- To increase the precision of the Eastern and Western Grey Kangaroo ratios in the grey kangaroo overlap zone, more ground surveys need to be conducted in the Ararat, Buloke, Gannawarra, Horsham, Hindmarsh, Loddon, Northern Grampians, Southern Grampians and Yarriambiack LGAs. Future ground survey transects should ensure placement within the current location of the grey kangaroo overlap zone, which would allow more accurate and localised estimates of the ratio of Eastern to Western Grey Kangaroos.

- Aerial transect locations need to be revised to ensure that they do not cross townships and other obstacles that cannot be flown, as well as to avoid excessive topographic variation.
- Consideration could be given to using fixed-wing aircraft for some of the aerial transects, especially in the relatively open, flat areas of western Victoria. Use of fixed-wing aircraft reduces the possibility of responsive movement of kangaroos away from the aircraft compared with helicopters. However, in more heavily timbered and topographically undulating terrain, helicopter surveys are preferred due to their increased visibility.
- Consideration could be given to including two observers on one or both sides of the aircraft, and employing double-observer distance sampling techniques. This would allow correction for imperfect detection of animals close to, or on the transect line, resulting in more accurate abundance estimates.
- It is recommended that, following modifications to the survey design as suggested in this report, that a second aerial survey be undertaken within the next 12 months so that effort can be targeted in areas where estimates were relatively imprecise, especially those subject to a high number of Authority to Control Wildlife (ACTW) applications. Thereafter, surveys can be conducted at three-yearly intervals.

2. Introduction

The Authority to Control Wildlife (ATCW) provisions of the *Wildlife Act 1975* (Victoria) allows three species of kangaroos [Eastern Grey Kangaroo (*Macropus giganteus*), Western Grey Kangaroo (*M. fuliginosus*) and Red Kangaroo (*Osphranter rufus*)] to be subject to legal culling in Victoria for damage mitigation purposes. To determine whether control of kangaroos under the ATCW provisions are ecologically sustainable, the state of Victoria recently conducted a state-wide aerial population survey of the three species of kangaroo. Ecological sustainability can be defined as the maximum culling or harvesting rate that can be sustained in the long-term, while still ensuring conservation of the kangaroo population. Sustainable culling or harvest rates of kangaroos are usually based on a fixed proportion of the estimated population size, with harvest proportions of 10 – 20% of the population generally considered to be ecologically sustainable (Caughley et al*.* 1987; Hacker et al*.* 2004; McLeod et al*.* 2004).

The design of the aerial survey followed the recommendations and survey effort outlined by Scroggie et al. (2017). Briefly, these recommendations included the minimal amount of survey effort that should be required to estimate the population abundance of kangaroos within each of seven geographic regions (strata), with a specified level of confidence (expressed as a coefficient of variation (CV) of 20% or less). Strata were chosen to reflect the likely regional variation in the Victorian kangaroo population. Due to the difficulty in distinguishing the two species of grey kangaroo during aerial surveys, ground surveys were undertaken to estimate the relative proportions of Eastern and Western Grey Kangaroos within the overlap zone where the two species co-occur (Lower and Upper Wimmera). These proportions were then used to derive separate estimates of the abundances of the two grey kangaroo species within the overlap zone. Strata-level estimates of density for each species were then used to estimate kangaroo abundances in each of 58 non-metropolitan Local Government Areas (LGA). Heavily forested areas in each stratum or LGA were excluded from kangaroo abundance estimates as these could not be reliably monitored using aerial surveys.

In this report, we present the results of the first state-wide aerial survey of kangaroos in Victoria. Kangaroo abundance estimates (and their precision) are provided for each stratum and LGA. We also make some recommendations for improvements in the survey design that could increase the efficiency of aerial surveys and the precision of estimates for future state-wide surveys.

3. Methods

3.1 Species distribution, study area and stratification

Aerial surveys using the methodology outlined by Scroggie et al. (2017), were conducted in September 2017 to estimate the kangaroo population in each Victorian LGA. The survey and estimates exclude LGAs entirely (or almost entirely) located within highly urbanised parts of the Melbourne metropolitan area. Estimates also excluded thickly forested areas due to the unreliability of kangaroo detection in those areas as well as kangaroo-free offshore islands (e.g. French Island). Therefore, the survey and estimates were restricted to the 58 non-metropolitan LGA listed in Table 1.

Table 1. Local government areas included in the survey and estimates.

Alpine	Gannawarra	Mansfield	Strathbogie
Ararat	Glenelg	Melton	Surf Coast
Ballarat	Golden Plains	Mildura	Swan Hill
Bass Coast	Greater Bendigo	Mitchell	Towong
Baw Baw	Greater Geelong	Moira	Wangaratta
Benalla	Greater Shepparton	Moorabool	Warrnambool
Brimbank	Hepburn	Mornington Peninsula	Wellington
Buloke	Hindmarsh	Mount Alexander	West Wimmera
Campaspe	Hobsons Bay	Moyne	Whittlesea
Cardinia	Horsham	Murrindindi	Wodonga
Casey	Hume	Nillumbik	Wyndham
Central Goldfields	Indigo	Northern Grampians	Yarra Ranges
Colac Otway	Latrobe	Pyrenees	Yarriambiack
Corangamite	Loddon	South Gippsland	
East Gippsland	Macedon Ranges	Southern Grampians	

Three kangaroo species are distributed over parts of Victoria. Red Kangaroos (*Osphranter rufus*, – RK) are restricted to the north-west corner of the state. Eastern Grey Kangaroos (*Macropus giganteus*, – EGK) are found across most of Victoria, with the exception of the north-west of the state. Western Grey Kangaroos (*M. fuliginosus*, – WGK) are found in the north-west of Victoria. The range of EGK and WGK overlap in a broad band across the west of the state, which is part of the grey kangaroo overlap zone (GKOZ) (Caughley et al. 1984). To account for the different kangaroo distributions and potential differences in density, Scroggie et al. (2017) subdivided Victoria into seven strata by amalgamating ecologically similar LGAs (Figure 1). The GKOZ occurs in an area covered by the Lower and Upper Wimmera strata.

