Revisiting the Victorian Kangaroo Aerial Survey Design

P. Moloney, M. Scroggie, and D. Ramsey

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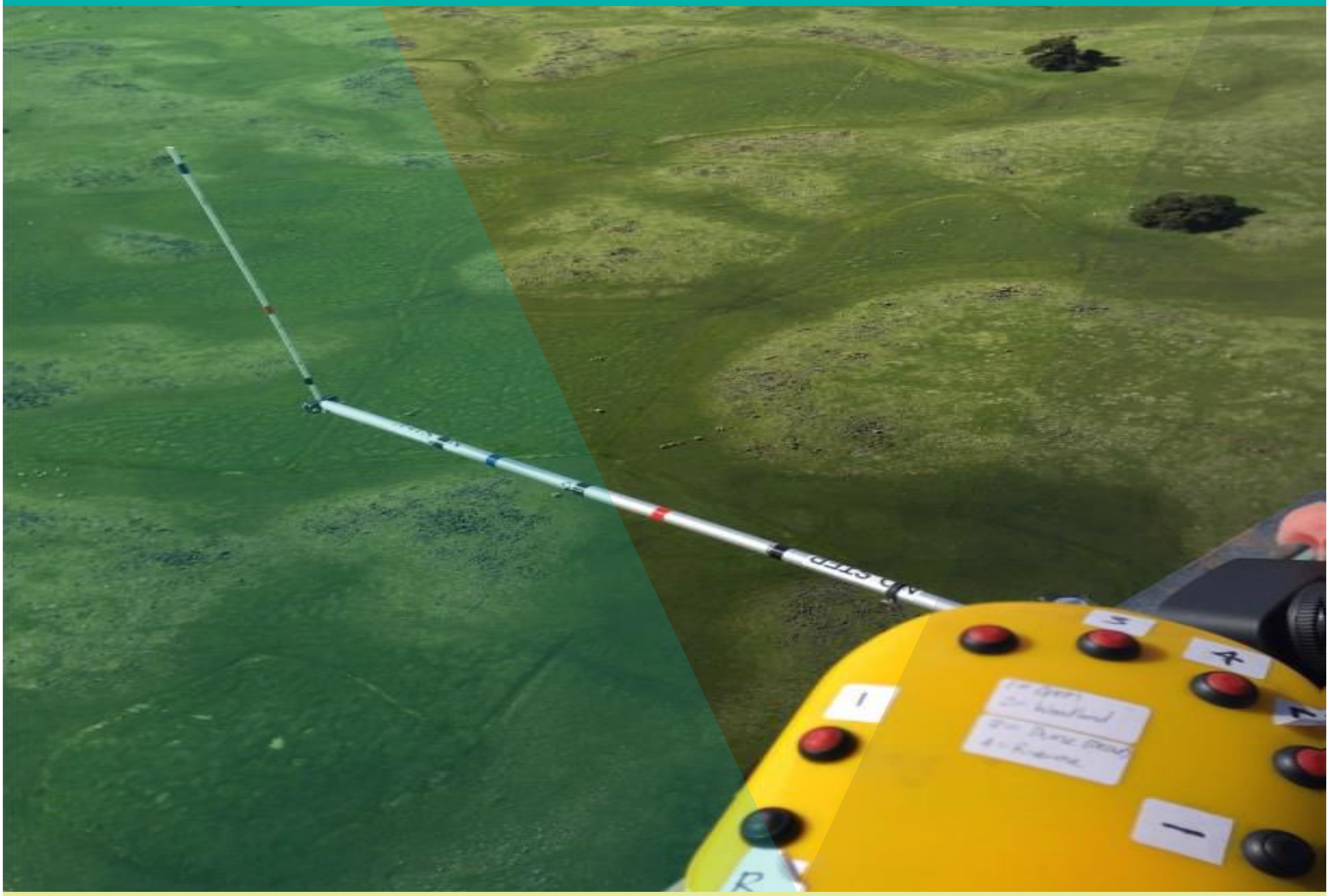

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Arthur Rylah Institute for Environmental Research
Department of Environment, Land, Water and Planning
PO Box 137
Heidelberg, Victoria 3084
Phone (03) 9450 8600
Website: www.ari.vic.gov.au

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Revisiting the Victorian Kangaroo Aerial Survey Design

Paul Moloney, Michael Scroggie and Dave Ramsey

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Department of Environment, Land, Water and Planning
Heidelberg, Victoria

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Arthur Rylah Institute for Environmental Research
Department of Environment, Land, Water and Planning
Heidelberg, Victoria

1 Summary

Using the results from the first aerial survey of Victoria's kangaroo population (Moloney *et al.* 2017), we revised the estimates of the amount of aerial and ground survey sampling effort required to provide increased precision of kangaroo abundance estimates for Victoria. A new model of the occurrence of Eastern Grey kangaroos (EKG) and Western Grey kangaroos (WGK) in south-eastern Australia enabled a revision of the likely current location of the grey kangaroo overlap zone (GKOZ). This, in turn, allowed more targeted sampling of the GKOZ, which should result in improved estimates of the relative proportions of EKG and WKG within the overlap zone (primarily within the Lower and Upper Wimmera strata). Based on this revised analysis, a total of 1850 km of ground transects across the GKOZ have been identified (Table 1).

