A Comparison of Methods for Kangaroo Population Monitoring

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Author's Declaration:

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution with the work of others cited where appropriate.

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Matthew Johnson

Abstract

Context. Macropods represent a multimillion-dollar industry within Australia, with multiple states employing management and commercial culling operations. All states require monitoring of abundance and distribution to target quotas and management actions. Terrestrial transect techniques such as walked transect survey (WTS) have been traditionally used in the peri-urban context, although new techniques and technologies are emerging. Remote Piloted Aerial System Survey (RPASS), and Camera Trapping (CT) are two such technologies with growing use in wildlife population monitoring, and there exists the need to compare their implementation over WTS methods. **Aims**. This study compared a WTS, RPASS and CT methods to estimate the abundance of *Macropus fuliginosus* in an enclosed peri-urban reserve to evaluate the use of these technologies for estimating macropod populations at a small scale. **Methods**. Survey of *M. fuliginosus* at a peri-urban reserve (Thompsons Lake, Perth, Western Australia) was carried out over two sampling periods (April: summer and August: winter). Data were analysed using Distance Sampling for both WTS and RPASS, and a spatially correlated detection model for CT survey. **Key results**. WTS yielded the highest population estimate and variability of all techniques [April: 1687±216, August: 2773±760 kangaroos in the reserve], with RPASS generating number estimates around half of these (with less variability) [April: 796±225, August:1326±365 kangaroos in the reserve]. Estimates derived from CT were unreliable due to statistical method variability. **Conclusions**. This study finds that RPASS and CT both have significant potential for future survey of *Macropus* populations; however, does not recommend implementation for monitoring of population number, until further study occurs. CT is highly subject to requirements of the modelling method; and whilst RPAS technology provides a number of benefits detection bias precludes its broad-scale adoption at this time. **Implications**. CT and RPAS exhibit a number of benefits that would make them

ideal for future use in management of *Macropus* spp. provided that sufficient research can be conducted to overcome the current limitations which inherently bias their estimates, and hence limit their employability

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Next, I would like to acknowledge the assistance of the Western Australian Department of Biodiversity, Conservation, and Attractions (DBCA). I would like to acknowledge not just the contributions of the department as a group but also make special note of both Tim Fischer and Ezgi Perincek. Tim and Ezgi acted as my contacts in the DBCA, Tim in establishing this project and finding it a home in the Thomsons Lake Reserve. Ezgi in advising me during data collection and constantly offering whatever assistance I may require. They have both made significant contributions to the success of this project, and things would not have gone nearly as smoothly without them.

I can not ignore the contributions of the Department of Primary Industries and Regional Development (DPIRD), without them it would have not been possible for me to conduct the drone surveys and this project may never have happened. Furthermore, I need to make specific mention of Dr Tracey Kreplins, who provided extensive assistance with the statistics used in this study, both in terms of implementation and troubleshooting.

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Abbreviations

Abbreviation	Definition
CASA	Civil Aviation Safety Authority
CT	Camera Trap; a remote sensing device used to gather data over extended periods of time via photography or videography
CTS	Camera Trap Survey; a survey via varying methods of a population or area employing a series/array of camera traps
DBCA	The Western Australian Government Department Biodiversity, Conservation, and Attractions
DPIRD	The Western Australian Government Department of Primary Industries and Regional Development
FLIR	Forward-Looking InfraRed, a form of camera technology that allows for collecting thermal imaging data
RPAS	Remote Piloted Aerial System; i.e. a RPAS or other Un-manned Aerial System
RPASS	Remote Piloted Aerial System Survey i.e. aerial survey conducted through use of an RPAS “Drone” system
ReOC	Remotely Piloted Aircraft Operator`s Certificate; issued by CASA this allows an individual; to operate a drone outside of standard conditions.
RePL	Remote Pilot Licence; a licence issued CASA that allows an individual to operate outside standard drone safety rules
WTS	Walking Transect Survey; a survey of a predetermined route through walking and recording of metrics such as distance and bearing

Chapter 1 Introduction

Kangaroo harvesting represents a multimillion-dollar industry within Australia (Spiegel and Wynn 2014), with multiple states employing management and commercial culling operations (Pople and Grigg 2000). Best practice management operations require monitoring of key population factors such as abundance and distribution because, without accurate and repeated assessment, any actions taken to conserve or manage populations can quickly be found insufficient or counterproductive. Monitoring is therefore central to wildlife management.

Traditionally, broad-scale surveys of kangaroo (*Macropus* spp.) populations have been carried out using manned aircraft such as fixed-wing planes and helicopter transect surveys, with exact choice of method depending on environmental factors such as ruggedness of terrain (Pople and Grigg 2000). Aerial techniques require use of correction factors derived from ground survey; and terrestrial techniques have flaws due to potential statistical violations related to underlying presumptions of the Distance Sampling method often used (importantly, that animals do not show reactive movement away from the observer). Within the peri-urban space, direct counts are more often performed using techniques such as walked transects, which have previously proved effective and accurate (Southwell 1989, Southwell 1994, Glass et al. 2015), or vehicle transects, which are subject to bias (Sinclair, Caughley et al. 2006).

1.1 Remote Piloted Aerial Survey

In recent years the rapidly evolving Remote Piloted Aerial Systems (RPAS) (colloquially referred to as a “drone” or UAV) has found growing support for use in wildlife monitoring, with some authors suggesting that the technology will revolutionise spatial ecology (Anderson and Gaston 2013). Remote Piloted Aerial System Survey

(RPASS) methods have increasingly been implemented for multiple species including birds in Europe (Sardà-Palomera, Bota et al. 2012), deer in North America (Chrétien, Théau et al. 2016), and large herbivores in China (Guo, Shao et al. 2018). A single study has been performed using RPASS for macropod population estimate (Gentle, Finch et al. 2018), comparing a fixed-wing RPAS against helicopter transects over a broad scale survey area. The authors found that the RPASS method was less effective than helicopter surveys (which are known to be more effective than walked transects (Clancy, Pople et al. 1997)). The RPAS system employed was more similar to a fixed-wing plane than a helicopter, and effects observed reflected such, with issues related to the ability to effectively identify animals noted. Previous research has indicated that fixed-wing aircraft are less accurate than a helicopter (Pople, Cairns et al. 1998, Pople, Cairns et al. 1998). This begs the question in relation to RPASS, what about use of a ‘quadcopter’ style system? Which hypothetically should not experience the effects observed in fixed-wing RPASS to the same degree being far more similar compared to a helicopter. The ‘quadcopter’ RPAS is expected to be far less susceptible to issues pertaining to loss of resolution due to speed, where the fixed-wing RPAS suffers from the inability to maintain position for long enough to generate effective or accurate imagery. The ‘quadcopter’ RPAS is additionally able to maintain this lower speed at a lower altitude, increasing the effective resolution in terms of pixels/m^2 compared to a fixed wing with the same camera that is forced to operate at a higher altitude.

RPASS in general presents several benefits:

- Generally RPAS present a physically smaller profile and is typically quieter than manned aerial vehicles (Mulero-Pazmany, Jenni-Eiermann et al. 2017).
- Disturbance from RPAS is significantly reduced when flying over macropods at elevations greater than 60m compared to increased or decreased elevations (Brunton, Bolin et al. 2019).

- Using a ‘lawn-mower’ flightpath (where an animal was not directly followed) reduces disturbance compared to targeted surveillance (Mulero-Pazmany, Jenni-Eiermann et al. 2017).
- RPASS presents a distinct advantage because permanent detailed digital records are generated and can be either analysed repeatedly by different observers, or multiple times abating of a number of concerns regarding previous aerial vehicle survey techniques (Fleming and Tracey 2008).

Despite these benefits it is known that obstruction can still occur in areas of thick canopy and obstructive cover (Chrétien, Théau et al. 2016). Combined with kangaroos preference for different environments based on time of day (Coulson 1993) this could have severe effects on detectability. These factors combined with a lack of specific literature relating to the application of RPASS for wildlife surveillance, represent a need for further research to assess the accuracy of RPASS against existing methods to improve the accuracy and bias of population estimates.

1.2 Camera Trap Survey (CTS)

Camera Traps have not seen significant adoption in macropod population estimation, despite their ubiquitousness with wildlife population monitoring globally accounting for hundreds of papers a year (Wearn and Glover-Kapfer 2017). Camera traps often rely on capture/recapture methodologies with animals that are uniquely identifiable such as *Pathera* spp. (Karanth and Nichols 1998, Silver, Ostro et al. 2004) or able to be rendered as such i.e. tapir (*Tapirus* spp.) (Trolle, Noss et al. 2008), quokka (*Setonix brachyurus*) (Dundas, Adams et al. 2014), or rock-wallaby (*Petrogale penicillata*) (Gowen and Vernes 2014).

It is only in recent years that spatially correlated models are being defined that have the capability to generate estimates of density where it is not possible to uniquely identify animals. The most recent of these methods being the technique ‘Estimating population density from presence-absence data using a spatially explicit model’ (henceforth referred to as “SPA”) developed by Ramsey et al. (2015).This model estimates density from spatial presence-absence data coupled with home range, avoiding the need to use Distance Sampling which has been required for previous models such as the random encounter model (Rowcliffe, Lucas et al. 2015).

Management of peri-urban kangaroo populations is typically complicated by the need to manage the expectations of a range of stakeholder groups whilst attempting to provide the best outcomes for the kangaroo population. Public perceptions have been shown to significantly affect the implementation of proposed management plans. This is demonstrated by a recent case in Perth, WA where plans to cull a population of kangaroos were cancelled following severe public outcry (Buck 2019). It is therefore necessary to implement controls and monitoring protocols that are not just realistic or cost-effective, but also socially and politically justifiable. The ability to generate these protocols stems not just from community engagement and education, but also through possessing robust data, an area in which the ability to employ CTS to generate population estimates potentially represents a significant advantage. This benefit would exist not just in the contexts of peri-urban reserves, but in broad-scale surveys as well with the potential to utilise several key benefits of camera trapping to generate more accurate data.

The ability to deploy CTS systems for long periods, and over extensive ranges has historically made camera traps a highly attractive approach when surveying terrestrial species (Wearn and Glover-Kapfer 2017, Wearn and Glover-Kapfer 2019). This allows for generation of extensive data and should result in less variability in estimates due to reduced effects of single day variability. Furthermore, the ability to generate measures regarding behaviour, animal interaction, condition score, and group dynamics would allow population monitoring for welfare and other factors simultaneously. This would increase the ethical return on investment for disturbance and impact caused by sampling allowing better implementation of the three R's; whilst providing additional data for community engagement and support of management decisions.

Despite this potential, there are significant limitations that may impact the applicability of this method for *Macropus* spp. that should be noted (Table 1). Notwithstanding these limitations, the potential benefit to be gained and the general trend of literature indicating camera traps as being highly effective tools for population surveillance, supports further investigation of the use of camera traps and SPA to estimate *Macropus* population abundance.

Table 1: Some of the key factors affecting the implementation of camera trapping methods, in relation to *Macropus* spp.

Factor Type	**Examples**
Technical	Camera traps have been shown to be more effective in closed habitats due to the range of a Passive Infrared Sensor (PIR) and/or the ability of an animal in an open environment to pass outside the activation range of the sensor (Wearn and Glover-Kapfer 2019). Given the available space this may result in erroneous counts, or misestimation. Misconceptions exist surrounding the nature of PIR that acts as a triggering unit for the majority of modern camera traps (Welbourne, Claridge et al. 2016). This may result in bias as a result of deployment architecture, altering measures gained The PIR requires a disparity to be observed between environmental and target temperature. This can affect the detection probability from these systems in cases where this is not observed. Such may occur on either warm days or where animals have attempted thermoregulation
Biological	Certain mammals including Kangaroos can detect the camera traps and their triggering, due to the ultrasonic and infrasound spectrums generated by the cameras during operation (Meek, Ballard et al. 2014). This may alter the interactions observed, the rate of interaction, or other factors, altering the number of contacts generated The variability observed in home range estimates of *Macropus* spp. at different locations such as that exhibited by *M. fuliginosus*, where variability depends on source and location with estimates in WA of 39-70ha, compared to eastern states estimates ranging from 221-769ha (Priddel, Shepherd et al. 1988, Arnold, Steven et al. 1992, Coulson 1993, Van Dyck, Gynther et al. 2013). This variability can potentially affect the underlying SPA method utilised, altering the usability of estimates generated, by altering the fit of the underlying statistical model.
Deployment characteristics	Deployment architecture structured to prevent theft or vandalism alters detection probability (Meek, Ballard et al. 2014). Such may result in disparate results depending on how each camera was deployed, and if bias occurred in site selection that differed based on individual locations.