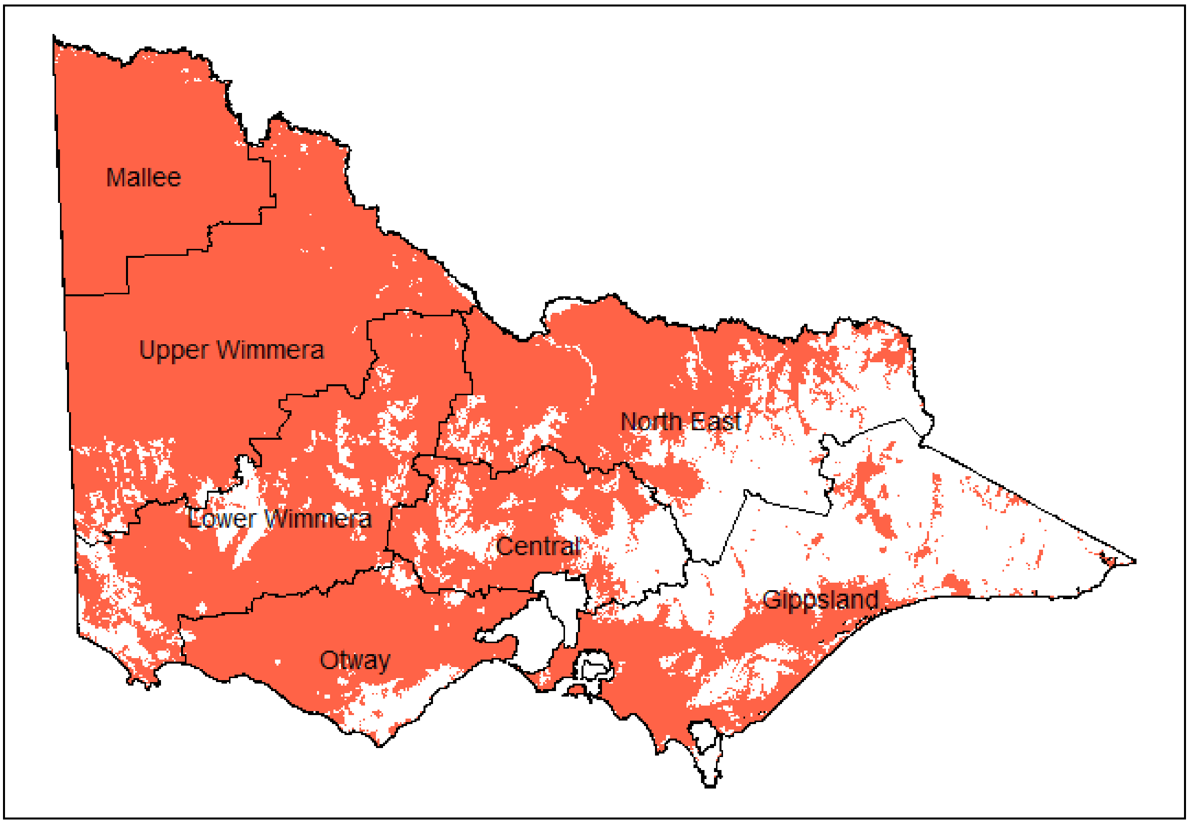

Figure 1. Map of stratification scheme for the statewide kangaroo survey. Coloured shading corresponds to open or lightly forested areas and/or mallee vegetation types, and are included in the survey and estimates. Unshaded areas are heavily forested, highly urbanised or kangaroo-free offshore islands and therefore excluded from survey and estimates.

3.1.1 Aerial survey

Aerial surveys and line-transect distance sampling (Buckland et al*.* 1993) were used to estimate kangaroo densities across Victoria. Aerial surveys were conducted by EcoKnowledge in September 2017 (Lethbridge and Stead 2017). The surveys were conducted in a Bell LongRanger helicopter. A total of 1600 km of transects were flown within three hours of sunrise or sunset in an easterly or westerly direction (flying away from the sun) at a height of 200 feet (AGL), at a speed of 50 knots. Locations of the transects are shown in Figure 2. A five-zone survey pole was used on either side of the aircraft, allowing observed kangaroos to be placed into one of five distance classes (0-20, 20-40, 40-70, 70-100 and 100-150 m). The species, size and distance class of the first observation of each group of kangaroos observed was recorded. Due to the difficulties in accurately determining the difference between EGK and WGK from the air, only two "species" of kangaroos were recorded, RK and grey kangaroo (GK).

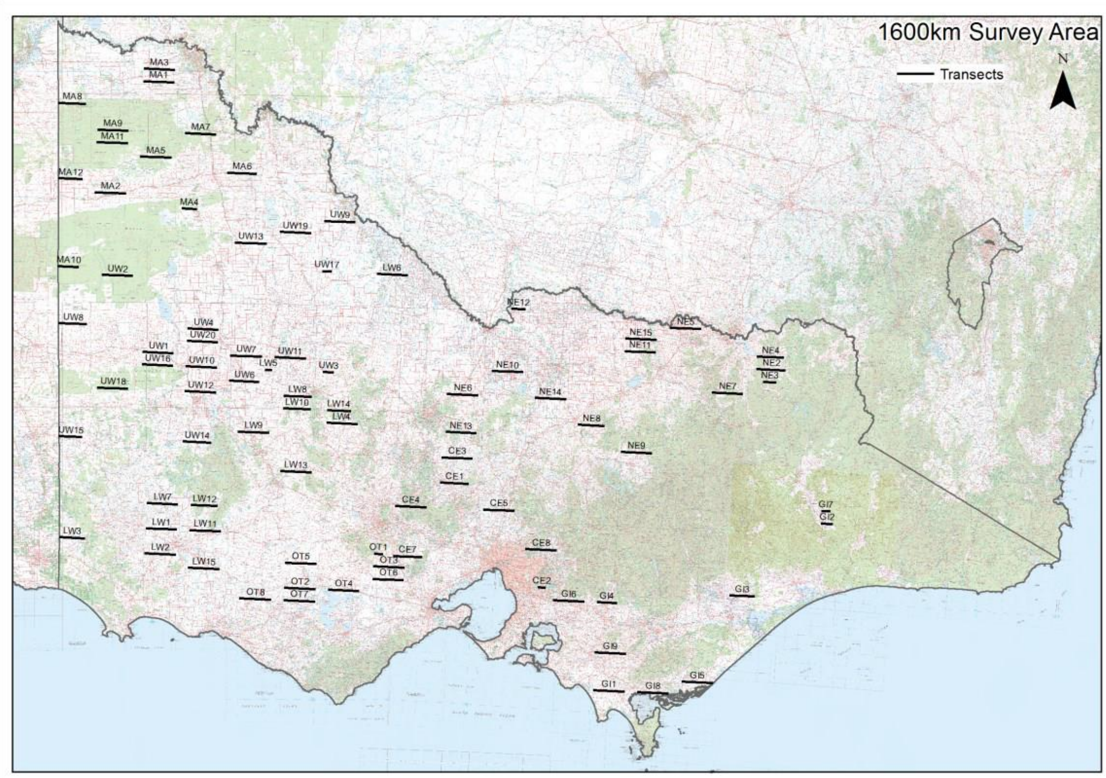

Figure 2. Map of transects flown in the 2017 kangaroo aerial survey (from Lethbridge and Stead (2017))