Using the abundance estimates and other parameters from the line transect distance sampling analysis of the initial survey data (Moloney *et al.* 2017), we conducted simulation modelling to revise the amount of aerial survey effort that should result in abundance estimates for each stratum with high precision (i.e. coefficient of variation (CV) < 20%). Based on these results we identified two possible options for the required survey effort. The preferred option, represented by 151 transects totalling 3100 km, resulted in median CVs of < 20% for all strata. Alternatively, the minimal option represented by 111 transects totalling 2321 km had median CVs of < 20% for all strata except the Otway and Mallee. It was notable that the minimal option was likely to produce estimates with < 20% CV in those strata having a high proportion of Authority to Control Wildlife (ACTW) and/or kangaroo pet food trial applications (i.e. Central, North East and Lower Wimmera), where management of any risk of inadvertent overharvesting is most needed.

1.1 Recommendations

- A total of 1850 km of ground transects should be surveyed in the GKOZ. The locations of suggested routes are identified in Table 1 and are available as GIS shapefiles.
- The preferred option of 151 transects should be aerially surveyed across Victoria using a helicopter to provide the greatest likelihood of precise abundance estimates for all surveyed strata.
- Alternatively, a minimal option of 111 transects could be surveyed across Victoria, providing high likelihood of precise abundance estimates for all strata except the Mallee and Otway.
- Starting and ending locations for all aerial transects are provided in a spreadsheet as well as GIS shapefiles. Transects for the minimal option are labelled “priority 1”. The preferred option includes both “priority 1” and “priority 2” transects. A set of contingency transects are also provided, if required.
- Due to potential issues with insufficient detections of kangaroos, we do not recommend the use of fixed-wing aircraft for conducting aerial surveys in parts of Victoria.
- To overcome potential bias caused by failure to detect kangaroos on the transect line, we recommend the use of four observers in the aircraft (two on each side) and the employment of mark-recapture distance sampling techniques.

2 Introduction

The first aerial survey of the three kangaroo species inhabiting Victoria [Eastern Grey Kangaroo (*Macropus giganteus*), Western Grey Kangaroo (*M. fuliginosus*) and Red Kangaroo (*Osphranter rufus*)] was undertaken in September 2017 (Moloney *et al.* 2017). This aerial survey used line transect distance sampling methods (Buckland *et al.* 1993) conducted using a helicopter on 25 km transects randomly located across the state (Scroggie *et al.* 2017). Abundances of grey kangaroos in the area where these two species overlap, the grey kangaroo overlap zone (GKOZ), were also subject to a ground survey to assess the relative proportions of Western and Eastern Grey Kangaroos (Coulson 2017). These relative proportions were then used to adjust the aerial survey data of grey kangaroos within this region to obtain separate estimates for each species (Moloney *et al.* 2017).

Analysis of the combined aerial and ground survey data revealed that the overall abundance of kangaroos in the non-heavily forested areas of the state was around 1,442,000 kangaroos (95% confidence interval: 976,000 – 2,132,000). In addition to the overall abundance, kangaroo abundance estimates were also generated for each of 58 local government areas (LGA). This was undertaken to support decisions on kangaroo culling conducted under the Authority to Control Wildlife (ATCW) provisions of the Victorian *Wildlife Act* 1975. 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; 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). The amount of survey effort calculated was, in turn, dependent on the abundances of kangaroos that were likely to be encountered during the survey. Given that that this was the first such survey of kangaroos in Victoria, these abundance estimates were necessarily based on expert opinion (Scroggie *et al.* 2017). Analysis of the data from the 2017 aerial survey data indicated that the precision of abundance estimates for each stratum varied from 32% to 67%, somewhat higher than the target CV of 20%. Now that the first survey has been completed, an opportunity exists to use the results from the original survey to readjust the amount of survey effort to improve the precision of kangaroo abundance estimates.

2.1 Objectives

The analysis of the initial aerial survey data by Moloney *et al*. (2017) made the following recommendations to improve the precision of abundance estimates for individual LGAs:

- Increase the number of aerial survey transects in the Mallee, Otway and Gippsland strata to increase the precision of LGA abundance estimates in those regions, and especially for Red Kangaroo in the Mallee stratum.
- Reposition the ground survey transects in the grey kangaroo overlap zone to account for the apparent movement of this zone to the northwest. Ground survey effort in the Ararat, Buloke, Gannawarra, Horsham, Hindmarsh, Loddon, northern Grampians, southern Grampians and Yarriambiack LGAs should be increased.
- Ensure aerial transects do not cross townships or other obstacles and avoid excessive topographic variation.
- Consideration should be given to employing two observers on either side of the aircraft (four in total) and employing mark-recapture distance sampling techniques. This would allow correction for imperfect detection of animals close to the transect line.
- Consideration should be given to the use of fixed-wing aircraft for surveying transects in relatively flat open areas of the state. Use of fixed-wing aircraft reduces the possibility of responsive movement of kangaroos away from the aircraft compared with helicopters.

This report details work undertaken to revisit the original survey design methodology of Scroggie *et al*. (2017) in light of the above recommendations to recommend an improved survey design that should result in increased precision of abundance estimates within the sampled strata. In redesigning the aerial survey methodology, we considered areas subject to frequent ACTW applications, so as to obtain high precision in those areas where risk of overharvesting is highest. Both aerial and ground survey components were considered in the redesign.

3 Methods

3.1 Ground surveys of the grey kangaroo overlap zone

While Red Kangaroos are readily distinguished from grey kangaroos (GK) during aerial surveys, the two species of grey kangaroos are morphologically very similar, and cannot be reliably distinguished from the air (Caughley *et al.* 1984). Accordingly, aerial surveys conducted in the strata where both species of grey kangaroos co-occur [mainly Lower and Upper Wimmera, Moloney *et al*. (2017)] will only allow estimation of the abundance and density of both grey kangaroo species combined. Partitioning these estimates into separate estimates for Eastern and Western Grey Kangaroos requires additional data that provide information on the proportions of the two species present within the relevant strata. Related to this is some understanding of the likely location of the grey kangaroo overlap zone (GKOZ) that could be used to direct sampling effort most efficiently.