1.3 Walked Transect Survey

The method that these measures are to be compared to is the Walked Transect Survey. The WTs has been selected due to its extreme prevalence within the field and the similarity to the RPASS. There are multiple methods for conducting transect survey of macropods (Southwell 1989), with these often suffering bias introduced as a result of statistical violations. Inaccessibility of terrain along the transect (Southwell, Weaver et al. 1995), changes in detectability as a result of differing viewable distance between stratifications (Southwell, Weaver et al. 1995), and disturbance as a result of sampling (Glass et al. 2015), are all notable factors that may introduce estimation bias.

This bias is linked to violation of the underlying Distance Sampling assumptions; i) when conducting survey for Distance Sampling all animals must be detected at their initial points, ii) all animals present must be detected, iii) the measurements taken of the locations of these animals must be unbiased, and iv) the likelihood of detection must exhibit a ‘shoulder’, i.e. the odds of detection must change over distance. (Buckland, Anderson et al. 1993, Buckland, Anderson et al. 2001).

Assuming these four key assumptions are met, there is little reason to doubt the validity of generated data solely based on statistical grounds (Buckland, Anderson et al. 1993, Buckland, Anderson et al. 2001, Buckland, Anderson et al. 2004), and even suffering from such violations there is significant evidence that WTS provides accurate estimates of macropods (Glass et al. 2015), with accuracy affected significantly by sampling intensity where elevated numbers of survey and higher sampling intensity are required to generate accurate estimates (Glass et al. 2015).

1.4 Why did we use this species?

In this study *Macropus fuliginosus* was utilised as an analogue for other *Macropus* spp. due to the availability of a sufficiently large population in an enclosed reserve which are the focus of current management consideration. This availability is considered alongside several other key factors such as, physiological factors where *M. fuliginosus* is large and sexually dimorphic but individually unidentifiable (Coulson 2008, Menkhorst and Knight 2011) aligning with use of the SPA method. Behavioural factors where crepuscular behaviour of *M. fuliginosus* which employs heterogenous environs with preference shifting with time of day; grazing in twilight hours before moving to open grassy areas to feed throughout the night (Coulson 1993, Coulson 2008), potentially aligning with ideal detection conditions for the RPASS used. Scalability, where *M. fuliginosus* shows extensive distribution across Australia inhabiting multiple habitat types (Menkhorst and Knight 2011, Van Dyck, Gynther et al. 2013), with variable home range noted representing a factor that will play a key determination of applicability of the SPA method. These characteristics represent factors that will affect the use of our assessed techniques, and that will potentially carry over into other species of macropod.

1.5 Aims

This study focuses on assessment of the effectiveness of emerging techniques and technologies such as RPASS aerial survey and the SPA CTS method; compared to a traditional WTS utilising *M. fuliginosus* as an analogue for other *Macropus* species. This assessment to be performed in an enclosed peri-urban reserve aims to compare estimates generated from each method, intrinsic factors that affect deployment of these systems, and effectiveness of these systems in a management context.

Chapter 2 Methods

2.1 Study Site

Thomson's Lake Reserve is a 551ha peri-urban fenced nature reserve (Australia 2005) located approximately 34km Southwest of Perth Western Australia (Latitude, -32.150025, Longitude, 115.8290346) (Figure 1). Approximately 151 ha of the reserve is comprised of seasonally ephemeral wetlands (Australia 2005); the wetlands are heavily influenced by yearly and seasonal climatic conditions, with the lakebed observed to dry entirely for extended periods during the summer months (Australia 2005).

Woodland areas within the reserve are primarily comprised of *Eucalyptus* spp. and *Banksia* spp. (dominated primarily by *E. marginata, B. menziessii and B. attenuata*) with areas surrounding the lake comprised of sedgelands and fringing woodland comprised of *Eucalyptus* spp. and *Melaleuca* spp. (primarily *E. rudis* and *M. preissiana)* (Australia 2005). The Department of Biodiversity Conservation and Attractions (DBCA) acknowledges the presence of three native terrestrial vertebrate species of relevance to this study that occur within the reserve; western grey kangaroo (*Macropus fuliginosus*); quenda (*Isoodon fusciventer*), and brush-tailed possum (*Trichosurus vulpecula*) (Australia 2005).

The reserve is managed by Department of Biodiversity, Conservation and Attractions (DBCA) with adjacent land use, including semi-rural and urban developments (Australia 2005). The site is bounded by a 'vermin-proof' secured chain-link perimeter fence built-in 1993 with several fauna 'underpasses' to enable passage of tortoises at the north end of the reserve (Australia 2005). There is an existing history of management actions at Thomson's Lake Nature Reserve including a cull of *Macropus spp.* in 2006-7 where at least 1000 kangaroos were removed from the reserve, with anecdotal evidence suggesting that numbers have returned to their pre-cull numbers (Parks and Wildlife Service 2019).

The reserve is open to the public with several walking trails both around and through the site (Australia 2005) (Figure 2). Domestic animals such as dogs and horses are prohibited within the reserve (Australia 2005). *Phytophthora cinnamomi* (commonly termed 'Dieback') has been recorded in Thomson's Lake Nature Reserve (Australia 2005). A map showing affected areas is included in Figure 3

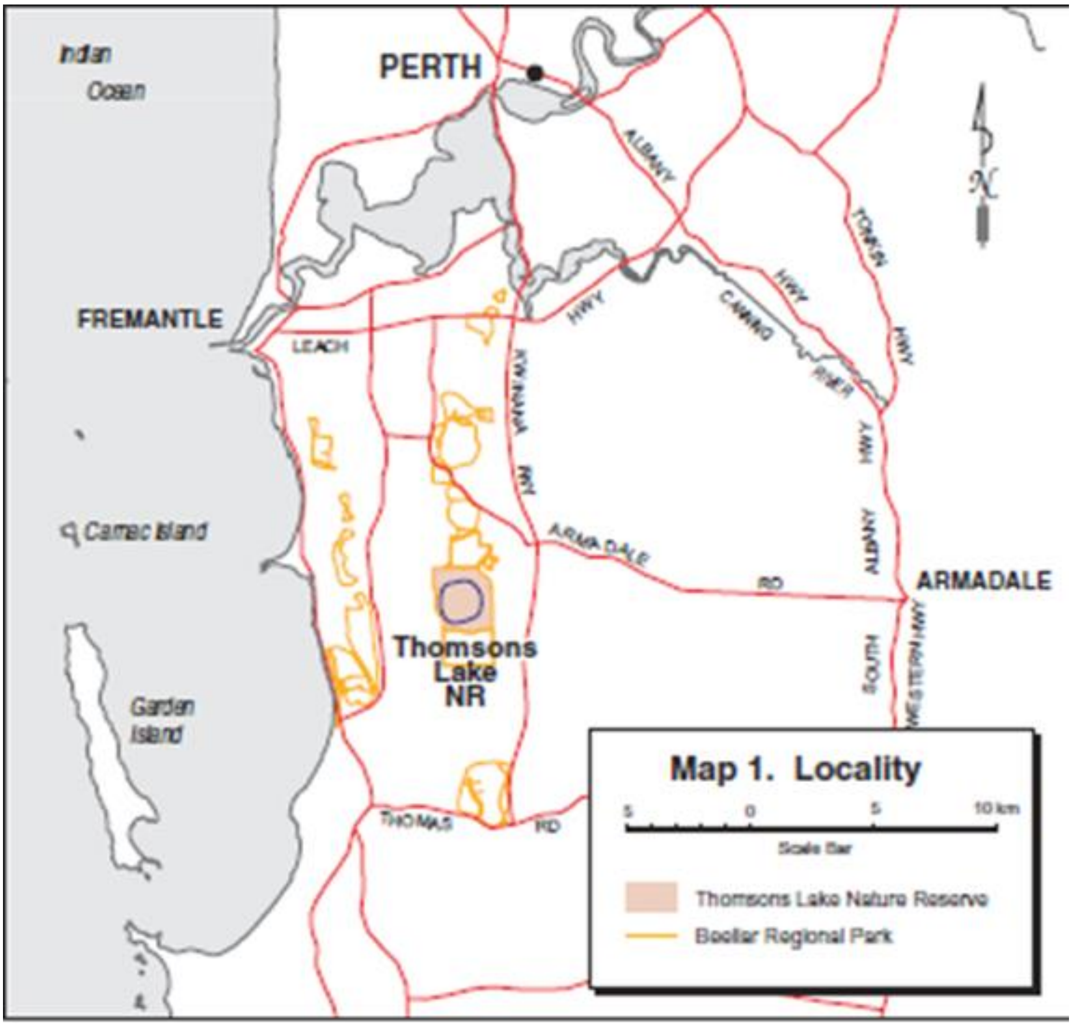

Figure 1: The geographical location of the study site, Thomson's Lake Nature Reserve, in relation to surrounding points of interest from (Australia 2005)

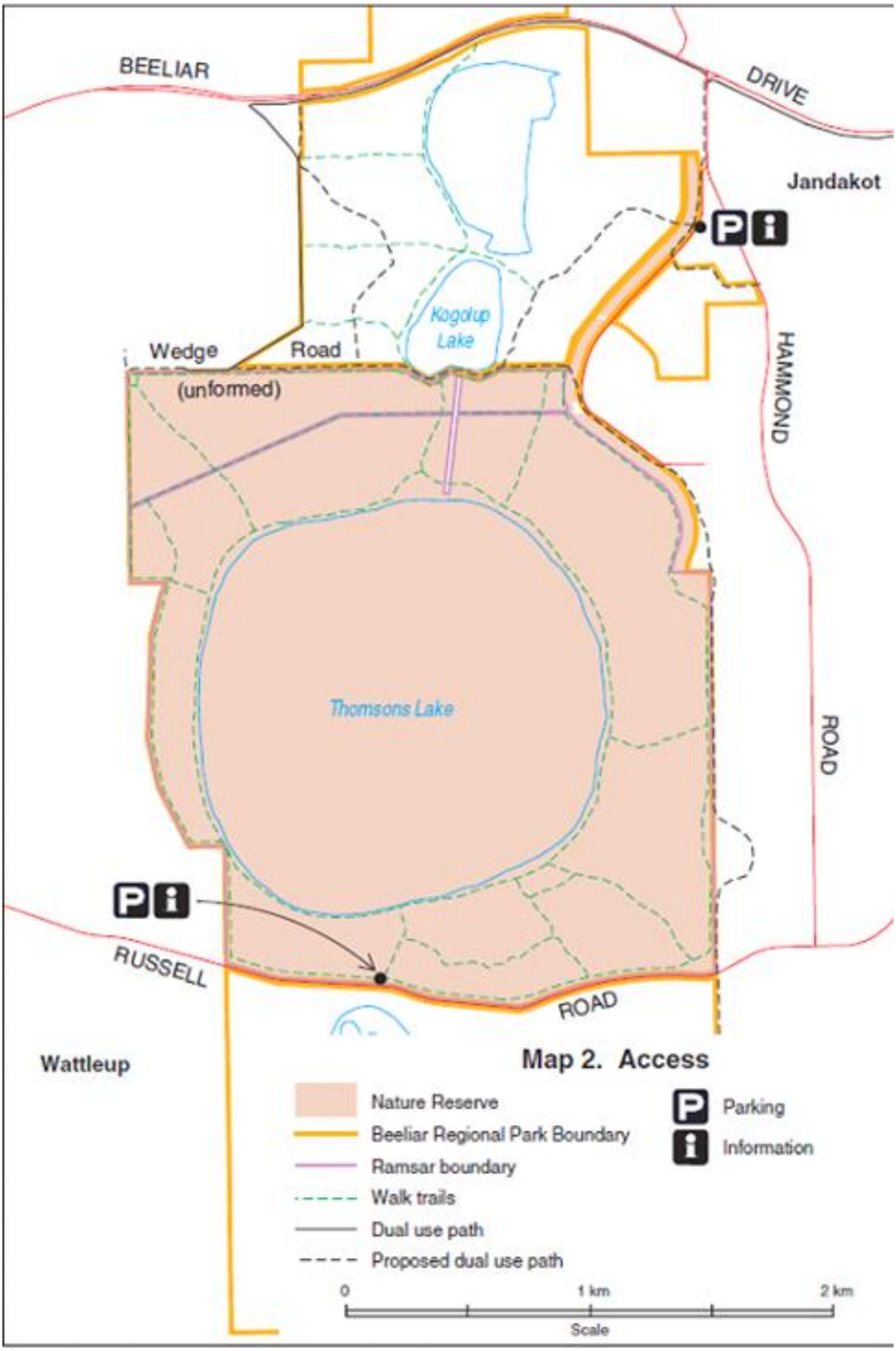

Figure 2: A map of the Thomson's Lake Reserve study site showing access features within and surrounding the site, from (Australia 2005).