3.1.2 Ground survey

Ground surveys to estimate the ratio of EGK to WGK in western Victoria were conducted by Macropus Consulting in September 2017 (Coulson 2017). Six ground transects traversed the GKOZ in the Upper and Lower Wimmera strata. The transect locations were similar to those suggested by Scroggie et al. (2017), totaling nearly 1600 km of roads. Two observers were used, with transects driven in the two hours after sunrise and the two hours before sunset. Both live and dead kangaroos were included in the counts of EGK and WGK. In addition to the species and number of kangaroo observed the location was also recorded, as well as some other relevant covariates.

3.1.3 Kangaroo estimates by LGA

The density of GK and RK (kangaroos/km^2) was estimated for each stratum using standard line-transect distance sampling techniques (Buckland et al*.* 1993). Half-normal and hazard-rate detection functions with potential second order cosine adjustments were considered, with the model with the lowest Akaike's Information Criteria (AIC) (Burnham and Anderson 2001) used for the final inferences. Kangaroo abundance estimates for each LGA were then calculated by multiplying the stratum density estimates for each kangaroo species by the area (in square kilometres) of habitat (i.e. non-forested) in each LGA. In LGAs outside the GKOZ, grey kangaroos were assumed to be either EGK or WGK (Mallee stratum) and estimates were derived directly from the distance sampling model. However, in the GKOZ the density of grey kangaroos needed to be assigned to EGK and WGK. This was done by multiplying the relevant density estimates by the proportion of grey kangaroos in that LGA that were either EGK and WGK, respectively. Bootstrapping was used to estimate the standard error and confidence intervals of the EGK and WGK densities within the GKOZ (Efron and Tibshirani 1993). We bootstrapped sampled ground survey kangaroo observations at the strata level with replacement and used 1,000 replicates. The analysis was carried out using the statistical program *R* (R Development Core Team 2015), with the package "Distance" (Miller 2017) used to estimate the distance sampling model.

4. Results

4.1 Distance sampling model

A total of 2,607 GK and 23 RK were observed from the 1600 km of transects during the aerial survey. Studies have shown that at least 80 observations are required to provide a reasonable estimate of the detection function, necessary to estimate density with acceptable precision and accuracy (Buckland et al. 1993). Therefore, a single detection function was fitted for all kangaroos, with the assumption that the distance-detection functions for GK and RK was very similar, if not identical. It was noticed that there was some responsive movement of kangaroos away from the aircraft (Lethbridge and Stead 2017), which could have violated some of the assumptions of the distance sampling model. However, combining the 0-20 m and 20-40 m distance classes accounted for the movement effect close to the transect line (Figure 3). A half-normal detection function with second order cosine adjustments was selected after comparing the fit of the half-normal and hazard rate distance functions, with and without second order cosine adjustments (Table 2). The monotonicity assumption was not violated, with the estimated detection function decreasing as distance from the transect increased (Figure 3). A goodness-of-fit test indicated that the model was an adequate fit to the data (p-value = 0.985).

Table 2. Akaike's information criterion (AIC) comparing the relative support of the different detection functions fitted to the distance sampling data. Models with AIC values within 3 of the model with the lowest AIC, have relatively similar support.

Model	AIC	ΔAIC
Half-normal with second order cosine adjustments	1,989.7	
Hazard-rate	1,991.3	1.6
Hazard-rate with second order cosine adjustments	1,991.7	2.0
Half-normal	2,001.4	11.7

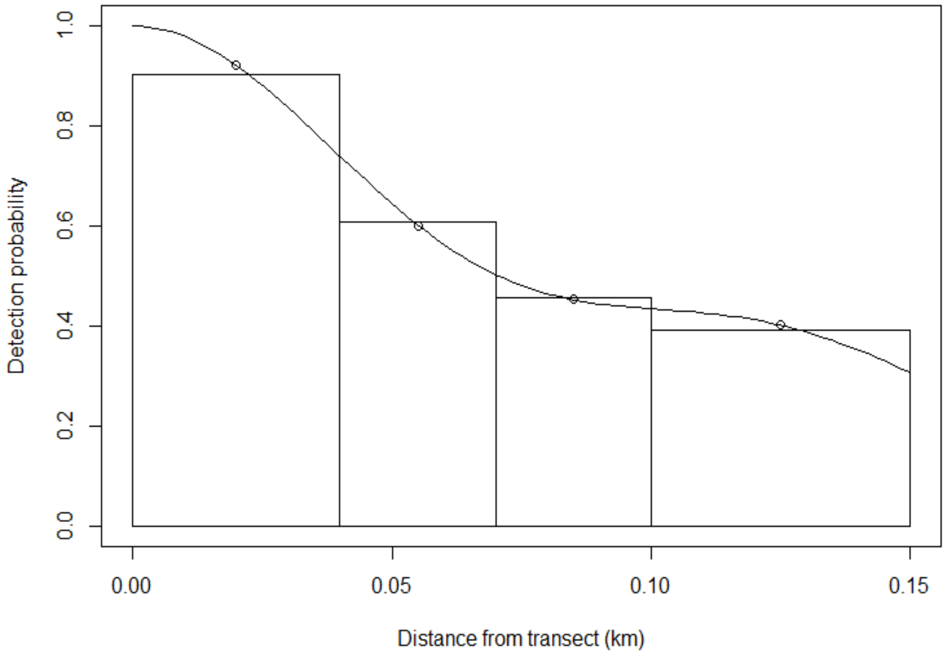

Figure 3. Estimated detection curve for kangaroos. Bar heights indicate the relative number of observations in each distance class.

The distance sampling model was used to estimate the GK and RK density (kangaroos/ km^2) for each of the seven strata (Table 3). The Central stratum had the highest density of EGK (48.5 kangaroos/km^2; 21.5 – 109.5), much greater than the next highest density, which occurred in the Gippsland stratum (10.7 kangaroos/km^2; 3.3 – 34.8). Generally, the north-west of Victoria (Mallee and Upper Wimmera) had lower densities, with the lowest in the Upper Wimmera stratum (1.7 kangaroos/km^2). As expected, RK were only observed in the Mallee stratum and had a lower density than GK in this stratum (0.6/km^2 vs 1.9/km^2, respectively) (Table 3).