Initial attempts at defining the GKOZ was undertaken by fitting a binomial generalised additive model (GAM) to the spatially referenced occurrence records of WGK and EGK, and using the spatial predictions of this model to infer the likely location of the midpoint (contour of locations where the probability of a randomly sampled grey kangaroo is equally likely to be EGK or WGK) of the GKOZ. A predictive surface from this model (in raster GIS format) described spatial variation in this probability across the entire state (Scroggie *et al*. 2017, Figure 9). Based on this model, a series of ground transect surveys were planned and implemented (Coulson 2017). Overall, 90% of the grey kangaroos sighted by Coulson (2017) were EGK, making effective statistical estimation of the location and width of the GKOZ from this data difficult, due to the scarcity of WGK in the sample. The most likely explanation for the paucity of WGK observations by Coulson (2017), is that the current location of the GKOZ has been displaced in a north-westerly direction from where the model of Scroggie *et al*. (2017) had predicted.

3.1.1 Revising the location of the grey kangaroo overlap zone

To guide the selection of ground survey transects, additional statistical modelling of all currently available GK records from south-eastern Australia was undertaken. We extended the static spatial GAM of Scroggie *et al*. (2017) to include a temporal component, to allow estimation of movement of the GKOZ over time. This was done by referencing the records of both GK species from the Atlas of Living Australia in both space (latitude and longitude) and time (year of recording). The records of both species obtained during the previous ground surveys by Coulson (2017) were also included.

A GAM was fitted to the spatially and temporally referenced GK occurrence data to allow joint estimation of smoothing spline terms in both space and time. To eliminate influence of coastlines on the spatial inferences, a soap-film smoothing spline (Wood *et al.* 2008) was used for the spatial component of the smooth. A thin plate spline (Wood 2003) was used for the temporal trend, and the interaction between the space and time components of the smoothing was implemented using a tensor product approach (Wood 2017). The model was fitted using the R package `mgcv` (Wood 2017) using restricted maximum likelihood (REML) to fit the smoothing terms.

The fitted space-time model was then used to estimate the expected proportions of the two species at a fine-scaled grid of points (0.1° resolution in latitude and longitude) across the entire state, and into adjacent areas of NSW and SA during the year 2015. Spatial predictions for latter years (2016, 2017) were found to be somewhat unstable, so these were not used for prediction. We would anticipate that inclusion of further survey data from the proposed ground surveys in an updated version of the model would improve the stability of the inferences.

A contour line was drawn linking locations which were estimated to have approximately equal probabilities of occurrence for EGK and WGK (i.e. predicted probability of EGK=0.5), and this line was then used to select the location of road transects for further ground surveys. Eleven ground transects were selected and mapped. The following principles were used to inform the choice of transect locations:

- Transects were placed along roads, with most transect orientations close to right angles to the 50% GKOZ contour line.

- Transects were placed at approximately even intervals along the length of the GKOZ in Victoria.
- Transects were generally selected such that they were 150 – 200 km long, which approximates the width over which the expected proportion of Eastern Grey Kangaroos changes from 20% to 80%.
- Lower traffic “C” roads were preferred, to allow slow driving during surveys, and for the safety of the personnel undertaking the surveys. During surveys, personnel will need to frequently stop, park their vehicle, and observe at close quarters on foot any live or dead grey kangaroos encountered, which is easier and safer on roads with minimal traffic.

The intention of the above principles for transect choice was to ensure thorough coverage of the GKOZ, with approximately equal coverage of areas on either side of the GKOZ mid-line. The total length of the transects finally selected was 1850 km. Coulson (2017) detected over 1200 individual grey kangaroos (comprised of 180 distinct groups), suggesting that the overall survey effort (1587 km of formal transects, plus some incidental, off-transect sightings) was adequate to detect sufficient grey kangaroos to estimate the relative proportions of EGK and WGK across the state. Accordingly, the level of survey effort chosen here should provide an adequate number of observations for analysis.

We have prepared a set of example road transects that meet the above requirements (Table 1 and Figure 1). GIS files for the transects will be made available for use in the field by uploading to portable GPS receivers or other mapping devices.

The methodology to be used during the proposed program of ground surveys should be identical to that specified in Scroggie *et al*. (2017) and reported by Coulson (2017). Where necessary for practical reasons, such as road closures or observer safety, alternative transect locations could be used, provided they are generally representative of the overlap zone, meet the requirements specified above, and maintain a similar level of overall survey effort and coverage. If circumstances in the field dictate that a transect should be relocated, then a new transect in the same general area should ideally be surveyed using the same methodology to maintain approximately even survey coverage across the width and length of the GKOZ.

Table 1. Start and end points for eleven proposed ground transects across the Victorian extent of the GKOZ. Approximate lengths for each transect were determined using Google Maps.