Figure 3: A cropped satellite image taken from the Beeliar Regional Park Fire Response Plan November 2018 (Western Australian Government 2018), showing Thomson’s Lake Reserve.

NOTE: Areas highlighted in red or pink represent critical areas of *Phytophthora cinnamomi* risk within the Thomson’s Lake Nature Reserve, blue lines represent the access trails within the reserve, and the yellow lines represent the reserve boundaries.

2.2 Experimental design

For the purposes of this study Thomson's Lake Nature Reserve was stratified into three common vegetation types;

1. Bushland- defined by densely packed *Eucalyptus* spp. or *Banksia* spp. typically located on the raised sandy uplands surrounding the lake and its intermittent areas.
2. Transitionary- defined by sparse woodlands and large contiguous open spaces often bisected by fire access trails and vehicle trails located primarily between the bushland stratum and open lakebed areas.
3. Lakebed- comprised of the areas that commonly are submerged during winter. This area was defined by vast open spaces and minimal obstructive ground cover.

The Bushland stratum represented the greatest proportion of the reserve (51%), followed by the Lakebed stratum (27%) and Transitionary stratum (22%). During the August sampling period as a result of aqueous inundation of the Lakebed stratum, the Bushland stratum comprised a significantly elevated percentage of the reserve (70%) as did the Transitionary Stratum (30%) of the above water reserve (Table 2).

Sampling was initially scheduled to occur starting on the first of each month between April and August inclusive. Due to unforeseeable limitations this was adjusted to only include sampling during April and August. These limitations were associated with environmental conditions and availability of critical resources and personnel that precluded the employment of RPAS and CTS systems.

Table 2: List of the approximate areas of each habitat stratum within Thomson's Lake Reserve by sample period including the percentage of the reserves total sampleable area.

Sample Period	Stratum	Approximate Area (ha)	Percentage of Sampleable Area
April	Bushland	281	51%
	Transitionary	119	22%
	Lakebed	151	27%
August	Bushland	281	70%
	Transitionary	119	30%
	Lakebed	151	0%

2.3 Population estimates

2.3.1 Walking Transect Survey

There were a total of four WTS conducted for each sample period at Thomson's Lake Reserve with each survey occurring in numerical sequence beginning at 8:30am on the day in question. Surveys dates were selected around weather, within a week of the camera trap collection dates. All surveys were conducted by travelling from the outermost edge of the reserve on a bearing for the middle of the lakebed or as close as possible and noting any and all animals at their initial distance within the visual field. The total time to complete the surveys was approximately 2–3 hours. The allocation of the exact start position for each transect was initially random with both sample periods attempting to employ the same start point and bearing across both periods (Figure 4). In August, transect 3 was moved due to part of the original being submerged and due to *P. cinnamomi* control quarantine restrictions. Data was gathered by a single individual for the April sample period and with a recorder for August. The specific data gathered by survey was relative compass bearing to animal contact, distance to contact (measured using a laser Rangefinder, (Pinloc 5000i, Sureshot, Nunawading, VIC 3131)), and animal cluster/group size.

Reactive movement was observed in all instances of WTS sampling, subsequently it was not possible to assess the distance to the target animals directly. This resulted in all distances recorded being for landmarks that were in closest proximity to where the animal had been on initial detection.

WTS data was analysed using Distance Sampling. The varied assessable areas that were observed during the survey due to the differing densities of obstruction by stratum necessitated analysis treat viewable area as a covariate for each detection. This was performed by utilising the median viewable distance observed at the point of detection (distance between the observer and the major obstruction up to 200m) paired with transect length (effort) to calculate assessed area for each transect, allowing for calculation of density.

Figure 4: Walked Transect Sampling locations, (a) April and (b) August

NOTE: red lines with yellow pins are the transect paths, while the boundary is represented by a solid red line

2.3.2 Camera Trap Survey

Thirteen Reconyx™ Hyperfire HC500 (Reconyx Inc., Wisconsin, USA) camera traps were mounted to an individual post at approximately 1m above ground level per stratification. The cameras were calibrated to their highest sensitivity to be triggered using motion or PIR sensors and set to collect five images in 'rapid-fire' mode, with no 'quiet' interval between triggers. All cameras were deployed between 08:00h–13:00h and recovered 14 days later. Deployment was conducted using three transects per stratum (two transects of four cameras and one of five) placed at random positions within each stratum. Cameras were established at random intervals along these transects. No camera trap location was reused during both sample periods. All cameras were deployed facing south to reduce solar glare. Where possible, cameras were secured to a large object with a 'python-Lok' (Python™ adjustable locking cable, Masterlock Co., Wisconsin, USA) and all cameras were deployed with 'codelock' password protection enabled. Cameras were tagged with a precise GPS location using the author's phone and a photo of their surrounds taken to ensure the best chance of recovery using the application *Trail Maker* (DiDomenico 2019). The location of all cameras during both the April and August sample periods are shown in Figure 5.

During April sampling two cameras malfunctioned, resulting in 12 working cameras in the Bushland stratification, and 14 in both the Lakebed and Transitionary stratifications. During August sampling, one camera was unable to be deployed due to lack of sample sites along the first transitionary transect and was reallocated to another transect within the same stratum.

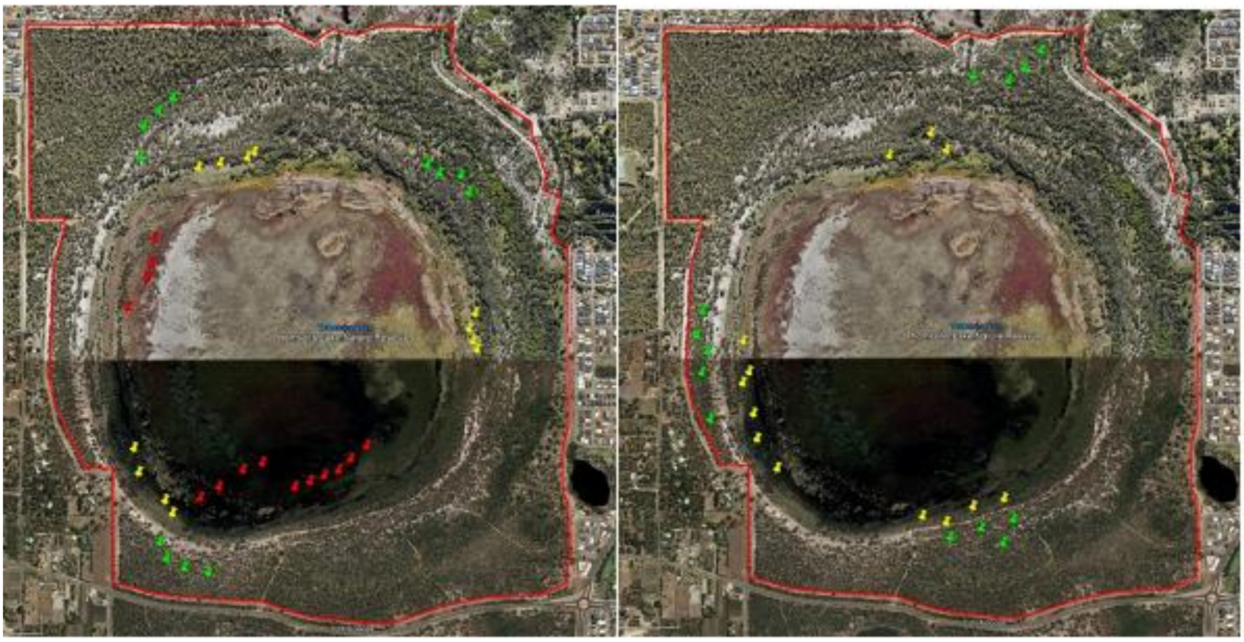

Figure 5: Camera Trap Locations, Thomson’s Lake Reserve, (a) April and (b) August. NOTE: Red: Lakebed, Green: Bushland, Yellow: Transitionary

Following retrieval photos were tagged using *ExifPro2.1* (Kowalski 2013) using the tags listed in addendum (Appendix B, Figure 12) and metadata for each camera trap was then extracted into directories and subdirectories (stratum and transects). Images of bycatch, recaptures of the same animals, or images that were not interpretable were removed. The remaining images subsequently had their ‘EXIF Info’ exported through the program *ExifPro* (Kowalski 2013), and into a comma-separated value (.csv) format that could be managed through the use of Microsoft Excel. Additional processing was then conducted to ensure standardised formatting within the exported .csv file.

The R package *unmarked* (Fiske and Chandler 2011) was used to calculate measures of occupancy from this data, focussing on effects of stratification and sample period on detection and occupancy. The SPA code developed by Ramsey et al. (2015) was employed to generate estimates of density and occupancy, with additional testing performed using 17 identical computers to run the SPA code a total of three times per machine to generate estimates of variability observed in the estimates of both density and SE.

2.3.3 Remote Piloted Aerial System Survey

Remote Piloted Aerial System Surveys undertaken in this study was conducted using a DJI Matrice 210 “Quadcopter” (SZ DJI Technology Co., Shenzhen, China.). This system was equipped with a dual gimbal mount holding both a Zenmuse X4S 4K RGB camera (Zenmuse X4S, SZ DJI Technology Co., Shenzhen, China.) and a Zenmuse XT Forward-Looking InfraRed (FLIR) Thermal Camera (Zenmuse XT (9hz, 640 x 512, 9mm lens), SZ DJI Technology Co., Shenzhen, China.)). This system used interchangeable batteries (TB50, SZ DJI Technology Co., Shenzhen, China) that allowed for repeated operations with an average lifespan of 15 minutes of flight time.

All RPASS operations were targeted to comply with Civil Aviation Safety Authority directives in AC101-01v2.1 (Australian Government 2018) to ensure legislative compliance (see Appendix A Legislative Compliance). Data gathering occurred over three consecutive days per sample period with flightpaths utilised shown below (Figure 6). Survey consisted of six flightpaths, five covering the area surrounding the lake with one covering the lakebed itself. These same flightpaths were to be carried out across both periods. Deviation from this occurred where in August:

a. Technical difficulties related to change in restricted airspace permissions arose resulting in an initial attempt being used as a pilot survey, the data for which has been excluded.
b. The ‘Lakebed’ flightpath was discontinued following the initial pilot survey, due to flooding of the stratum rendering it inaccessible for the target species.

c. ‘Flightpath 4’ showed an increase in electromagnetic interference during pilot survey resulting in prematurely terminated operations. To avoid recurrence during further operations and impediment of sampling efforts flightpath four was abbreviated and is termed as such

Arrival at the reserve was targeted for sunset with movement into the reserve to the points of launch being undertaken at this time. Travel via vehicle within the reserve was at no greater than 20km/h to reduce disturbance of kangaroos. Flight surveys were conducted sequentially with RPASS flight transects operating ahead of the vehicle to minimise the likelihood of animals being dispersed prior to surveys.

All RPASS operations used a pre-plotted and automated flightpath undertaken through use of the ‘DJI Pilot’ flight control software *(*DJI Go 4, SZ DJI Technology Co., Shenzhen, China.), installed on a ‘DJI CrystalSky monitor*’* (GL800A (Android), SZ DJI Technology Co., Shenzhen, China.). This was done to minimise the possibility of user error and allow for comparison of flightpaths more accurately across individual days and sample periods. Surveys were conducted during post twilight hours to increase thermal discrimination between the target species and the environment (Anderson and Gaston 2013) in an effort to increase detectability.

All survey operations used a flight altitude of 55m above ground level, this height being chosen to reduce reactive movement as a response to the RPAS (Brunton, Bolin et al. 2019), whilst maintaining sufficient resolution from the thermal sensor. The proximity of the Jandakot Aerodrome which is expected to result in habituation of the populations to the presence of aerial traffic. A velocity of 5m/s was used to increase the accuracy of coverage at the altitude chosen and resolution available on the FLIR camera, with RPAS sensors orientated at 55 degrees to allow for operator override in case of unforeseen physical obstruction i.e. trees.

Figure 6: RPASS Flightpaths over Thomson's Lake Reserve.

NOTE: red lines: RPASS Flightpaths; blue lines: perimeter of the reserve; red line with a yellow background indicates the Truncation point for Flightpath 4 during August sampling.

Data generated by the RPASS was viewed using a standard computer monitor displaying at 1080p resolution (S230HL, Acer Inc., New Taipei City, Taiwan) with distance boundaries (0-10m, 10-20m, 20-30m, 30-40m, 40-50m, and >50m) marked off using string, Blu-Tac and duct tape (Figure 7). Analyses used the midpoints of these ranges for Distance Sampling due to an inability to determine exact distance. Due to the nature of imagery generated by the RPAS system, all assessment was done in a blackedout room to minimise glare or reflection. The calibration information for this analysis including basic scoring instructions and scoring device creation is included in appendices (Appendix B, RPASS Scoring Directions).