Table 3. Kangaroo density (kangaroos/km^2) estimates by strata for grey and Red kangaroos. Lower and upper bound are the 95% confidence intervals.

Species	Strata name	Density estimate	Standard error	Coefficient of variation	Lower bound	Upper bound
Grey	Mallee	1.9	0.83	0.43	0.8	4.8
Grey	Upper Wimmera	1.7	0.68	0.39	0.8	3.8
Grey	Lower Wimmera	10.4	3.37	0.32	5.3	20.4
Grey	Otway	2.6	1.41	0.54	0.8	8.9
Grey	Central	48.5	16.82	0.35	21.5	109.5
Grey	North East	7.7	3.04	0.40	3.4	17.4
Grey	Gippsland	10.7	5.71	0.53	3.3	34.8
Red	Mallee	0.6	0.39	0.67	0.1	2.3

Based on the density estimates for each strata derived from the distance sampling analysis, and the known surveyable areas of each stratum, the estimated overall kangaroo population in Victoria was 1,442,000 (95% confidence interval, 976,000 – 2,132,000).

4.1.1 Group size

The mean group size of kangaroos observed in the aerial survey varied between strata (Table 4). Highest mean group sizes occurred in the Gippsland stratum (4.24 kangaroos per group) with the lowest occurring in the Mallee strata for both RK and GK (1.64 and 1.63 kangaroos per group, respectively).

Table 4. Kangaroo group size estimates by strata for grey and red kangaroos.

Strata name	Species	Group size estimate	Standard error
Central	GK	4.10	0.35
Gippsland	GK	4.24	1.66
Lower Wimmera	GK	3.40	0.56
Mallee	GK	1.63	0.07
Mallee	RK	1.64	0.06
North East	GK	3.84	0.51
Otway	GK	2.06	0.11
Upper Wimmera	GK	2.26	0.44

4.2 Grey kangaroo ground surveys

A total of 1,169 EGK and 82 WGK were observed during the nearly 1600 km of ground transects within the grey kangaroo overlap zone. Initially it was hoped that a spatial model could be fitted to the ground survey locations to model spatial variation in the proportion of EGK to WGK within each LGA in the GKOZ. However, subsequent to the ground surveys, it was found that in some LGAs, the number of GK observed was too low for such a spatial model to be reliable (Figure 4). For instance, within Gannawarra LGA only one EGK and no WGK were observed. In Buloke, Gannawarra, Hindmarsh and Yarriambiack LGAs a total of 8 groups of GK were observed for a total of 29 individual GK. Due to these low numbers, it was decided to estimate the overall ratio of EGK to WGK in the GKOZ as a whole, and to use bootstrapping to estimate the uncertainty in this proportion. The resulting estimates of the ratio of EGK to WGK were then combined with the aerial survey estimates to apportion the total density of grey kangaroos between EGK and WGK at the strata level (Table 5). A visual summary of those results for EGK and WGK is shown in Figures 5 and 6. The total abundances of EGK and WGK across all strata were estimated to be 1,3590,000 EGK (95% confidence interval, 902,000 – 2,049,000) and 70,000 WGK (95% confidence interval, 38,000 – 128,000).

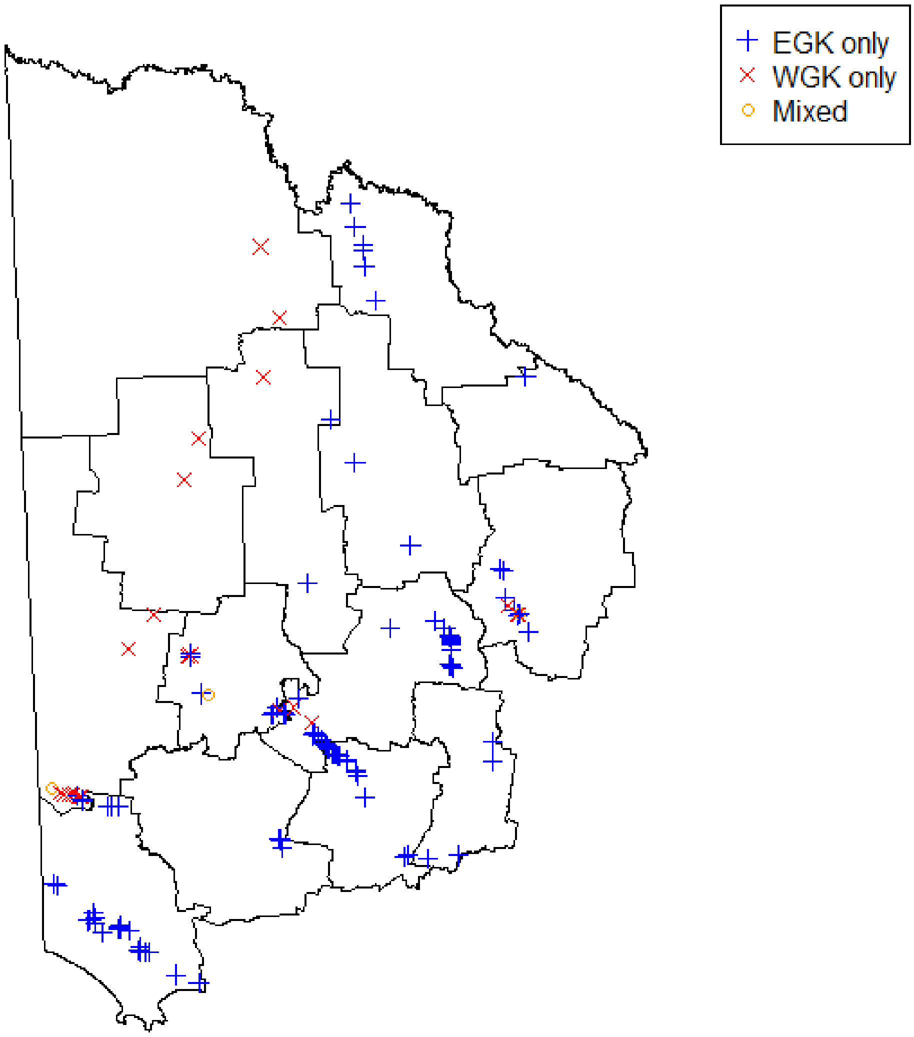

Figure 4. Locations of Eastern Grey Kangaroos (EGK) and Western Grey Kangaroos (WGK) observed during the ground survey.