Transect	Start locality	End locality	Latitude Start	Longitude Start	Latitude End	Longitude End	Transect length (km)
1	Swan Hill	Honeymoon Hut Track	-34.913	143.553	-35.340	142.035	177
2	Lake Boga	Pine Plain Lodge	-35.431	143.631	-35.460	141.933	175
3	Kerang	Lake Albacutya Park	-35.723	143.926	-35.741	141.994	200
4	Boort	Birdcage Nature Reserve	-35.933	143.725	-36.117	141.830	193
5	Wedderburn	Nhill	-36.333	143.617	-36.417	141.650	197
6	Logan	Cooack Settlement Road	-36.614	143.474	-36.617	141.757	180
7	Coleraine	Netherby	-37.600	141.663	-36.141	141.700	178
8	Casterton	Telopea Downs	-37.583	141.112	-36.126	141.400	194
9	Cavendish	Lake Road, Natimuk	-37.517	141.945	-36.700	142.034	108
10	Cavendish	Murra Warra	-37.517	142.224	-36.482	142.034	131
11	Barkly	Horsham	-36.719	143.222	-36.946	142.196	117
Total							**1850**

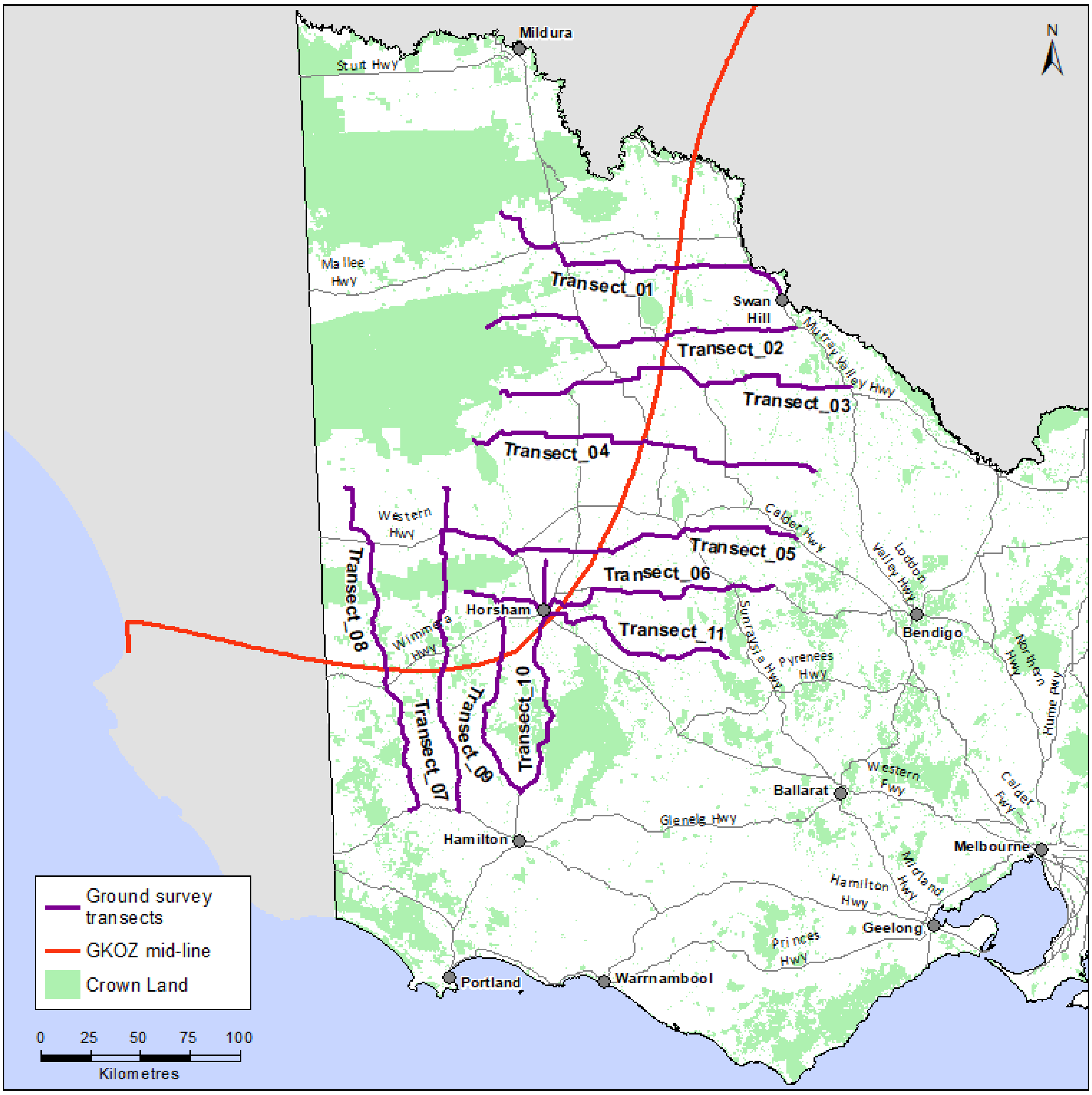

Figure 1. Proposed arrangement of ground transects for sampling the Grey Kangaroo Overlap Zone (GKOZ) in Victoria (purple lines). The overlaid red line is the approximate mid-point of the GKOZ, based on the predictions of the spatiotemporal GAM model.

3.2 Aerial survey design for Victoria

3.2.1 Study area and stratification

In general, we followed the same principles and methods used to design the initial aerial survey (Scroggie *et al.* 2017), which we briefly summarise here. We subdivided the state of Victoria into seven strata by amalgamating adjacent, ecologically similar LGAs (Figure 2). This stratification matches the stratification used in the initial design. It seeks to include the majority of the overlap zone between EGK and WGK within only two strata, to limit the geographic scale over which it would be necessary to apportion aggregated aerial count data for the two grey kangaroo species into separate assessments for EGK and WGK.

Several parts of the state were excised from consideration in our aerial survey design. First, we excluded LGAs that were entirely (or almost entirely) contained within highly urbanised parts of the Melbourne metropolitan area, given the regulatory and practical difficulties inherent in conducting aerial surveys at low altitude over urban areas as well as the likely low abundance of kangaroos in these areas. However, urban-fringe municipalities containing significant rural or semi-rural land use, such as Wyndham, Hume, Nillumbik and Casey, were included (see Figure 2), as these municipalities are known to support significant populations of EGK.