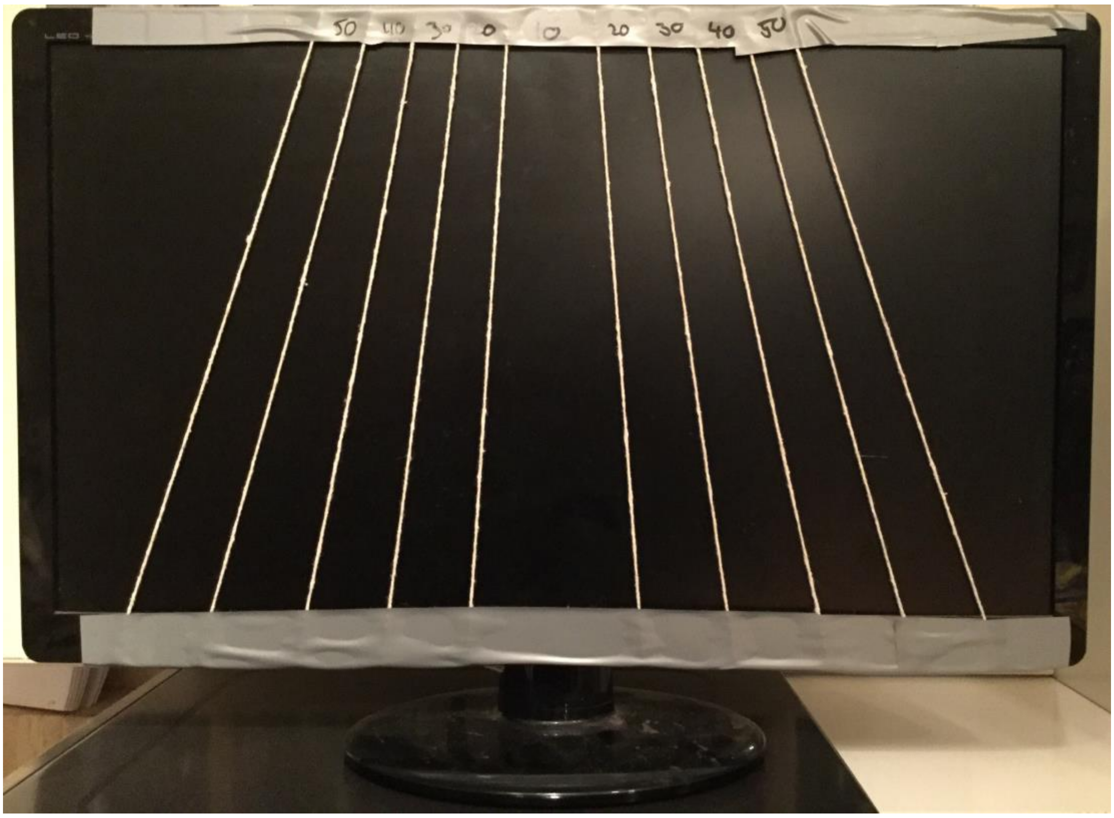

Figure 7: RPASS Scoring Monitor used in this study

The nature of data generated necessitated further analysis pertaining to average assessable area for each stratum during each sample period. To this end still images were taken from footage generated for each flightpath at thirty (30) second intervals. These images were then entered into the program ImageJ (Rasband 2012) and assessed for the total area within each image that was coloured as bright or brighter than the animal heat signatures appeared. This was done to give an estimate of the percentage area that was thermally obstructed within each image and the results tabulated. The code for this operation is included in the Appendices (Appendix B Figure 11). This data was then associated with location by timestamp to associate each value with a specific stratum to give data on average “thermally obstructive cover percentage” by stratum and detection location.

Detection data was processed using a generalised non-linear model with the distribution defined as a Poisson distribution due to the data distribution shown (Figure 8), and using the Distance Sampling method using the R Package Distance (Miller, Rexstad et al. 2019). The use of Generalised non-linear model was undertaken to assess the correlation between covariates and detection rates. Specifically, this analysis assessed the relationship between detection number and; stratum, sample period, or thermally obstructive cover percentage. Estimates derived from individual stratum Distance Sampling analysis were then used to extrapolate both stratum specific values and estimates of number for the reserve as a whole using conversion factors proportional to the area of the whole reserve represented by such during each period.

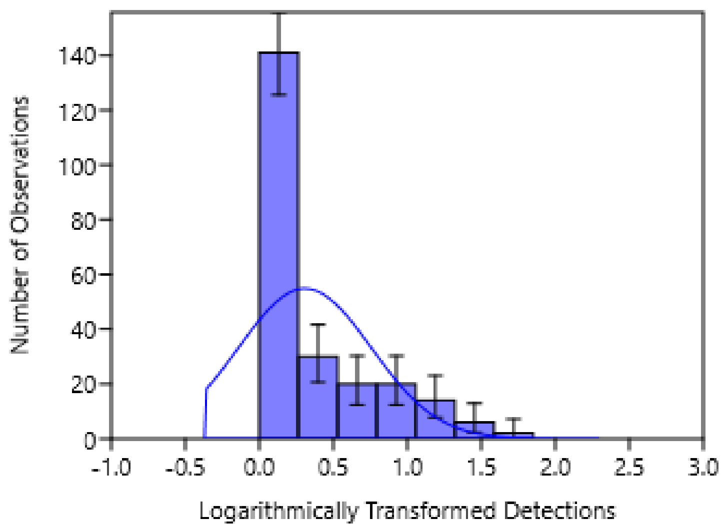

Figure 8: The distribution of logarithmically adjusted RPASS detection data, fitted to a Poisson distribution

NOTE: Error bars are presented as CI95%

2.4 General Statistical Conditions

All analysis conducted within this study assesses statistical significance at a P-value of 0.05 ($p<0.05$).

All analysis conducted for Distance Sampling was conducted using the package *Distance* (Miller, Rexstad et al. 2019) for *R Statistical analysis software* (R-Core Team 2019`) within the program *RStudio* (RStudio Team 2019).

Any estimations of number presented were corrected in the following ways: In instances of negative values (i.e. CI95% <0) such estimates were corrected to zero (0). In the case of decimal numbers as estimates of animal number all numbers are rounded up to the nearest whole animal for presentation with exact values being used for calculation.

All values are presented as mean ± 1 standard deviation except when stated otherwise

Chapter 3 Results

The estimates derived from on foot survey (WTS using Distance Sampling) resulted in the largest mean estimate and most extensive range [April: 1687 individuals (1264–2110 95% CI), August: 2773 (1282–4265 95% CI) individuals]. The estimate derived from the aerial survey (RPASS using Distance Sampling) was almost half of these values (Table 3). The estimates generated through analysis of camera trap data (CTS using the SPA method) were 22.1 and 221 times smaller than that produced by RPASS in April and August, respectively (Table 3) and inconsistent with even uncorrected counts.

Table 3: *Macropus fuliginosus* population estimates for Thomsons Lake Reserve by sample period and method

Sample Period	Method	Estimation Method	Mean	(95% CI range)	SE	CV
April	WTS	DS	1687	(1264–2110)	216	0.128
	CTS	SPA	36	(0–85)	25	0.694
	RPASS	DS	796	(355–1374)	225	0.283
August	WTS	DS	2773	(1282–4265)	760	0.274
	CTS	SPA	6	(4–7)	2	0.333
	RPASS	DS	1326	(611–2042)	365	0.275

3.1 Walking Transect Survey

There was a significant difference in sampling intensity because of an alteration to transect length and the use of median viewable distance to estimate area experienced between April and August. April showed an average sampling intensity of approximately 1.96 times that of the August period (Table 4).

Table 4: Average Sampling intensity for all Walked Transects undertaken within each sampling period.

Sample Period	Area assessed by WTS (ha)	Total Accessible Area of Reserve (ha)	Percentage of Reserve sampled (%)
April	30.188	551	5.48
August	11.141	400	2.79

Walking Transect Survey data indicated an on average 16% greater estimate across all transects during April (93 ± 12 animals) compared to August (78 ± 21 animals) (Table 5) but this change does not account for the difference in sampling intensity observed between the two periods. The changes in density between these two periods indicated on average density was 2.2 times higher in August [April (3.06 ± 0.39), August (6.93 ± 1.9)]; with more significant variability being observed during August, generating a coefficient of variation 2.14 times greater than during the April period (Table 5).

Table 5: Estimates of *Macropus fuliginosus* number and density obtained by WTS combined for all transects by sample period prior to extrapolation for whole reserve numbers.

Sample Period	Density (Animals/ha)				Estimated number		
	Mean	SE	(95% CI)	CV	Mean	SE	(95% CI)
April	3.06	0.39	(2.29-3.83)	0.128	93	12	(70-116)
August	6.93	1.9	(3.21-10.66)	0.274	78	21	(37-120)

3.2 Camera Trap Survey

Camera Trap Survey data analysed using occupancy methods indicated differences in occupancy observed were best explained by sample period and by stratum (Table 6).

There was a significant increase in occupancy during the August period (*β*, 8.31 ± 43.9) compared to the April sample period (*β*, 2.51 ± 0.6) (Table 6). Detection was significantly varied by stratum with higher detection probability for Lakebed (*p*, 1.1 ± 0.19) cameras compared to both Bushland (*p*, 0.16 ± 1.10) and Transitionary cameras (*p*, 0.33 ± 0.33) (Table 6). There was no measurable difference in occupancy estimates with stratum ($H_{2, N=18}$ = 2.17, p=0.339) or time of day (day/night: $H_{1, N=18}$ = 0.018, p=0.894).

Table 6: Truncated results showing the best model from occupancy analysis of CTS data generated for *Macropus fuliginosus* showing occupancy and detections estimates.

Model	Parameter	Estimate (SE)	AIC	AICwt
4	*β* (Intercept-April)	2.51 (0.6)	1245.22	1.00
	β(August)	8.31 (43.9)		
	p (Intercept-Bushland)	0.16(1.10)		
	p (Lakebed)	1.10(0.19)		
	p (Transitionary)	0.33(0.15)		

β = coefficients of logistic regression on the probability of occurrence. *p* = detection probability. Results are truncated due to the differences in AIC observed between models with only the best-fitting model being shown. A complete table of all models examined is available in appendices (Appendix B Table 15)

The SPA analysis method indicated significant variation within results generated for measures of density from the repetitions completed (n=51) an overall mean coefficient of variation of 0.993 ± 1.734 was generated. The observed variation in coefficient of variation indicating extensive variability within estimates generated from the same dataset. Data used in this analysis is available in Appendix D.

The estimates derived for whole reserve number because of use of differing home ranges showed significant variation. This variation was not consistent across estimates nor was there a discernible pattern to the variability introduced (Table 7).

Table 7: Estimates of density for CTS employing SPA method and differing home range estimates

Home Range Estimate values (Min, Median, Max)	Sample Period	Density (Animals/ha)			Reserve Number Calculated Values	
		Mean	**SD**	**(95% CI)**	**Mean**	**(95% CI)**
A = (39, 54.5, 70 ha)	April	0.064	0.045	(0*–0.153)	36	(0*–85)
	August	0.013	0.002	(0.008-0.017)	6	(4-7)
B = (221, 340, 459 ha)	April	0.962	0.409	0.161-1.763	531	(89-972)
	August	0.012	0.003	0.007-0.018	5	(3-8)
C = (540, 692, 844 ha)	April	0.064	0.028	0.009-0.119	36	(6-66)
	August	0.012	0.003	0.006-0.018	5	(3-8)

*Negative values converted to a minimum of zero.

3.3 Remote Piloted Aerial Survey

Remote Piloted Aerial System survey data analysed by Distance Sampling indicated a higher number of animals around the lake (Transitionary Stratum) compared to the Bushland, or Lakebed (April only) (Table 8). During April the Bushland Stratum showed an elevated density and estimate of kangaroo number compared to the Lakebed Stratum (Table 8). During August the Bushland Stratum had the lowest estimates of kangaroo number overall where Lakebed sampling was discontinued during the August period (Table 8).