Table 5. Estimates for the probability of a grey kangaroo being either an Eastern (EGK) or Western (WGK) Grey Kangaroo in the overlap zone, and the corresponding density estimate (kangaroos/km^2). SE is standard error and CV is the coefficient of variation respectively for the density estimate.

Strata name	Species	Probability	Density estimate	SE	CV	Lower bound	Upper bound
Lower Wimmera	EGK	0.98	10.1	3.3	0.324	5.2	19.9
Lower Wimmera	WGK	0.02	0.2	0.1	0.324	0.1	0.5
Upper Wimmera	EGK	0.72	1.2	0.5	0.393	0.6	2.7
Upper Wimmera	WGK	0.28	0.5	0.2	0.393	0.2	1.1

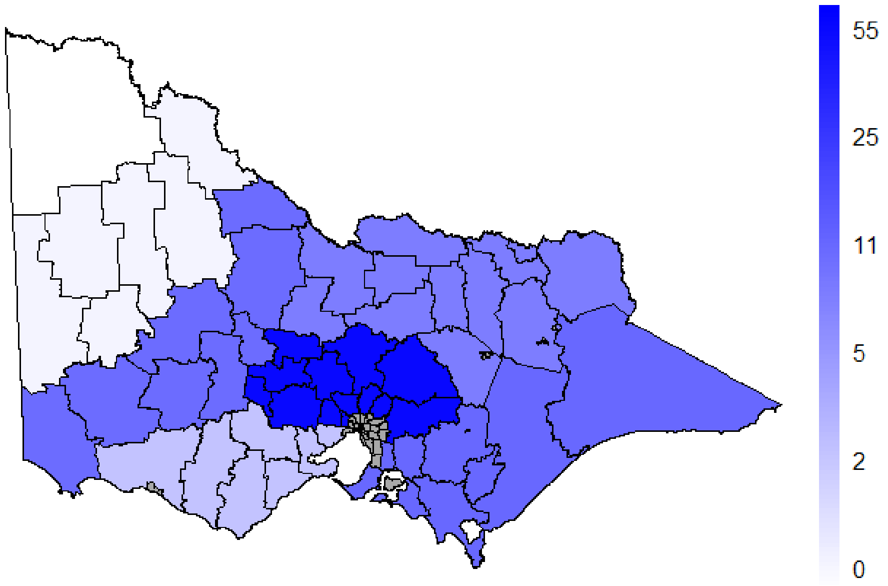

Figure 5. Eastern Grey Kangaroo density estimates (kangaroos/km^2) by LGA. Colour on logarithmic scale. Grey LGAs were excluded from analysis.

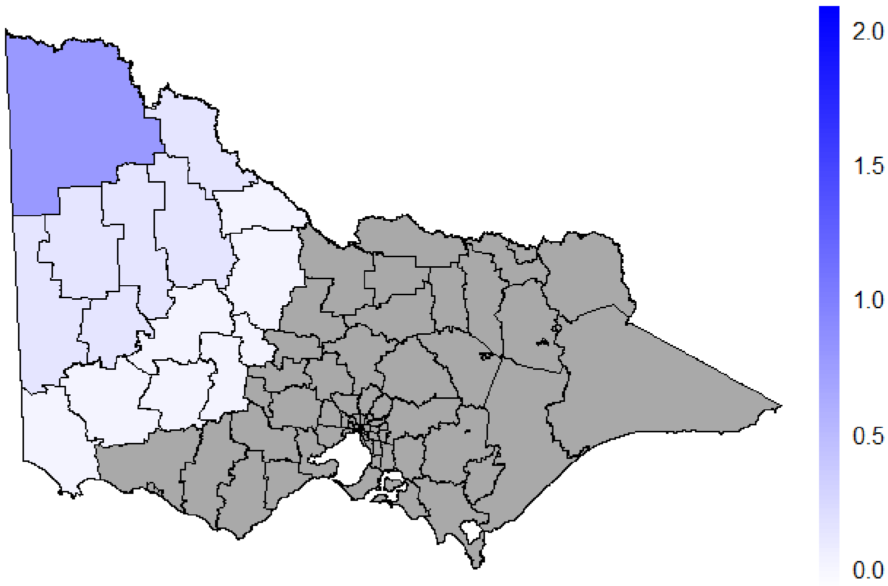

Figure 6. Western Grey Kangaroo density estimates (kangaroos/km^2) by LGA. Grey LGAs were excluded from analysis.

4.3 Kangaroo abundance estimates by LGA

Estimates of the number of EGK, WGK and RK in each LGA derived from the aerial and ground survey data are provided in the Appendix in Tables 6, 7 and 8 respectively. A visual summary of those results for EGK and WGK is shown in Figures 7 and 8. The highest abundances of EGK were found in the Central stratum LGAs of Mitchell, Murrindindi, Moorabool and Macedon Ranges, with abundances ranging from 66,600 – 110,600 EGK (Table 6 – Appendix). Lowest abundances of EGK were found in the smaller LGAs in the Otway stratum, with the Warrnambool and Hobson's Bay LGAs abundances ranging from 200 – 300 EGK (Table 6 – Appendix). For WGK, the highest abundances were found in the Mildura LGA (41,800 WGK) with the lowest abundance in the Central Goldfields LGA (300 WGK) (Table 7 – Appendix). The abundance of RK in the Mildura LGA was estimated to be 12,800. However, this estimate was imprecise, with a coefficient of variation (CV) of 67% (Table 8 – Appendix).