It is not practical to aerially survey kangaroos in those parts of the state covered by dense forest, as kangaroos cannot be reliably detected from the air in thickly forested habitat. However, we included areas with mallee vegetation in the area encompassed by our surveys, as experience both in Victoria and in other states has demonstrated the feasibility of conducting aerial surveys for kangaroos in mallee vegetation, given the low canopy height and density of this vegetation type. Further justification for the choice of sampling frame is provided in Scroggie *et al*. (2017).

We used the TREE100 GIS layer to excise forested areas (other than mallee) from the seven survey strata (Figure 2). We retained in our surveyed area those patches of forested habitat that were less than or equal to 100 ha in size—such fragments of forest typically exist as small islands of forest in larger areas of treeless or lightly timbered vegetation, and their exclusion from the survey area was therefore not considered desirable or necessary. Finally, we excluded from further consideration small offshore islands lacking extant kangaroo populations, including French Island (Figure 2).

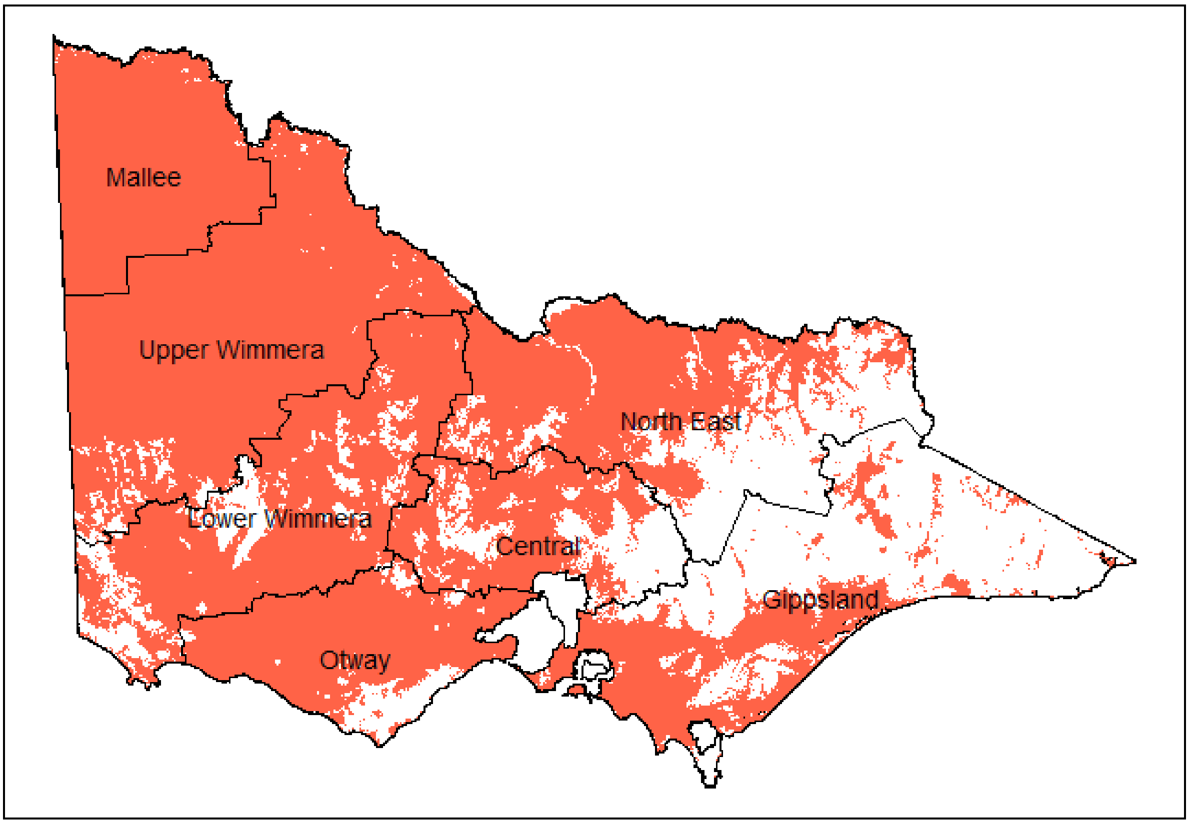

Figure 2: Map of proposed stratification scheme for state-wide kangaroo surveys. Shaded orange areas are non-forested and mallee vegetation types and are to be included in the survey. Unshaded areas are forested, highly urbanised or located on kangaroo-free offshore islands and therefore excluded from the survey.

3.2.2 Abundance simulation study

Utilising the data collected in the 2017 Victorian kangaroo survey (Moloney *et al.* 2017), a new simulation study was conducted to estimate the required amount of aerial survey effort. The goal was to obtain stratum abundance estimates with coefficients of variation (CV) less than or equal to 20%, the same goal as the previous design. The advantage now is that having actual survey data allows us to more accurately estimate the required amount of survey effort.

Our simulations have all made the simplifying assumption that groups of kangaroos are distributed entirely at random within each stratum. The density of the kangaroo groups and the mean group size for each stratum was estimated from the 2017 Victorian kangaroo survey (Table 2). The number of kangaroos in each group was assumed to be random and follow a truncated Poisson distribution. Based on the 2017 Victorian kangaroo survey, a hazard rate detection function was used with a scale parameter of 58.9 meters and a shape parameter of 1 (i.e. an exponential distribution).

Table 2: Parameters values used for each stratum in the aerial survey simulation. Coefficient of variation (CV), density of groups and average group size was estimated from the 2017 Victorian kangaroo survey.