Table 8: *Macropus fuliginosus* density and number estimates generated from Distance Sampling using the RPASS method categorised by sampling period and stratum

Sample Period	**Stratum**	**Estimated Number**				**Density (Number of Animals/ha)**			
		Mean	**SE (3dp)**	**(CI 95% Range)**	**CV**	**Mean**	**(CI 95% Range)**	**SE**	**CV**
April	Bushland	55	46.554	(0-147)	0.847	0.80	(0*-19.30)	9.4	11.835
	Lakebed	25	13.076	(0*-51)	0.536	0.67	(0*-17.56)	8.6	12.908
	Transitionary	239	35.930	(168-309)	0.151	4.70	(0*-49.49)	22.9	4.866
August	Bushland	117	42.568	(34-201)	0.365	1.60	(0*-27.53)	13.2	8.414
	Transitionary	381	90.084	(204-558)	0.237	8.70	(0*-69.66)	31.1	3.588

*Negative values converted to a minimum of zero.

The Bushland stratum showed the highest median percentage thermally obstructive cover followed by the Transitionary stratum with the Lakebed showing the lowest percentage (Figure 9).

Non-Linear Modelling of aerial data indicated no change was observed in detection number because of either sample period or thermally obstructive cover percentage (Table 9). There was indication of an effect generated by stratum on number of detections (Table 9) (Figure 10).

Table 9: Results from the non-linear regression showing the effects of multiple covariates on *Macropus fuliginosus* detection numbers generated by the RPASS method

	Degrees of Freedom	Wald stat (2dp)	*p* (3sf)
Intercept	1	6.22	0.013
Sample Period	1	1.67	0.196
% Thermally Obstructive Cover	1	0.72	0.396
Stratum	1	26.03	**<0.001**

Red Indicates a statistically significant result

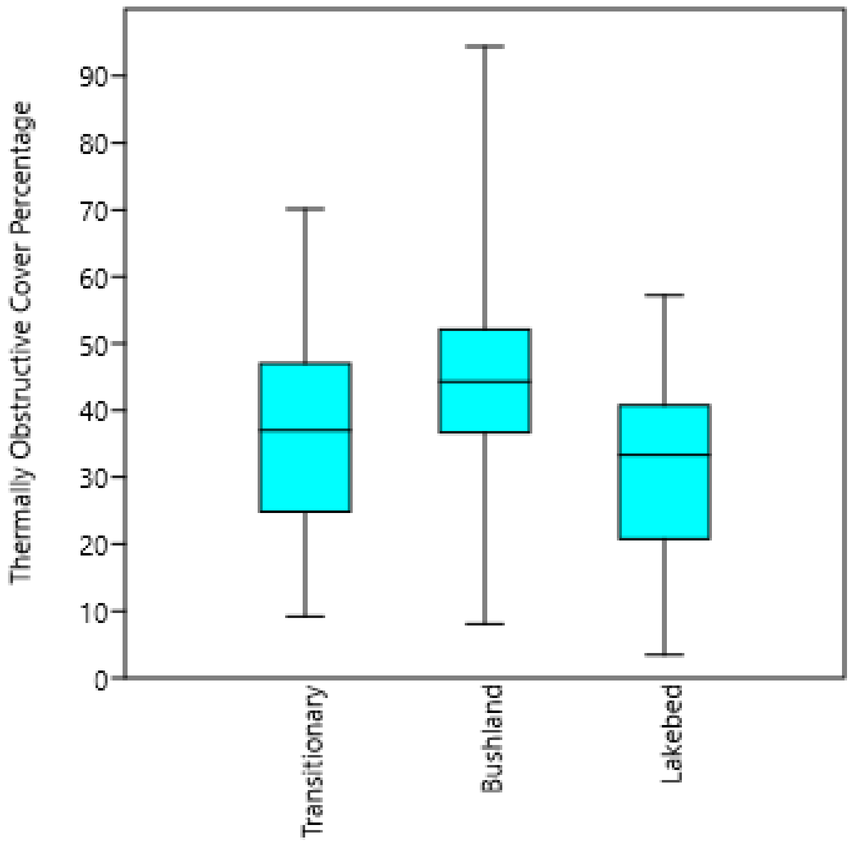

Figure 9: The distribution of Percentage Thermally Obstructive Cover observed by RPASS survey categorised by stratum across both sample periods

NOTE: For all box plots; median is represented by the horizontal line within the box, where the quartile range represented by the box. Non-outlier range (Mean ± 2SD) is represented by the whiskers, with asterisks indicating outliers

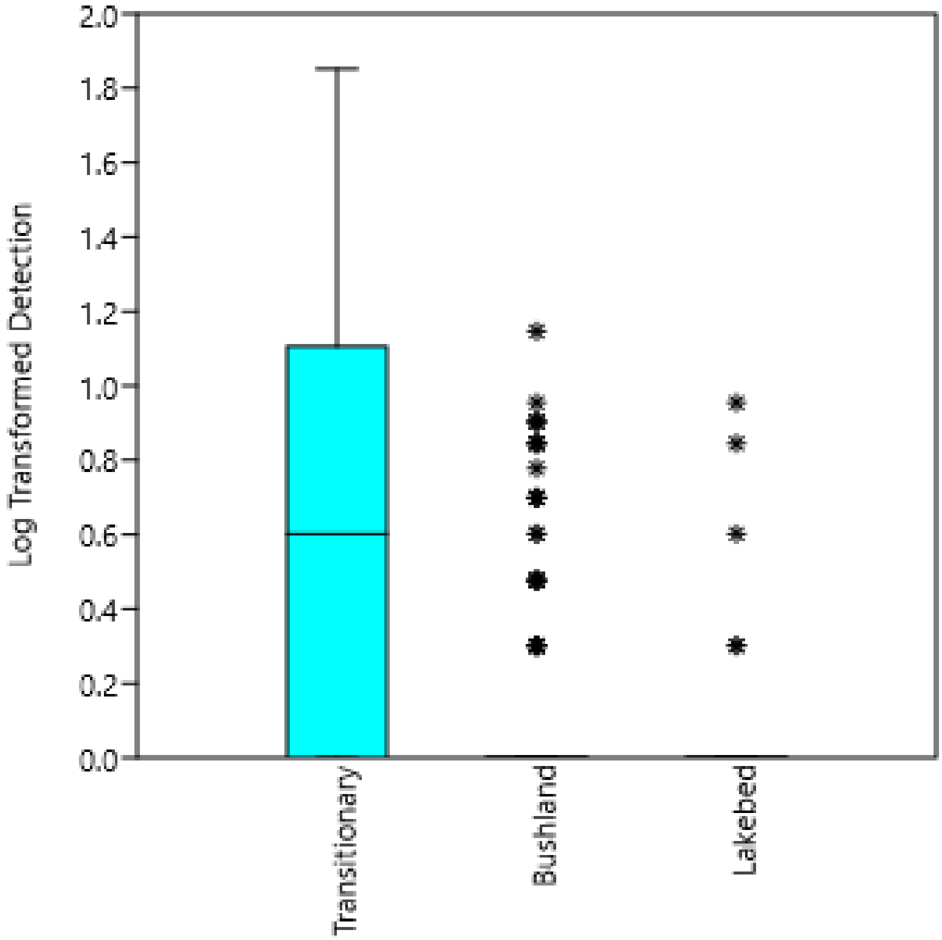

Figure 10: The distribution of logarithmically transformed RPASS *Macropus fuliginosus* detection numbers categorised by stratum across both sample periods

3.4 Cost Analysis

The most expensive method to initially undertake was the aerial survey (RPASS method using Distance Sampling) costing 8.1% more than the camera trapping (CTS using SPA) which was 16.4 times more expensive than the foot survey (WTS using Distance Sampling)(Table 10).

The cost disparity decreased between methods when assuming initial purchase during subsequent sampling. Resulting in costs being 2.4 times higher for aerial survey compared to foot survey; and camera trapping being 3.8 times more expensive than foot survey (Table 10).

The initial cost to undertake surveys was decreased for camera trapping when renting equipment by approximately two thirds. The cost did not decrease with subsequent sampling periods with costs 1.6 times greater than the costs of survey assuming equipment acquisition (Table 10). The cost estimates for aerial survey contracting experienced similar effects to camera trapping. When considering the cost of acquisition of RPAS equipment compared to contracting during a single sample using contractors showed an 80% decreased cost compared to initial purchase cost. When utilising multiple repetitions of survey cost for subsequent sampling assuming equipment acquisition was 1.7 times smaller than that when using contractors (Table 10).

Our data suggest that this cost disparity would result in purchase being the more economical option compared to rental/contracting after 7 camera trapping surveys or 13 RPAS surveys.

Table 10: Summary costs of each method including the costs of fieldwork data analysis and in the case of the RPASS and CTS survey the cost to either purchase or rent the equipment necessary to undertake the survey within this study.

Method **Purchase**	**Cost of fieldwork** **($)**	**Data Processing wages** **($)**	**Cost Equipment** **($)**	**Overall cost** **($)**	**Total Cost per session** **($)**	**Cost for each additional session** **($)**
WTS	900	1,000	265	2, 165	$1,082	$950
CTS	1,300	6,000	28,215	35,515	$17,758	$3,650
RPASS	3,100	2,000	33,145	38,245	$19,123	$2,550
Method **Rental** **/ Contracted**	**Cost of fieldwork** **($)**	**Data Processing wages** **($)**	**Cost of Equipment**	**Overall Cost** **($)**	**Total Cost per session ($)**	**Cost for each additional session** **($)**
CTS Rental	1,300	6,000	4,690	11,990	5,995	5,995
RPASS Contracted	1,200	2,000	5,300	7,700	3,850	3,850

This data is a summary only; complete pricing is available in Appendix C tables 16a, b, c

Chapter 4 Discussion

It was found that use of an RPAS system using a Distance Sampling method and a CTS array using SPA method were not currently fit for employment to accurately survey populations of *Macropus* spp. within the context of an enclosed reserve. This finding exists because of methodological incompatibilities observed in the CTS method and due to the currently undefined effect of sampling bias on RPASS. WTS remains an effective method for population survey when not subject to incompatibilities with the underlying Distance Sampling method, and when undertaken at a high degree of sampling intensity. Based on past population management efforts and estimated population growth rates within the reserve, there are considered to be approximately 1,000-1,500 kangaroos within Thomson`s Lake Reserve (Parks and Wildlife Service 2019). This indicated that given the SE generated results from RPASS (April 796± 225, August 1326±365) and WTS (April 1687 ± 216, August 2773± 760) may be accurate but discounted the use of estimates generated by CTS (April 36 ± 25, August 6 ± 2). Considering the estimates of RPASS and WTS together data indicated an estimate of between 1264-1374 animals present in April and 1282-2042 animals present in August of 2019 for Thomson`s Lake Reserve given the overlap expressed by the CI95% ranges of these estimate methods.

Beyond such findings a number of disadvantages (Table 11) and benefits (Table 13) associated with the methods assessed and their implementation (Table 12) were detected. This study attempts to provide guidance on future implementation of these methods in the context of what has been learnt from our experiences throughout this project with a specific focus on applicability to enclosed urban reserve management.

4.1 Walked Transect Survey

Walked Transect Survey analysis found in similar effects as noted in previous study conducted by Southwell (1994) and Glass et al. (2015). The WTS limitations being primarily associated with violation of underlying statistical methodologies and the requirement for increased sampling intensity to abate such bias. This study noted significant evidence that the Distance Sampling assumptions offered by Buckland et al. (2001) were violated as a result of the factors listed in Table 11, potentially introducing bias into estimations generated. These measures were additionally subject to significant impact from methodological incompatibilities (Table 12) that reduced the applicability of these measures and limited their employability. The combination of these factors align with findings by Glass et al. (2015), where estimates were more useful when derived at larger sampling intensities. This finding was reinforced by the experienced increase in CV when sampling intensity was decreased. This served to reinforce the inference that sufficiently high sampling intensity should lessen the increased variability and violation incurred because of bias generated in estimates by violation of underlying statistical methods.

A caveat exists to this assessment where our study was forced to use a different sampling site due to management of *P. cinnamomi* in addition to seasonal inundation of the lakebed stratum. This is expected to introduce variability due to differences between sample sites paired with an alteration in the distribution and density of animals in the reserve affecting detection rates.

Changes in detection rate can affect the number and density of animals detected altering the fit of the Distance Sampling model and affecting both the variance generated in estimates and the ability to compare estimates from different periods. Change in detection rate can therefore alter the observed effects of sampling intensity by acting as a confounding factor through influencing the detection probability of these transects. This confounding effect may potentially explain the disproportionately higher observed CV between these periods that can not be attributed to sampling intensity. Analysis of this effect is not possible given current data and this study does not directly assess the effect on bias by sampling intensity within sample periods which may introduce additional confounding factors.