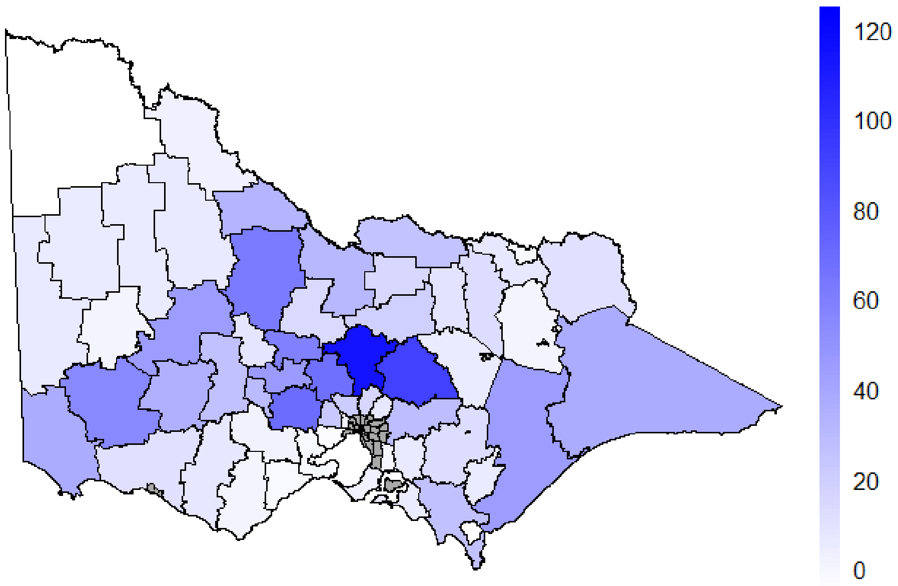

Figure 7. Eastern Grey Kangaroo abundance estimates by LGA. Scale is in thousands. Grey LGAs and heavily forested areas of each LGA were excluded from analysis.

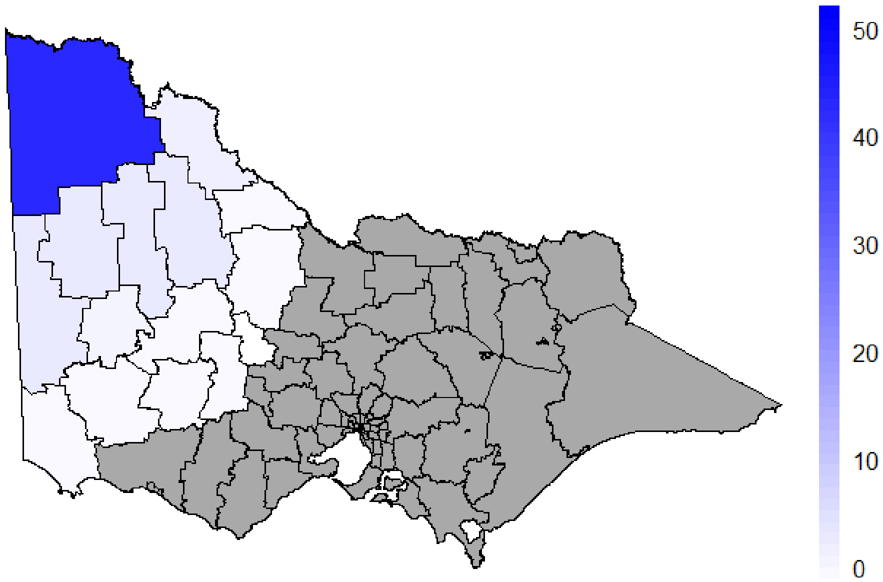

Figure 8. Western Grey Kangaroo abundance estimates by LGA. Scale is in thousands. Grey LGAs and heavily forested areas of each LGA were excluded from analysis.

5. Discussion

Analysis of the combined aerial and ground survey data estimated that the overall kangaroo population in Victoria was 1,442,000 (95% confidence interval; 976,000 – 2,132,000). There were an estimated 1,359,000 (902,000 – 2,049,000) Eastern Grey Kangaroos, accounting for the overwhelming majority (94%) of Victorian kangaroos. The remaining kangaroos comprised an estimated 70,000 Western Grey Kangaroos (38,000 – 128,000) and 13,000 (3,000 – 51,000) Red Kangaroos. It should be noted that these estimates exclude the heavily forested areas of the state and hence, are a conservative estimate of kangaroo abundance in Victoria.

No estimate of EGK was undertaken for the Mallee stratum even though small populations of EGK are known to occur in the area. This is due to EGK being restricted to the areas near the Murray River, and at apparently low densities. The ground surveys conducted as part of this study (Coulson 2017) did not observe any EGK within the Mallee stratum. A recent Parks Victoria ground-based distance sampling survey detected EGK in only one area (Hattah-Kulkyne), at less than 0.5 kangaroos/km^2 (Mackenzie 2017). Given the highly restricted distribution of EGK in the Mallee, it was not practical to estimate the density of EGK for the Mallee stratum as a whole from the available data.

The distribution of EGK and WGK in the grey kangaroo overlap zone needs further clarification. The ground surveys covered a large area and observed a total of 1,251 grey kangaroos. That number of grey kangaroos sampled exceeded the effort recommended to give the desired precision for the estimate of the relative proportion of EGK and WGK in the overlap zone (Scroggie et al. 2017). However, there were very few GK observed in the LGAs on the southern border of the Mildura LGA. Therefore, the sample of GK was inadequate for the LGAs in this region and hence, we have a relatively poor understanding of spatial pattern in the transition from EGK to WGK in this region. Additionally, in comparison to the historical data from the Atlas of Living Australia used in designing the survey (Scroggie et al. 2017), and to historical accounts (Caughley et al. 1984) the GKOZ appears to have moved somewhat to the north-west. We recommend that any future ground survey undertake relatively more effort within the Mildura LGA and the LGAs bordering the Mildura LGA (e.g. Swan Hill, Buloke, Yarriambiack and Hindmarsh). The existing ground survey data could be used to inform the design of future ground surveys with the aim of improving understanding of the location and structure of the grey kangaroo overlap zone.

The RK population was restricted to the Mallee stratum, with a density of 0.6 kangaroos/km^2 (0.1 – 2.3). This estimate had a high level of imprecision due to the high variability in the numbers of RK sighted on individual aerial transects, with no RK observed on 7 out of the 10 transects in the stratum. This imprecise density estimate means the abundance estimate of RK in the Mallee stratum is unreliable, with the 95% confidence interval for the abundance estimate for RK ranging from 3,000 – 51,000 individuals. This variability was also evident in the recent aerial surveys around Murray-Sunset National Park where it was estimated that RK were at densities of 0.6 kangaroos/km^2 south of the park (similar to this report), but at densities of 9.6 kangaroos/km^2 north of the park. (Mackenzie 2017). Total abundance just in the Mallee parks areas surveyed by both aerial and ground surveys was 11,000 RK (Mackenzie 2017). This highlights the potential for RK densities to be locally high within the Mallee stratum and much more spatially heterogeneous than assumed in the original sampling design. In the face of such a degree of spatial variation in density, distance sampling surveys require much more sampling effort (more, or longer transects) to obtain a given level of precision, than would be the case in regions where densities are more uniform.