Group	Strata	CV (%)	Density of groups (km^2)	Average group size
Grey kangaroo	Mallee	43	1.2	1.6
	Upper Wimmera	39	0.8	2.3
	Lower Wimmera	32	3.1	3.4
	Otway	54	1.3	2.1
	North East	40	2.0	3.8
	Gippsland	53	2.5	4.2
	Central	35	11.8	4.1
Red Kangaroo	Mallee	67	0.4	2.3

Analysis of the data from the 2017 aerial survey indicated that the precision of abundance estimates for individual strata ranged from a CV of 32% (Lower Wimmera stratum) to 67% (Red Kangaroos – Mallee stratum) (Table 2), which were greater than the target CV of 20%. Therefore, the overall level of survey effort needs to be increased to meet the CV target of 20%. The total length of transect used in the 2017 kangaroo surveys was approximately 1600 km. Therefore, we examined the improvement in stratum-level CVs that would be obtained from increasing the overall level of survey effort from 1600 km to 3200 km in increments of 400 km. The CV for each stratum was then assessed against the target of 20% to determine the appropriate effort for each stratum. We aimed for the highest precision within strata with the largest amounts of kangaroo culling occurring from ATCW applications (i.e. Central, North East and Lower Wimmera) or within the GKOZ (Upper and Lower Wimmera), as the risks associated with miscalculation of the harvest rate are greatest in these strata. Provided that placement of transects within the strata are a representative sample of prevailing kangaroo densities, within-strata variation in density should have a limited effect on the accuracy or precision of density estimates.

3.2.3 Results of the distance-sampling simulation study

The distance-sampling simulation study showed that the survey intensity did not have to be uniform across strata to achieve the target CV of 20% (Figure 3). The preferred option (3100 km of total survey effort) had all strata with a median CV less than 20% (Figure 3 & Table 3). The Mallee, Upper Wimmera, Otway and Gippsland required a doubling of the effort compared to the 2017 kangaroo survey while the Central, North East and Lower Wimmera strata could achieve the target with smaller increases in effort. It is possible that the total transect length within Lower Wimmera, North East and Central strata could be reduced and still achieve a target CV of 20%. However, this may impact the accuracy of abundance estimates in those areas with the highest number of ACTW applications or kangaroo pet food trial activity (Table 4). If the preferred option is not desirable, then it is suggested that a minimum option be undertaken (2,300 km of total survey effort). For the minimal option, all strata except the Mallee and Otway strata should have median CV under 20% (Table 3).

Table 3: Number of transects and effective transect length for the preferred and minimal options.

	Minimal option			Preferred option		
Strata	**Transects**	**Distance (km)**	**CV**	**Transects**	**Distance (km)**	**CV**
Mallee	14	314	20	19	439	18
Upper Wimmera	27	592	19	37	802	17
Lower Wimmera	19	402	12	24	489	11
Otway	11	238	23	17	359	19
North East	20	407	15	26	555	13
Gippsland	13	222	17	20	308	15
Central	8	145	10	10	180	9
Total	111	2321	7	150	3133	**6**

Table 4: The nominal kangaroo harvest rate (percentage of the estimated kangaroo population that potentially could be culled under ACTW authorisations) based on ACTW applications from January to October 2017. The percentage of ACTW (total authorisations) and kangaroo pet food trial authorisations (KPFT) within each stratum is also given.

Stratum	Harvest rate (%)	Total authorisations (%)	KPFT (%)
Mallee	3	1	0
Upper Wimmera	6	3	2
Lower Wimmera	11	30	47
Otway	8	3	0
North East	21	34	30
Gippsland	3	4	0
Central	5	25	20