4.2 Camera Trap Survey utilising SPA

This study experienced significant incompatibilities when applying the SPA method (Table 11). These incompatibilities resulted in the SPA method being unable to accurately model density of our target species *M. fuliginosus* presumably due to the way data were captured. Ramsey et al. (2015) discussed possible limitations in the SPA method where the spacing between cameras was less than the home range exhibited by the study animal(s) or where their density was high. Ramsey et al (2015) noted that this was likely to result in array saturation, reducing the amount of spatial correlation in detections. This restriction may limit the applicability of SPA analysis for assessing population abundance of species contained within fenced reserves due to the potential for an artificially high density and altered encounter pattern. The data generated supports this finding and indicates that the SPA model is not fit for situations where population density or distribution can cause saturation of the detector array.

In the absence of direct home range measures from animals within the reserve estimates were drawn from literature. These estimates were taken from an unenclosed reserve

(Priddel, Shepherd et al. 1988), representing conditions that were similar to Thomsons Lake Reserve. However, this similarity is limited as a result of factors such as reserve type, with the potential for pressures such as predation, density dependent factors i.e. disease processes or confounding as a result of sympatric species presence to represent altered conditions between the two different types of reserve. The estimates of home range are hence expected to be different to those that would have been directly derived and it is not unreasonable to anticipate that disparity may exist. This disparity may be due to the estimate used being ascertained of an unenclosed reserve with the topological features present within Thomson's Lake Reserve such as; the inundated lakebed during August or the barrier fences encompassing the reserve altering the behaviour of the kangaroos and their home range. The difference in home range estimates or behaviour may potentially affect the applicability of our findings given the reliance of SPA on an accurate estimate of home range to generate array locations and map encounter incidences. However, data generated did not indicate an effect based on home range with varied home range estimates not providing a consistent scalable effect.

Considering the data on the effect of home range it is reasonable to assume that in the present study the variability encountered may be associated with array saturation and distribution. It should further be considered that an attempt to account for this was made utilising a range of Home range sizes. Subsequently the SPA measures are unlikely to provide an accurate estimation of abundance this inference being supported by the observed disparity between estimates generated from SPA and other methods. This is a significant indication that the SPA method is not applicable in cases of high-density animal populations as are expected in enclosed peri-urban reserves.

It is recommended that this method should be employed with caution, especially where the reserve characteristics may alter animal behaviour to increase encounter rate. Evidence suggests that inferences made regarding the requirement for a fixed array distance are supported and that all future studies should avoid the variability experienced here and to generate usable measures.

4.3 Remote Piloted Aerial System Survey

In relation to Remote Piloted Aerial System Survey, this study partially upheld the known limitations of previous aerial survey techniques relating to physical obstruction of line of sight experienced by manned aircraft (Fleming and Tracey 2008) for RPAS technologies. This study additionally offered novel findings these flaws (Table 11) and benefits (Table 13) are partially mitigated by the methodological incompatibilities of this study (Table 12). However, broadly these noted benefits and flaws stand as a form of guidance for future studies employing the RPASS method.

This study found that the RPASS method suffered significant disparity in detection probability by stratum. This potentially represents a failure of the method to account for canopy obstruction, as has been noted in other aerial surveys (Fleming and Tracey 2008). Alternatively this disparity may be due to the temporal preference for differing environments noted by (Coulson 1993) where due to the method employed the target animals may have been concentrated within a single stratum generating the observed effect on detection. Despite this the RPASS method appears to show far fewer of the issues raised by Fleming and Tracey (2008) than previous aerial techniques with noted benefits being observed (Table 12). These benefits support the assertion that RPASS provides benefits because of the recorded medium that potentially abate several key factors of human error. Additionally, data indicated that the increased speed exhibited by the RPASS, potentially coupled with the altered threat profile as a result of aerial position and our time of sampling decreased reactive movement when compared to WTS.

Table 11: Intrinsic method flaws observe within each of the assessed methodologies and the factors that contributed to their emergence

Method	Flaws and their contributing factor/s
WTS	WTS as it was employed exhibits violation of the DS assumptions offered by Buckland et al. (2001) these violations were associated with the following assumptions "Animals Sighted at Initial Location", this was violated due to reactive movement altering the location at which measures were taken such intrinsically introduces bias into the estimates (Southwell 1994). "All Animals Sighted", again violation occurs primarily due to Reactive Movement resulting in the possibility of animals evading sampling procedures and is enhanced by the varied viewable distance in different stratum altering the ability to sight animals by location altering the detection probability by location. "Detection is not Biased", this is initially violated by Reactive Movement introducing bias where non-mobile animals may not be recorded because they do not draw the eye and is furthered by the varied viewable distance in different stratum changing the probability of detection between stratum. Additionally • The process of undertaking WTS was time-consuming and laborious requiring significant effort to avoid biasing the transects taken by seeking the easiest route and potentially causing observer distraction. • The reactive movement observed required that the measures of distance were based on landmarks and not the animals themselves introducing further variability into estimates. • The density of animals resulted in instances of observer saturation and this may have introduced a form of bias.
CTS	The SPA method as it was employed did not account for density in the form of group size or repeated contacts during the same day this is expected to lead to underestimation and is a significant flaw as it stands to violate the intrinsic ability to assess *Macropus* due to their observed grouping behaviour. • Deployment of the array was laborious requiring significant physical exertion to undertake. Such has the potential of biasing assignment of sampling sites by the human preference to use the path of least resistance affecting the validity of the data by biasing the environment of deployment. • Data intensity was high with large data sets generated as a result of the short sampling period employed (N of images >14,000/sampling week) making data storage potentially difficult and analysis time-consuming. Additionally only 3% of images generated were of unique target contacts such representing a significant impact in terms of extraneous data that was then to be excluded.
RPASS	RPASS exhibits a degree of violation of the DS assumptions offered by Buckland et al. (2001), such violation is related to: "All Animals Detected", as it was not possible to detect animals through canopy cover or thermally obstructive cover using FLIR imagery; and "Detection is not Biased", due to detection number showing direct variation by stratum which was defined by morphological characteristics that additionally bias animal preference based on time of day. Additionally • Data intensity was high this method generated large data sets because of the short sampling period employed. • Interpretation of the data generated was time-intensive requiring on average 3 hours to analyse a single hour of recorded footage • Recordings lack the ability to generate more than just numerical counts given the currently available technology rendering data inapplicable when surveying for additional measures and increasing the possibility of misclassification amongst morphologically similar species. • Systems experience sensor saturation in instances where proximity allows animal thermal signatures to comingle and merge rendering them individually indistinguishable. • Control of the RPAS is affected by topography and proximity to other wireless signals imposing restrictions on the available range and control that vary based on location and sampling time.

WTS (Walked Transect Survey) CTS (Camera Trap Survey) RPASS (Remote Piloted Aerial System Survey)

Table 12: Factors or incompatibilities observed within the assessed methods because of implementation within this study that may affect the applicability of our findings

Method	Factors or incompatibilities and their contributing factors
WTS	The WTS utilised different methods in both sample periods. This change was due to direction by DBCA and seasonal inundation of the Lakebed stratum. This caused the exact locations and length of transects to change between sample periods. Such changes altered the sampling intensity observed between sample periods altered the percentage of each stratum assessed per transect and altered the distribution of conditions and animals seen. This is expected to have changed; the effects that were imposed on overall detection as a function of stratum where changes in the exact distribution of stratum locations and the percentage of each transect represented by such varied. Additionally, this is expected to have altered the effects of reactive movement due to changes in animal distribution and animal density as a result of the changes in length and composition potentially acting as a confounding factor for the effects of sampling intensity. Alteration of assessed area occurred as a function of changes in median viewable distance. This measure was used instead of exact area assessed due to limitations encountered due to design error. It was not possible to determine a fixed distance cut-off for WTS survey area calculation and the package *Distance* used to analyse such data did not support a diverse assessable area within data. It is believed that this will introduce an additional potential for error into the estimations of assessed area; causing changes in calculated sampling intensity and decreasing confidence in estimates generated by uncertainty imposed on exact density estimates used for total reserve estimates.
CTS	The implementation of the SPA method exhibits a potential flaw due to the inability to gather information on home range directly from the animals at Thomson's Lake. Several estimates of home range were drawn from existing literature with the ranges finally selected being those by Arnold et al. (Arnold, Steven et al. 1992), which was derived from an unenclosed survey site in Bakers Hill, Western Australia. This may result in variation within the estimates of density by altering the ability to represent the actual range of animal travel accounting for the spatial difference in contact location. Comparing measures of occupancy between sample periods flaws may be experienced. This may arise as a result of the different locations and exact distributions employed between sample periods. This is a result of a change in method where it was initially not intended for the array to be used for occupancy analysis but instead such occurred as an attempt to "value-add". This may lead to the possibility that metrics generated could be affected by topographical factors and other location-based factors. Such would limit their comparability across sample periods and stratum.
RPASS	There are 2 fundamental alterations that may affect applicability of RPAS these are a shortening of flightpath 4 during August and discontinuance of the lakebed flightpath. The truncation of flightpath 4 resulted in a change in the exact assessed area and reduced sampling intensity. This is expected to have resulted in a change in conversion factor and potentially altered the exact comparability of the flightpaths. The discontinuance of the lakebed flightpath occurred as a result of seasonal inundation due to rainfall resulting in a decrease in total reserve area assessed. The loss of accessibility to *Macropus* is hypothesised to have potentially increased density. This change is hypothesised to be a function the loss of area with redistribution of the animals from within the lost area. This may alter the estimates generated between periods potentially increasing observed density. However, there is insufficient evidence to quantify such definitively

Table 13: Noted and observed intrinsic method benefits for each method assessed

Method	Benefits and their contributing factor/s
WTS	• The WTS cost significantly less the other assessed methods (Table 10) was simple to undertake required minimal equipment or training and required no specialised licenses • Despite the variability noted WTS estimates may potentially be viable for use as a trigger for further investigation and sampling by more complex and expensive methods. • The data generated was small and easy to store enabling multiple surveys to be conducted and stored for analysis without requiring extensive resources. This increases the available data on hand when making decisions regarding management actions in a seasonal and year to year context.
CTS	• Camera Trap Survey generated more extensive data because of the single deployment than what could be acquired from the other methods; this additionally reduced the need for multiple periods of sampling to generate estimates of average number. • CTS did not generate periods of disturbance coinciding with every sampling day reducing the impact of disruption to both the animals and the environment. • There is a reduction in the impact of sampling on the data generated in terms of behavioural disturbance during placement and retrieval allowing animals to exhibit their normal behaviour during the survey. Such represents an increased ability to observe and record fluctuations in behaviour or occupancy and generate more accurate estimates. Additionally, these factors increase the ethical return on investment gained by any disruption or disturbance caused. • *The ability to isolate incidences over a longer period of time was evident such hypothetically allowing for the generation of more accurate average patterns of movement and behaviour. • *The Measures of occupancy generated, and the extended timeframe of dataset generated should allow for the generation of a correction factor for RPASS increasing accuracy of that method
RPASS	• This technique experienced zero responsive movement reducing the impact on statistics generated in line with findings by Southwell (1994). • There were no blindspots generated by physical structures or position within the vehicle as has been previously noted in aerial survey by Fleming and Tracey (2008) • This method met the unbiased measurement assumptions by a generating a uniform recording distance, and not generating notable variation in such • There was no observer fatigue/saturation/concentration loss as a result of survey unlike as has been noted in previous aerial techniques Fleming and Tracey (2008) • Implementation of this method was not physically taxing this is expected to reduce sample site bias. • This method showed increased sampling intensity due to the increased speed such potentially increasing the representativity of the sample taken • Reduced loss of acuity observer fatigue/distraction/ saturation were observed due to the nature of the recorded medium in line with previous findings by (Chrétien, Théau et al. 2016).

***noted, but not assessed due to method limitations**

4.4 Comparison of Multiple Methods

The estimates of population number derived from each of the three methods appear to be of varying usability and benefit in addition to each method representing a different return on investment.

The CTS population estimates derived from SPA are immediately discounted for use in their current form. This is due to the method incompatibilities observed for SPA (Table 12) rendering estimates clearly inaccurate compared to even uncorrected counts. SPA subsequently provided the lowest return on investment with the second-highest associated cost (Table 10) primarily as a result of extensive time spent performing manual image analysis and processing. The details of these costs are available within appendix Table 16. Costs are expected to be altered by either altering the scale of sampling. Increasing the scale of assessment is expected to increase analysis time and therefore cost; however, automation of processing and analysis may reduce this cost. Automation would have significantly reduced our observed costs with the return on investment expected to increase where the method incompatibilities (Table 12) and challenges (Table 11) are not observed.