The Victoria-wide estimate of the kangaroo population met the precision goal set by Scroggie et al. (2017). The precision of the estimates can be measured using the coefficient of variation (CV). The CV of the overall kangaroo estimate for Victoria was 18.8%, within the desired CV of 20% in the sampling design (Scroggie et al. 2017). However, the CVs at the stratum level were higher, ranging from 32.4% (Lower Wimmera stratum for GK) to 67% (Mallee stratum for RK). According to Pople (2008), when using a proportional harvest strategy, precision (CV) estimates greater than 50% increases the risk of over-harvesting. The CV for RK was 67%, clearly over the 50% threshold. The Gippsland stratum (53.2%) and the Otways stratum (53.9%) are both marginally over the 50% threshold for EGK. The CV for all other strata for EGK or WGK were below the 50% threshold. Therefore, it is recommended that, if future state-wide kangaroo surveys are undertaken, that the sampling design be revised to re-estimate the required amount of survey effort required for each stratum, based on the results from this survey. This would be driven, in part, by considering which LGAs would benefit the most from increased precision of abundance estimates. For example, LGAs subject to a high number of ACTW applications would clearly benefit from having a more precise estimate of abundance so that the risk of unsustainable culling is minimised. Hence, we recommend that the aerial survey be repeated within the next 12 months so that effort can be targeted in areas where estimates were relatively imprecise, especially those subject to a high number of ACTW applications. Thereafter, surveys can be conducted at three-yearly intervals as recommended by Pople (2008).

In addition to an increase and spatial reallocation of survey effort, there is also a need to revise some of the existing transect locations due to some of the transects traversing obstacles to safe and legal flight, and excessive topographic variation (Lethbridge and Stead 2017). These issues were especially apparent for transects in the Central and Eastern strata. Other issues encountered by the aerial survey contractor included (Lethbridge and Stead 2017);

- Difficulty assigning distance classes to kangaroos in large groups (30-100+ kangaroos).
- Kangaroos ‘flushing’ from the aircraft, leading to a higher proportion of animals assigned to the first or last distance class.

The first point can be easily accommodated by recording a single distance to the centre of the group and then counting the number of individuals in the group. Indeed, this is the recommended procedure for dealing with grouped animals during distance sampling (Buckland et al*.* 2001; Thomas et al*.* 2010). Group size is then accounted for in the analysis as an extra covariate (Clement et al*.* 2017). The second point refers to the responsive movement of kangaroos away from the helicopter during aerial surveys. This violates one of the assumptions of distance sampling (animals do not move before having their distance recorded). Responsive movement can bias estimates of density and abundance low, especially if animals move off the transect before they are observed (Buckland et al. 2001). We reduced the likely impact of animal movement within and close to the transect line by combining the first two distance classes. This resulted in a better fit of the distance sampling model to the data. A similar approach was also adopted in the analysis of the Mallee parks helicopter survey data (Mackenzie 2017).

Aerial surveys of kangaroos in other state jurisdictions are carried out for the purposes of supporting the sustainable commercial harvest of kangaroos. Fixed-wing aircraft are generally used in more open, flatter terrain, such as in inland NSW, SA and WA, while helicopter surveys are used in more timbered and topographically challenging areas, such as the Northern Tablelands of NSW and Qld. Fixed-wing aerial surveys usually use fixed strip-width sampling, where kangaroos are counted within a predefined distance from the aircraft. Correction factors are then applied to correct for the kangaroos present on the strip, but not detected (Pople et al. 1998). However, the use of correction factors are considered to be not as robust as methods that use survey-specific corrections for visibility bias, such as line transect methods (Pople et al. 1998). It is for this reason that the fixed strip-width method currently used in aerial surveys in inland NSW are being changed to line transect methods (Steve McLeod personal communication).

It has been recommended that transects in relatively open country be surveyed using fixed-wing aircraft rather than a helicopter, as fixed-wing aircraft are typically quieter and travel faster during aerial surveys, leaving less time for kangaroos to respond to the approaching aircraft (Lethbridge and Stead 2017). This recommendation deserves further consideration for future aerial surveys in the relatively open, flat areas of western Victoria. However, in more heavily timbered and topographically undulating terrain, helicopter surveys are preferred due to their increased visibility. Operational costs for conducting distance sampling in fixed-wing aircraft are also likely to be considerably lower than using a helicopter, which would mean that more survey effort could be conducted for the same cost as helicopter surveys.

One issue with conventional distance sampling is that the method assumes that animals on, or close to the transect line are detected with near certainty. Where this is not the case, estimates of abundance are biased low. We therefore recommend that consideration be given to using two observers on one or both sides of the aircraft and employing double-observer distance sampling methods (Clement et al. 2017). Double-observer distance sampling (or mark-recapture distance sampling) allows estimates to be corrected for imperfect detection of animals on the transect line and would result in more accurate estimate of kangaroo abundance than conventional distance sampling (Fewster and Pople 2008).

6. Recommendations

- The precision of abundance estimates at the LGA level would be increased by flying more aerial survey transects, especially in the Mallee, Otway and Gippsland strata. Extra survey effort in the Mallee stratum would also serve to increase the precision of Red Kangaroo abundance estimates, which had the lowest precision of all species and strata.

- To increase the precision of the Eastern and Western Grey Kangaroo ratios in the grey kangaroo overlap zone, more ground surveys need to be conducted in the Ararat, Buloke, Gannawarra, Horsham, Hindmarsh, Loddon, Northern Grampians, Southern Grampians and Yarriambiack LGAs. Future ground survey transects should ensure placement within the current location of the grey kangaroo overlap zone, which would allow more accurate and localised estimates of the ratio of Eastern to Western Grey Kangaroos.
- Aerial transect locations need to be revised to ensure that they do not cross townships and other obstacles that cannot be flown, as well as to avoid excessive topographic variation.
- Consideration could be given to using fixed-wing aircraft for some of the aerial transects, especially in the relatively open, flat areas of western Victoria. Use of fixed-wing aircraft reduces the possibility of responsive movement of kangaroos away from the aircraft compared with helicopters. However, in more heavily timbered and topographically undulating terrain, helicopter surveys are preferred due to their increased visibility.
- Consideration could be given to including two observers on one or both sides of the aircraft, and employing double-observer distance sampling techniques. This would allow correction for imperfect detection of animals close to, or on the transect line, resulting in more accurate abundance estimates.
- It is recommended that, following modifications to the survey design as suggested in this report, that a second aerial survey be undertaken within the next 12 months so that effort can be targeted in areas where estimates were relatively imprecise, especially those subject to a high number of Authority to Control Wildlife (ACTW) applications. Thereafter, surveys can be conducted at three-yearly intervals.