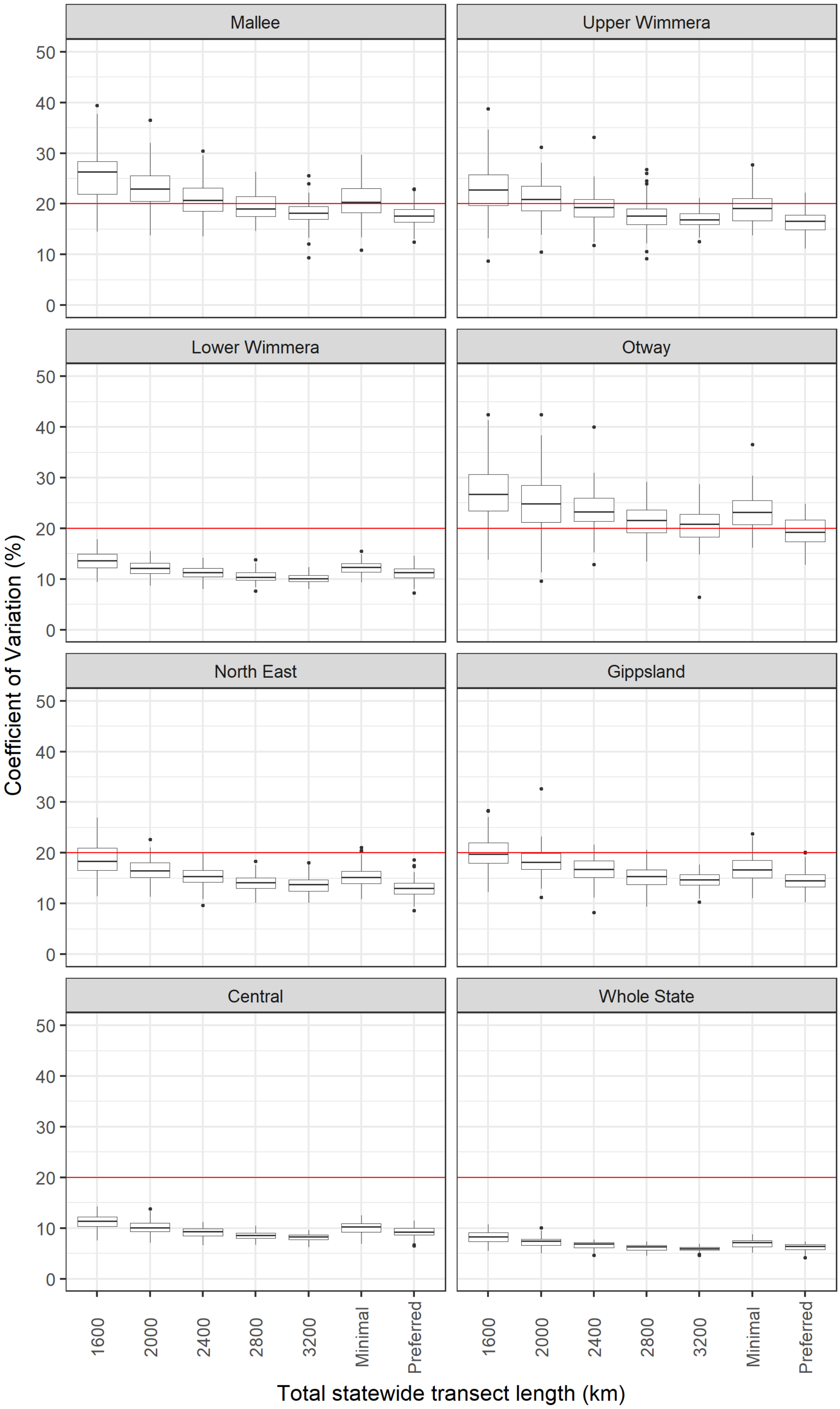

Figure 3: Simulation of the precision of kangaroo aerial surveys using the results from the 2017 survey. The horizontal axis denotes the total state-wide transect length in km; additionally, "Minimal" and "Preferred" represent options with mixed relative effort between strata; the vertical axis denotes the expected coefficient of variation of the kangaroo abundance estimates; the horizontal red line denotes the target CV of 20%. Results are based on 100 simulations of each level of total survey effort.

3.2.4 Location of aerial transects

A random selection of transects for each stratum has been generated for the preferred option (Figure 4). A further option (the minimal option) uses a subset of the preferred option transects. Two contingency transects for each stratum have also been included for use if a given transect cannot be surveyed for a specific reason. Some quality control has already been undertaken to ensure that transects avoid urban areas and waterbodies. The start and finish points of each transect can be found in the file "FlyCoords2018.csv". The file includes a column informing the type of transect. Priority 1 transects are part of both the minimal and preferred options and comprise the minimal number of transects to be surveyed. Priority 2 transects are only to be surveyed as part of the preferred survey option, or as a contingency transect for the minimal option. The number of transects per stratum and the total effective transect distance per stratum under the preferred and minimal options are given in Table 3.