The WTS and RPASS estimates did not experience method incompatibilities that would preclude their examination or adversely affect the assessment of the benefits provided. Comparing the WTS and RPASS estimates both estimates were on average 40% higher in August than in April with the estimates derived from RPASS on average 53% lower for both sample periods than estimates derived from the WTS. This seems to indicate that the disparity between the two methods in terms of average estimate is not due to sampling intensity as no significant change was observed in RPASS sampling intensity despite the significant change in sampling intensity for the WTS between April and August. The observed difference in the variability of WTS estimates observed may be as a result of the different sampling periods may potentially be able to be contributed to changes in sampling intensity where the CV of estimates from WTS was 2.14 times greater during August, aligned with a 1.96 times smaller sampling intensity. There are too many confounding factors such as changes in reserve area to definitively state that such is caused by sampling intensity; however, the similarity of these figures cannot be discounted.

The 40% increase in population estimate between sample periods does not align with the 20% change in accessible area because of seasonal lakebed inundation. Nor does this align with the average density increase observed between sample periods where approximately 2.26 times as many animals were observed on average per hectare during August. These changes in density suggest additional factors may be affecting the estimates derived and introducing detection bias.

To quantify the effects of stratum on RPASS and isolate sources of bias, attempts were made to use occupancy analysis from CTS. The occupancy analysis indicated significant differences in detection by stratum suggesting preferential utilisation between these areas, with a preference given to utilisation of the Lakebed areas followed by the Transitionary and Bushland areas respectively. This does not align with the patterns observed by the RPASS, which noted a preference for utilisation of the Transitionary areas with only sporadic animals noted in either the Bushland or Lakebed areas. This may be because the estimates derived from the CTS are limited due to sample site variability and change in exact distribution of sampling locations. The initial implementation of CTS was not targeted to create such measures instead being targeted to assess the conditions that affect SPA. Subsequently, these values may not be truly representative of the true distribution and their ability to be compared accurately across sample periods and methods is significantly reduced.

Another potential explanation is occupancy measures were not correlated by time of day and that the measures are not directly comparable due to the behavioural utilisation of different stratum at different times of day as noted by Coulson (1993). Attempts were made to generate measures of detection rate by time using CTS to assess this behavioural preference as an alternative measure to the base measures of occupancy. Due to issues resulting from failures of the use of the software "camtrapR" (Niedballa, Sollmann et al. 2016), this was not possible to be performed accurately and this data was excluded.

Of the two Distance Sampling methods assessed the method that appears to provide the largest return on investment in terms of applicability of measures is the WTS method (Table 10). This method shows a cost several times less than the RPASS both in terms of equipment cost and wage cost. If accounting for the cost of both methods assuming the initial purchase of equipment for 3 sampling days WTS costs $5,965 and RPASS costs $ 35,695. Using these figures there was a potential to conduct nearly 6 times as many WTS for the cost of a single RPASS.

There is a caveat to the return on investment of WTS, most notably in terms of wage cost associated with the RPASS method (Table 10). RPASS as it has been implemented has a wage cost approximately 2.7 times that of the WTS; however, the RPASS uses 3 repetitions per survey period compared to a single incidence for WTS. When accounting for this the WTS would have a wage cost of $5,700 making it $600 more expensive than RPASS in terms of wages paid. This alters the cost-benefit analysis placing the cost of implementing subsequent RPASS on par with, or cheaper than, a WTS survey when excluding equipment cost. This carries over into the time taken with the RPASS requiring 64 hours to undertake compared to an estimated 108 hours taken to conduct a WTS survey. With the WTS occurring at a significantly decreased sampling intensity compared to RPASS this makes RPASS the more expedient method with a higher return on investment and higher representivity of the conditions distribution noted throughout the whole reserve.

Alternatively, the surveys performed by RPASS could be contracted to an external contractor or equipment for CTS could be hired. These costs (assessed in Table 10) indicate it is possible to significantly reduce initial expenditure by either hiring equipment or contracting survey efforts. This action does not appear feasible over long term surveillance plans as the cost of subsequent surveys remains constant when using contractors/hire. This cost of subsequent hire/contracting is significantly greater than the cost of subsequent surveys post-purchase of either the WTS or RPASS method. Therefore, in terms of fiscality the use of RPASS and CTS should be considered on the ability to use equipment multiple times. With the benefits of purchasing RPASS or CTS equipment compared to rental/contracting in terms of financial benefit increasing as the number of surveys to be conducted does.

This study finds that where an extensive implementation is planned across multiple sites, as would be expected for a broadscale management plan, there is significant evidence to support purchase of RPASS and CTS equipment over rental/contracting. Similarly, there is significant evidence to support the use of RPASS over WTS in terms of return on investment.

Of the three methods assessed both the CTS and RPASS analysis required significantly more time to undertake compared to the WTS method. This increased time requirement was paired with an increased data intensity with the deployment times being either lower than the WTS (in the case of RPASS) or approximately equivalent (in the case of CTS).Despite this additional time requirement the measures that were gained were subject to significantly less variability or bias as they involved multiple sampling periods. The caveat to this was the incompatibilities observed between the CTS method employed and the SPA requirements. Indications are that if such limitations did not occur the estimates derived from CTS would experience significant benefits of scale and sampling intensity compared to the WTS. Our data suggest that the ability to use a digital data analysis method such as the RPASS or CTS should provide significant benefits in terms of data generated where the underlying statistical methods are observed and accounted for properly.

Both Distance Sampling methods assessed (WTS and RPASS) exhibited significant violation of the underlying Distance Sampling assumptions (Table 11). However, the types of violation occurring are significantly different. With the RPASS method these violations were primarily due to physical factors such as canopy obstruction whereas the WTS violations were due to animal behaviour and physical obstruction. RPASS additionally provided benefits in the form of increased sampling intensity compared to the WTS accessing not just more of the reserve but accessing areas that would have otherwise been impassable. This was performed in an expedient manner and showed no evidence of reactive movement unlike the WTS that showed reactive movement in all cases. This indicates a significant benefit to the RPASS method where the system can better meet the underlying statistical requirements of modelling compared to the WTS method.

The caveat to this is the flaws in relation to violations incurred by RPASS these violations despite being comparably minimal indicate the need for survey using RPASS to be carefully considered alongside known behaviours and distribution patterns of animals such as the crepuscular nature of *M. fuliginosus* as was targeted here to reduce the bias incurred as a result of technological factors. It is believed that based on this and using further study to determine the exact effect of this detection bias such flaws can be substantially mitigated.

4.5 Future Study

This study is at current unable to provide definitive findings on the implementation of Remote Piloted Aerial Survey, or Camera Trap Survey using the SPA method due to a lack of available data. Additionally, this study has identified an additional area of interest for Walking Transect Survey for *Macropus fuliginosus*. This study therefore recommends future study to quantify the effects of the key method findings, prior to rendering a definitive assessment of any method.

4.5.1 Camera Trap Survey utilising SPA

Future study is recommended of the application of the SPA method using the findings of our research to avoid the issues experienced. These should aim to determine the exact effect of site distribution and site saturation on estimates generated. This should occur in a broad-scale evaluation using multiple sites and deployment scales over a period of years to generate sufficient data to either support or oppose the use of SPA in macropod population assessment.

4.5.2 Remote Piloted Aerial System Survey

In relation to RPASS there are an extensive list of studies to be conducted. Suggested follow-up studies include:

Study of the effect of stratum conditions that cannot be assessed accurately given our available data. Focussing on the exact effects of stratum because of; canopy cover, thermal obstructive cover, and animal behaviour as key areas to be identified prior to broadscale implementation.

Study of the effects on detection because of using a thermal signature only method, with focus on the ability of thermal data to generate verifiable species identifications or accurate estimates from thermally indistinct data. This is necessary to reduce the possibility of misidentification that would result in incorrect estimates or classification of non-target species as detections. This assessment should include the effects observed by grouping behaviour of animal contacts on detectability and effects observed due to decreased thermal discrimination due to environmental conditions. These factors being what the author terms ‘sensor saturation’ defined by its similar effects to observer saturation and loss of acuity at different resolution, altitudes, and animal sizes.

Another area for future research is investigation into the ability of machine learning to assess and score RPASS footage for population estimation. Specifically, study is recommended into the disadvantages, advantages and costs associated. With a focus on the cost-effectiveness of RPASS compared to alternative methods and the accessibility of the technique.

4.5.3 Walked Transect Survey

In relation to the use of the Walking Transect future study should be conducted with the aim to quantify the absolute variation because of varied sampling intensities. Such study should aim to assess the cost associated with implementing a WTS at sufficient sampling intensity to reach accuracy sufficient for deployment in management actions. Where such accuracy is comparable to other techniques i.e. RPASS, and the effects observed because of reaching such a sampling intensity

Chapter 5 Conclusion

This study found that that the SPA method as it was assessed here did not provide accurate estimates and is not appropriate for the generation of population estimates in this context. This does not stand as an indictment of the SPA method but rather as a representation of the limitations of our implementation. While this study is unable to recommend findings on the use of the SPA method for assessment of *Macropus* spp. in the context of an enclosed reserve it does note several key factors, related to use of a uniform array distribution, reutilisation of sample sites, and avoidance of array saturation that must be implemented in all instances moving forward.

This study found that the use of WTS employing a Distance Sampling method remains an effective method for monitoring *Macropus* populations within the context of an enclosed reserve. This finding is subject to WTS employing sufficiently high sampling intensity and utilisation of a uniform and repeatable survey pattern over an extended period and multiple seasons to account for the effects of seasonally associated factors on the estimates generated.

At current there is insufficient research or data available to find definitively on the use of RPASS to monitor *Macropus* populations within the context of an enclosed reserve. Rather this study serves as an indication of the factors that need to be assessed before broadscale implementation could be adopted or attempted. There is significant evidence to suggest that in the future use of RPAS technology in population monitoring may provide several benefits in terms of sampling intensity, decreased disturbance caused, and expeditiousness of data collection. This evidence being predicated on the assumption that future research generates ways to abate the factors related to detection bias experienced.

Management implications

Data and analysis gathered by this study indicate that in future the use of RPASS techniques will provide both a cost effective and accurate means of population survey. For populations of non individually identifiable animals of a large thermogenic capacity over extensive ranges. At this time this ability has not been developed and is not presently available, being subject to future research. The use of spatially explicit models such as SPA for CTS additionally have potential for future use; however, at current their use can not be recommended due to method incompatibilities observed. Subsequently the use of CTS should only be considered after future study.

If one does intend to implement RPASS or CTS such should be predicated on the purchase of system technologies, with data indicating that in cases of repeated survey this is of greater cost effectiveness, with cost expected to further decrease over time.

The use of WTS techniques remain an accurate method subject to sufficiently high sampling intensity with the benefits of Distance Sampling being clear in generating reliable estimates.

Ultimately, this study does not recommend a shift to utilisation of CTS or RPASS for population management at this stage with recommendation being that such should only occur after further development and study of the methods.

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Chapter 6 Appendices

Appendix A Legislative Compliance

Legislative limitations apply when conducting RPAS operations within Australian Airspace pertaining to the conditions under which sampling is conducted using RPAS systems. In Australia, the usage of RPAS falls under the purview of the Civil Aviation Safety Authority (CASA), and further legislative requirements may be enforced by state-level agencies such as the Western Australian Department of Biodiversity, Conservation, and Attractions (DBCA).

The Civil Aviation Safety Authority enforces restrictions when undertaking RPAS operations apply to all general users. Such restrictions can be found in AC101-01v2.1 (Australian Government 2018). To ensure compliance with these restrictions, this study used an operator who possessed both a Remote Pilot Licence (RePL) and who was operating under a Remotely Piloted Aircraft Operator`s Certificate (ReOC) (ReOC held by Interspacial Aviation Services Pty Ltd) for all sampling operations in compliance with the terms set out in AC101-01v2.1. Subsequently sampling was required to only occur when such an authorised individual was present and the RPAS was able to be operated in compliance with such legislative requirements

Within Western Australia operations where scientific study occurs within a nature reserve such as Thomson’s Lake Nature Reserve are covered under the Biodiversity Conservation Regulations 2018. To this end, the author was required to and did obtain a ‘Regulation 4 Authority’, under the regulations allowing operations to occur with all operations conducted under the directives issued by such.

Appendix B Method Specific

Image J Code for individual still image

```
run("32-bit");

setAutoThreshold("Default");

//run("Threshold...");

setThreshold(0.000000000, 228.000000000);

setThreshold(111.8400, 228.0000);

run("Close");

run("Analyze Particles...", "summarize");

close();
```

Figure 11:ImageJ Image Analysis Code

RPASS Scoring Directions

This is an abridged and modified version of a document provided by the RPAS operator (Control 2018)

Table 14: Values for scoring of RPASS flight data under which scoring is conducted

RPAS Model	Altitude (m AGL)	Sensor Angle (^{o})	Velocity (m/s)	Projected field of view (m on ground)	
				Top	Bottom
MATRICE 210	55	55	5	135	68

Instructions for creating scoring device:

When opening thermal footage files, DO NOT alter the aspect ratio of the window.