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8. Appendix – Kangaroo abundance estimates for each LGA

Table 6. Abundance estimates for Eastern Grey Kangaroos (EGK) by LGA to the nearest 100. These estimates only apply to the surveyable parts of LGA. Most notably, heavily forested areas are excluded from consideration.

LGA name	Strata name	Area (km^2)	Estimate	SE	Lower bound	Upper bound
Alpine	North East	607	4,600	1,800	2,000	10,600
Ararat	Lower Wimmera	3,649	37,000	12,000	18,900	72,700
Ballarat	Central	659	32,000	11,100	14,200	72,100
Bass Coast	Gippsland	846	9,100	4,800	2,800	29,400
Baw Baw	Gippsland	1,530	16,400	8,700	5,100	53,200
Benalla	North East	1,727	13,200	5,300	5,800	30,100
Brimbank	Central	123	6,000	2,100	2,600	13,500
Buloke	Upper Wimmera	7,991	9,800	3,800	4,400	21,600
Campaspe	North East	4,267	32,700	13,000	14,300	74,400
Cardinia	Gippsland	967	10,400	5,500	3,200	33,600
Casey	Gippsland	391	4,200	2,200	1,300	13,600
Central Goldfields	Lower Wimmera	1,159	11,800	3,800	6,000	23,100
Colac Otway	Otway	1,907	5,000	2,700	1,500	17,000
Corangamite	Otway	4,230	11,000	6,000	3,200	37,700
East Gippsland	Gippsland	3,617	38,900	20,700	12,000	125,800
Gannawarra	Lower Wimmera	3,490	35,400	11,500	18,100	69,500
Glenelg	Lower Wimmera	3,816	38,700	12,600	19,700	76,000
Golden Plains	Otway	2,295	6,000	3,200	1,800	20,500
Greater Bendigo	North East	2,268	17,400	6,900	7,600	39,600
Greater Geelong	Otway	1,220	3,200	1,700	900	10,900
Greater Shepparton	North East	2,317	17,700	7,000	7,800	40,400
Hepburn	Central	965	46,800	16,200	20,800	105,700
Hindmarsh	Upper Wimmera	7,523	9,200	3,600	4,100	20,400
Hobsons Bay	Otway	65	200	100	0	600
Horsham	Upper Wimmera	3,844	4,700	1,800	2,100	10,400
Hume	Central	503	24,400	8,500	10,800	55,100
Indigo	North East	1,421	10,900	4,300	4,800	24,800
Latrobe	Gippsland	880	9,500	5,000	2,900	30,600
Loddon	Lower Wimmera	6,119	62,100	20,100	31,600	121,900
Macedon Ranges	Central	1,372	66,600	23,100	29,500	150,300
Mansfield	North East	1,205	9,200	3,700	4,000	21,000
Melton	Central	508	24,600	8,500	10,900	55,600
Mitchell	Central	2,278	110,600	38,300	49,000	249,500
Moira	North East	3,651	27,900	11,100	12,300	63,700
Moorabool	Central	1,431	69,500	24,100	30,800	156,800
Mornington Peninsula	Gippsland	644	6,900	3,700	2,100	22,400
Mount Alexander	Central	1,223	59,300	20,600	26,300	133,900
Moyne	Otway	5,387	14,100	7,600	4,100	48,100
Murrindindi	Central	1,832	88,900	30,800	39,400	200,700
Nillumbik	Central	225	10,900	3,800	4,800	24,600
Northern Grampians	Lower Wimmera	4,564	46,300	15,000	23,600	90,900
Pyrenees	Lower Wimmera	2,891	29,300	9,500	15,000	57,600
South Gippsland	Gippsland	2,686	28,900	15,300	8,900	93,400

Southern Grampians	Lower Wimmera	5,552	56,300	18,300	28,700	110,600
Strathbogie	North East	2,901	22,200	8,800	9,700	50,600
Surf Coast	Otway	1,063	2,800	1,500	800	9,500
Swan Hill	Upper Wimmera	5,903	7,200	2,800	3,300	16,000
Towong	North East	1,871	14,300	5,700	6,300	32,600
Wangaratta	North East	2,059	15,800	6,300	6,900	35,900
Warrnambool	Otway	120	300	200	100	1,100
Wellington	Gippsland	4,277	46,000	24,400	14,200	148,800
West Wimmera	Upper Wimmera	8,054	9,800	3,900	4,400	21,800
Whittlesea	Central	392	19,000	6,600	8,400	42,900
Wodonga	North East	403	3,100	1,200	1,400	7,000
Wyndham	Otway	542	1,400	800	400	4,800
Yarra Ranges	Central	638	31,000	10,700	13,700	69,900
Yarriambiack	Upper Wimmera	7,320	8,900	3,500	4,000	19,800

Table 7. Abundance estimates for Western Grey Kangaroos (WGK) by LGA to the nearest 100.

LGA name	Strata name	Area (km^2)	Estimate	SE	Lower bound	Upper bound
Ararat	Lower Wimmera	3,649	900	300	400	1,700
Buloke	Upper Wimmera	7,991	4,100	1,600	1,800	9,000
Central Goldfields	Lower Wimmera	1,159	300	100	100	500
Gannawarra	Lower Wimmera	3,490	800	300	400	1,600
Glenelg	Lower Wimmera	3,816	900	300	500	1,800
Hindmarsh	Upper Wimmera	7,523	3,800	1,500	1,700	8,500
Horsham	Upper Wimmera	3,844	2,000	800	900	4,300
Loddon	Lower Wimmera	6,119	1,500	500	700	2,900
Mildura	Mallee	21,875	41,800	18,100	16,500	106,000
Northern Grampians	Lower Wimmera	4,564	1,100	400	600	2,100
Pyrenees	Lower Wimmera	2,891	700	200	400	1,400
Southern Grampians	Lower Wimmera	5,552	1,300	400	700	2,600
Swan Hill	Upper Wimmera	5,903	3,000	1,200	1,400	6,700
West Wimmera	Upper Wimmera	8,054	4,100	1,600	1,900	9,100
Yarriambiack	Upper Wimmera	7,320	3,700	1,500	1,700	8,300

Table 8. Abundance estimates for Red Kangaroos (RK) by LGA to the nearest 100.

LGA name	Strata name	Area (km^2)	Estimate	SE	Lower bound	Upper bound
Mildura	Mallee	21,875	12,800	8,600	3,200	50,700