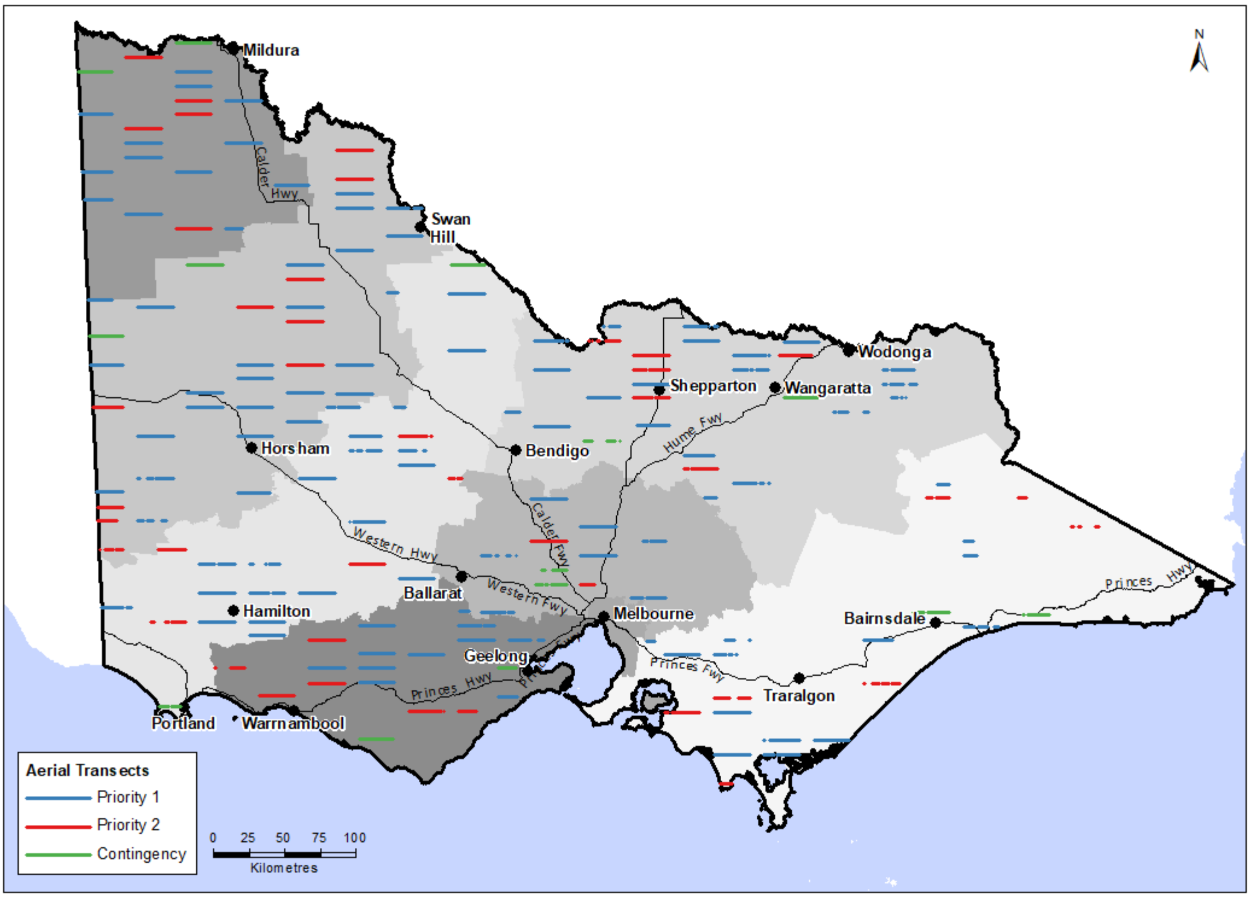

Figure 4: Map of proposed kangaroo aerial survey transects. Priority 1 transects will be used in either the preferred option or the minimal option. Priority 2 transects will be used only in the preferred option or contingency in the minimal option.

4 Conclusions

We have used the results from the first aerial survey of Victoria's kangaroo population to revise estimates of the amount of aerial and ground survey sampling effort required to provide increased precision of kangaroo abundance estimates. A new model of the occurrence of grey kangaroos (EKG and WGK) in south-eastern Australia enabled a revision of the likely current location of the grey kangaroo overlap zone (GKOZ). This, in turn, will allow more targeted sampling of the GKOZ, which should result in improved estimates of the relative proportions of EKG and WKG within the overlap zone (primarily Lower and Upper Wimmera).

Using the abundance estimates and line transect detection function fitted to the initial aerial survey data, we conducted simulation modelling to revise the amount of aerial survey effort that would result in abundance estimates for each stratum with high precision (i.e. CV < 20%). Based on these results we identified two possible options for survey effort. The minimal option represented by 111 transects totalling 2321 km had median CVs of < 20% for all strata except the Otway and Mallee. A preferred option represented by 150 transects totally 3100 km, had median CVs of < 20% for all strata. With either of these options it was likely that the precision of the overall estimate of kangaroo abundance for the state would be high, with a CV of less than 10%. It was notable that the minimal option was likely to produce estimates with < 20% CV in those strata having a high proportion of ACTW and/or kangaroo pet food trial applications (i.e. Central, North East and Lower Wimmera).

We initially considered the use of aerial surveys undertaken in the Mallee parks by Parks Victoria (Mackenzie 2017) as survey effort that could be incorporated into our analysis. However, the very low spatial coverage of the Mallee stratum by these surveys and their non-random location resulted in their having very little influence on our estimates. Essentially, the area sampled by the PV surveys amounted to only one to two extra transects. Although we did not include the PV surveys into our calculations, we will still be able to incorporate the results of these surveys into the abundance estimates, which should provide some additional sampling effort for the Mallee stratum.

It was reported that during the 2017 aerial survey that kangaroos often moved away from the helicopter during the survey (Lethbridge and Stead 2017), potentially violating the assumption that kangaroos are correctly allocated to distance classes. Although this responsive movement can often be accounted for in the analysis by combining distance classes, as was undertaken for the analysis of the 2017 survey data (Moloney *et al.* 2017), an option to reduce this responsive movement is the use of fixed-wing aircraft. The advantages of fixed-wing aircraft are that they are quieter and travel faster than a helicopter and hence, responsive movement by kangaroos is less likely and usually occurs after the aircraft has passed. A further advantage of fixed-wing aircraft is that operating costs are usually lower than for helicopters. The disadvantages are that due to the faster rate of travel over the transect, visibility is reduced and hence, fixed-wing aircraft are not suited to surveys of wooded or undulating terrain. In Victoria this would limit their use to certain parts of the state (e.g. Mallee, Upper and Lower Wimmera). In addition, dividing the survey into portions undertaken by two different techniques (fixed-wing and helicopter) would necessitate the estimation of separate detection functions for each aircraft type, lowering the sample sizes that could be used for estimation compared with the use of only one aircraft type. Since the lowest numbers of kangaroos occurred in those areas where fixed-wing aircraft would most likely be deployed, there exists the possibility that there might be insufficient number of detections to estimate the detection function for fixed-wing surveys. Therefore, we do not recommend the use of fixed-wing aircraft for part of the survey.

One of the assumptions of conventional distance sampling (CDS) is that all kangaroos on or very close to the transect line are detected with certainty. This assumption is unlikely to be true for aerial surveys (Fewster and Pople 2008). One way to overcome this issue is to use two observers on either side of the aircraft and employ mark-recapture distance sampling (MRDS) (Fewster and Pople 2008; Burt *et al.* 2014). Although logistically more challenging, mark-recapture distance sampling has the advantage of being able to correct for the bias introduced by imperfect detection on the transect line. Therefore, we recommend that mark-recapture distance sampling be employed for aerial surveys, preferably using four observers (two on either side of the aircraft). Use of mark-recapture distance sampling may serve to reduce the bias inherent in earlier estimates that assume perfect detection on the transect line. However, use of these methods will generally require a larger number of detections, to allow estimation of additional model parameters and hence obtain valid density estimates. It is important to note that the simulations presented in this report are not based on MRDS, and that the precision of MRDS estimates may be lower than the simulations (based on CDS) would suggest. Once MRDS data have been collected from the proposed surveys, further analysis and refinement of survey design methodology and parameters are advisable.