Maximise the video window on your screen so that it will be in the same position each time you open it and other video files.

Measure the actual size of the top and bottom of the video file window on your screen to calculate where the 10m intervals occur. (distance horizontal/distance on ground) for both top and bottom

Mark from the centre line of the window, at the calculated intervals

Extending a straight line through these points marked by distance category. This is your demarcation line.

Instructions for when scoring detections:

Mark each individual in the interval in which it is first detected.

There is no need to record whether a kangaroo occurs in either the left or right side

Record the stratum in which the animal was observed (record timestamp of contact and pair with flightpath data, distance travelled)

Do not count kangaroos immediately in the vicinity of the RPAS take off and landing site. Begin counting once the RPAS gets up to the operating height of 50m AGL and starts moving forward consistently,

Do not count kangaroos at turning points.

Metadata tags for CTS survey

Stratification: Bushland, Transitionary, Lakebed

Sample Period: April, August

Actions Being Taken: Animal in Transit, Animal Lazing or Grazing, Animal Performing Other

Transect Number: Transect Number 1, Transect Number 2, Transect Number 3

Image Quality: Good, Poor, Photo Not Interpretable

Presence of Animals: Animals Present in Image, No Animals Present in Image

Image Type: IR, RGB

Triggering Incident: Animal Trigger, Deployment/Recovery Trigger, Environmental Trigger, Human Triggered

Animal Sighted: Undefined Bird, Kangaroo, Rabbit, Raven, Magpie, Fox, Quenda, Possum, Wren

Detection type: Unique Sighting, Subsequent Sighting

Animals in Detection Zone: Numerical Value, i.e. 1, 2, 3

Animals Beyond Detection Zone: Numerical Value starting in 0, i.e. 01, 02, 03

Figure 12: Metadata Tags for Image Analysis

Camera Trap Occupancy Models

Table 15: Results of Occupancy Modelling for CTS survey, ordered by weighted AIC,

Model	Parameter	Estimate (SE)	AIC	AICwt
4	*β* (Intercept-April)	2.51 (0.6)	1245.22	1.00E+00
	β (August)	8.31 (43.9)		
	p (Intercept-bushland)	0.16 (1.10)		
	p (Lakebed)	1.10 (0.19)		
	p (Transitionary)	0.33 (0.15)		
3	*β* (intercept-Bushland)	3.173 (1.02)	1270.085	4.00E-06
	β (Lakebed)	6.335 (31.04)		
	β (Transitionary	-0.646 (1.26)		
	p (Intercept-April)	0.709 (0.903)		
	p (August)	-0.441 (0.1364)		
5	*β* (intercept-April)	2.51 (0.601)	1275.218	3.10E-07
	β (August)	6.8 (20.707)		
	p	0.522 (0.0673)		
6	*β* (Intercept- Transect 1)	2.202 (0.747)	1277.15	1.20E-07
	β (Transect 2)	5.676 (10.743)		
	β (Transect 3)	0.889 (1.270)		
	p	0.522 (0.0673)		
2	*β* (intercept-Bushland)	3.179 (1.02)	1278.56	5.80E-08
	β (Lakebed)	6.252 (29.86)		
	B (Transitionary)	-0.653 (1.26)		
	p	0.522 (0.0673)		
9	*β* (Intercept-April)	2.51 (0.601)	1278.93	4.80E-08
	β (August)	7.16 (24.743)		
	p (Intercept-Transect 1)	0.5786 (0.127)		
	p (Transect 2)	-0.0756 (0.169)		
	p (Transect 3)	-0.0839 (0.170)		
7	*β*	3.04 (0.591)	1280.024	2.80E-08
	p (Intercept-Transect 1)	0.5786 (0.127)		
	p (Transect 2)	-0.0755 (0.169)		
	p (Transect 3)	-0.0839 (0.170)		
8	*β* (intercept-Bushland)	3.190 (1.03)	1282.289	8.90E-09
	β (Lakebed)	4.251 (11.08)		
	β (Transitionary)	-0.665 (1.26)		
	p (Intercept-Transect 1)	0.5791 (0.127)		
	p (transect 2)	-0.0761 (0.169)		
	p (Transect 3)	-0.0848 (0.170)		
1	*β*	28.7 (Error)	1337.37	9.80E-21
	p	.0648)		

β = coefficients of logistic regression on the probability of occurrence. *p* = detection probability

Appendix C Method Costings

Preface to Method Costings

All wages assume values by Dundas et al. as an indication of likely cost (Dundas, Ruthrof et al. 2019) but experience two (2) primary alterations: 1. Cost of travel including fuel was estimated at a total value of $50 per person per day due to the proximity of our site, which precluded the need for accommodation or food to be charged. 2. wages for the RPAS operator have been are calculated at double the standard rate ($100/person/hour) due to the additional technical skill required.

Enquiries were made to acquire hire values for both RPAS and CTS, at time of writing RPAS hire values were not available as such they are not assessed. CTS hire costs are based on an estimate of $5 per camera per day. Due to the lack of available hire estimates, RPAS instead used contractor costs based on multiple estimates for a survey as close to that undertaken by this survey as possible. Contractor costs are an average, and names are excluded due to confidentiality requests.

Assessed equipment cost excludes general equipment, such as vehicles. All time estimates are to the nearest hour with estimates rounded up to the nearest whole value. All cost estimates are to the nearest dollar.

Table 16a: Method fiscal, and resource cost based on the events of this study, Part a, Camera Trap Survey Costs, including costs of equipment hire

Method	Estimated Equipment cost			Estimated time taken	Total
CTS 2 sample periods, 1 repetition	Cameras (HC500)	41 units, ($600/unit)	$ 24,600	Image processing; 80 hours (one person required)	
	SD Cards (32gb)	41 units ($10/unit)	$ 410	Deployment; 2 days (12 hours) (one person required)	
	Batteries (NiMH)	492 units ($50/8 units)	$ 3,000		Purchase $ 35,515
	Mounting post and lug		$ 205	Recovery; 2 days (10 hours) (one person required)	Rental $1,920
	Or		Purchase Total $28,215 or	Analysis; 40 hours (one person required)	
	Camera Rental	41 units ($5/unit/day)	Rental Total $4,620	Total = 142 hours (one person required) Cost = 7,300	

Table 16b: Method fiscal, and resource costs based on the events of this study, Part b, Costs associated with Walking Transect Survey

WTS 2 sample periods, 1 repetition	Laser Rangefinder	1 unit ($200/unit)	$ 200	Data Collection; 2 days (16 hours) (one person required)	
	Notebook	1 unit ($5/unit)	$ 5	Processing/analysis time; 20 hours (one person required)	
	Compass,	1 unit ($40/unit)	$ 40	Total = 36 hours (one person required)	$ 2, 165
	Miscellaneous	1 unit ($20/unit)	$ 20		
			Total: $265	Cost = 1,900	

Table 16c: Method fiscal, and resource costs based on the events of this study, Part c, Costs associated with RPASS survey, including average estimates for contractor hire

RPASS 2 sample periods, 3 repetitions	Matrice 210, w/ spare batteries	1 unit ($14,945/unit)	$ 14,945	Data Collection; 6 days (24 hours) (two persons required)	
	Zenmuse X4s Sensor	1 unit ($900/unit)	$ 900	Data interpretation; 20 hours (one person required)	
	Zenmuse XT Sensor	1 unit ($14,000/unit)	$ 14,000	Data processing/analysis; 20 hours (one person required)	Total assuming purchase $ 38,245 Total Assuming contracting 7,750
	Data Storage	1 unit ($99/unit)	$ 99		
	Licensing (ReOC & RePL)	1 unit ($3200/unit)	$ 3200 Purchase Total: $33,145 Or	Total = 64 hours (64 hours, one person required, 16 hours skilled operator required)	
	OR Contractor for RPASS	2 units ($2,650/unit)	Contractor Total $5300	Cost= 5,100	

Appendix D: Datasets

Data from Analysis of SPA Variability.

Table 17: Location data used in SPA analysis

Easting	Northing
389059.9	6441534
388887.1	6441813
389021.5	6441590
388907.1	6441709
389147.3	6443031
389241.4	6443053
389363.7	6443077
389149.4	6443031
389391.8	6443101
390361.4	6442412
388962	6442723
390372.5	6442255
390353.2	6442291
390333.8	6442344
390333.8	6442344
389181.8	6441602
389256.7	6441651
388892.1	6443073
388962	6442723
388852.1	6442421
388935.6	6442551
388953.8	6442607
389774.6	6441726
389718.2	6441703
389586.8	6441652
389652.5	6441677
389830.6	6441776
389896	6441833
389113.7	6441786
389033.7	6441343
389223	6441283
389004.6	6441412
388909.5	6443210
388974.8	6443277
389359.6	6441724
389030.8	6443333
390298.3	6443010
390203.9	6443018
390146.9	6443054

Table 18: Presence/Absence data used for SPA analysis

D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
1	1	0	1	0	1	1	1	1	1	1	0	1	1	1
1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
1	0	0	0	0	0	1	1	0	1	1	1	1	1	1
0	0	0	0	1	1	0	1	1	1	1	1	1	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	0	1	0	0	1	0	0	1	1	1	1
0	1	0	0	0	1	1	1	1	1	0	0	0	1	1
1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
0	0	1	0	0	1	1	1	1	1	1	1	1	0	0
0	1	0	1	1	1	0	0	1	0	1	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	1	1	1	1	0	1	0	1	1	1
1	1	0	0	1	1	0	0	1	1	1	1	0	0	1
1	1	1	0	1	1	1	1	1	1	1	1	1	0	1
0	0	1	0	1	1	0	0	1	1	1	1	0	1	0
1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
0	0	0	1	1	1	1	0	0	0	0	0	1	0	0
1	1	1	1	1	0	1	1	0	1	1	1	1	1	0
0	1	1	1	1	1	1	1	1	1	0	0	1	1	0
1	1	1	1	0	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
1	1	1	1	1	1	0	1	0	1	1	1	1	1	1
1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
1	1	0	0	1	1	0	1	1	1	1	1	1	1	0
0	1	0	1	0	0	0	1	1	1	1	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 19: Raw output used in analysis of SPA variation sorted by computer, and repetition

Computer Number	Run 1		Run 2		Run 3	
	Density (animals/ha)	SD	Density (animals/ha)	SD	Density (animals/ha)	SD
1	0.09623243	0.04994313	0.2566198	0.2139825	0.0962324	0.0598747
2	0.06415495	0.04762757	4.587079	0	0.06415495	0.05836548
3	4.555002	0	0.673627	0.2018092	0.8340144	0.3525857
4	0.1283099	0.07050676	4.458769	0	0.183099	0.09601962
5	0.673627	0.309315	0.673627	0.309315	0.06415495	0.04714037
6	0.9302468	1.46313	0.09623243	0.06079175	0.06415495	0.06070925
7	0.9623243	0.05152102	0.2245423	0.1143905	4.747466	0
8	0.06415495	0.03991793	0.06415423	0.0462295	0.5773946	0.2780172
9	4.170072	0	0.06415495	0.05263984	0.06415495	0.05151753
10	0.2566198	0.1436326	0.09623243	0.0581861	0.03207748	0.2405261
11	0.1283099	0.1018226	0.06415495	0.03228953	0.06415495	0.04852129
12	0.06415495	0.05949354	0.05453171	0.02899284	0.1603874	0.160294
13	0.7057045	0.3548978	0.02566198	0.3005019	0.09623243	0.05205467
14	0.09623243	0.08870045	0.08660919	0.3720164	0.2566198	0.3005019
15	4.779544	0	0.06415495	0.041707	0.1603874	0.09235115
16	0.09623243	0.04348758	0.6453171	0.041707	0.06415495	0.04360066
17	0.09623243	0.05855377	0.5453171	0.02904734	0.09623243	0.09786199

Table 20: Coefficient of Variation generated by SPA analysis sorted by computer and repetition

Computer Number	Run 1 CV	Run 2 CV	Run 3 CV
1	0.518984	0.83385	0.622188
2	0.742383	0	0.909758
3	0	0.299586	0.422757
4	0.549504	0	0.524414
5	0.459178	0.459178	0.734789
6	1.572841	0.631718	0.946291
7	0.053538	0.509439	0
8	0.622211	0.720599	0.481503
9	0	0.820511	0.803017
10	0.55971	0.604641	7.498285
11	0.793568	0.503305	0.756314
12	0.927341	0.301279	0.999418
13	0.502899	11.71	0.540926
14	0.921731	5.798717	1.171
15	0	0.764821	0.575801
16	0.451902	1.625245	0.679615
17	0.608462	0.335384	1.016934