Estimating Low-Density Koala Populations in Southeast Queensland: Comparing the Spot Assessment Technique and Distance Sampling

By

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A Thesis submitted as partial fulfilment for the Degree of Bachelor of Science (Honours)

in

Griffith School of Environment
Griffith University
Gold Coast, Queensland

May, 2010

TABLE OF CONTENTS

List of Figures

List of Tables

Abstract

Wildlife surveys are central to ecological studies as the knowledge of population size is fundamental for conservation and management purposes. In this study, a review of wildlife surveys is presented comparing distance sampling and presence-absence sampling using scats. Their suitability to survey low-density koala (*Phascolarctos cinereus*) populations is evaluated. Koala numbers are declining due to habitat loss and fragmentation and their conservation is jeopardised by the lack of coordinated regional and national estimates, which confound policy formulation. This research compared primarily the survey methods used for koalas, but also determined the species distribution at a mesoscale within an urban forest remnant, Karawatha Forest Park (KFP). Results demonstrated that the SAT was more efficient than distance sampling in detecting koalas occurring at low-density. Scats were found on 42% of the 33 plots, while only two koalas were detected during distance sampling surveys. Koalas were found to favour *Eucalyptus tindaliae, E. dura and E. propinqua* over other *Eucalyptus* species present in KFP and showed a preference for larger trees. Koala activity levels were low with a mean of 9% throughout KFP. Activity levels were greater within the centre of the remnant with no activity being detected on peripheral plots. Elevation, biomass, soil sodium and phosphorus concentrations, and tree species richness partially influenced koala distribution within KFP. The study provided a better understanding of koala ecology at the mesoscale in a fragmented patch of forest isolated by urbanisation, and was successful in detecting the existence of a low-density koala population in KFP. Ongoing monitoring of koala activity each year can provide an efficient method for detecting long-term trends in koala populations that can inform conservation efforts and management.

Acknowledgments

This thesis is part of a long-term monitoring project for the Planned Program for Biodiversity Studies (PPBio), funded by the Brisbane City Council, Griffith University and SEQ Catchments. I thank the Australian Koala Foundation for funding this study and for supporting this research.

I would like to thank specially my supervisor, Dr Guy Castley, for his constant support and valuable guidance throughout my Honours project.

Many thanks to Daniel Parker for his excellent work in the field. I would also like to thank the PPBio Australia team led by Associate Professor Jean-Marc Hero, who provided the different information needed and supported the project. Thanks also to Dr James Furse for his wise advice and to Dr Michael Arthur for his statistical help. As an international student, I would like to thank the Gold Coast Griffith University School of Environment for their warm welcome, particularly John Robertson for his help with administrative issues.

Special thanks to my parents who always encouraged me in my studies in Australia and supported me financially throughout my years at Griffith University. I would also like to acknowledge my partner, Yacine Echarif, for his continuous support and interest in my research.

Statement of Originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Signed: Alexa Mossaz

Date: 04th May, 2010

CHAPTER 1

1.1 Introduction

The knowledge of population size is critical in wildlife studies and population estimates are fundamental for management and conservation purposes (Caughley 1977; Ellis and Bernard 2005; Sinclair *et al.* 2006). Biological surveys allow the collection of information where a good sampling design is central to the success of ecological studies (Sutherland 2006). Population estimates rely on field surveys where animals are recorded using an array of different techniques (Cassey and McArdle 1999).

The total count of individuals in a population is usually difficult to obtain, therefore wildlife abundance estimates are often based on count statistics, representing only a sample of the population under study (Sutherland 2006; Wilson *et al.* 1996). Surveys are based on direct or indirect methods and must consider the study area and objectives, the biology of the species, seasonal effects and the resources available (Ellis and Bernard 2005; Marques *et al.* 2001). Direct methods are based on actual observations of the species in question, while indirect methods rely on interpreting the signs of animal presence such as tracks and scats (Wilson *et al.* 1996).

Visibility and detectability can often pose a problem when surveying terrestrial species therefore surveys relying on signs, such as presence of scats, are ideal for estimating mammal abundance and habitat use (Hayward *et al.* 2005; Sadlier *et al.* 2004; Sullivan *et al.* 2002). Such methods are particularly well suited to studying cryptic species that are difficult to detect (Ellis *et al.* 1998). Within Australia, the koala (*Phascolarctos cinereus*) is a species particularly vulnerable to habitat loss needing active management action to ensure its survival

(Melzer *et al.* 2000; Phillips 1990; Rhodes *et al.* 2006a). However, politics and conservation actions clash due to disagreements in the national koala population size, potentially threatening the persistence of the species (Melzer *et al.* 2000; Phillips 2000). Koala population assessments suffer from a lack of standardisation where surveys have been historically conducted on an *ad hoc* basis, relying on distance sampling surveys, community surveys, faecal pellet counts and presence-absence of scats (Curtin *et al.* 2002; Dique *et al.* 2004; Lunney *et al.* 1997; McAlpine *et al.* 2006b; Phillips *et al.* 2000; Phillips 2000; Rhodes *et al.* 2008; Sullivan *et al.* 2002; White 1999).

The Commonwealth Government of Australia, through the Threatened Species Scientific Committee (TSSC), is responsible for determining the national koala conservation status under the *Environment Protection and Biodiversity Conservation Act 1999.* The koala is currently not listed, as the IUCN criteria for Vulnerable listing requires data showing the likely disappearance of the species in the near future with a < 30% decline shown in the national population size over three generations (IUCN 2010). These requirements cannot be demonstrated for the koala due to the lack of standardised methods to quantify this cryptic species over its broad geographic distribution and a variety of stakeholders recommend applying the precautionary principle in the absence of national data (Phillips 2000). Sampling methods are the key components of a species' conservation assessment process, and this project aims to address the lack of standardisation in koala surveys on a regional scale.

1.2 Study Aims and Research Questions

The divergence in survey methods reduces the ability to compare data and establish reliable estimates, highlighting the need to standardise koala surveys. This study aims to provide a means to objectively assess koala population estimates by comparing two principal survey methods, distance sampling and detection through the presence-absence of scats.

This project will evaluate the suitability of distance sampling (Buckland *et al.* 1993) and the Spot Assessment Technique (SAT), a presence-absence of scats method (Phillips and Callaghan in press), to survey koala in a fragmented landscape and particularly in an area where the species exists in low densities. The study aims to assess how robust each method is in the detection of koala for direct estimation of population size, while also comparing this to the use of relative measures of presence based on the SAT methodologies. Interpolation of the results from the SAT and plotless distance based methods from the same study site (using a detection parameter) will ensure an accurate evaluation of these methods by mapping koala distribution and relative abundance using GIS. The study will also provide for a more detailed analysis of koala habitat use across the landscape in Karawatha Forest Park (KFP), the study site, as there are currently no existing data on this low density koala population. The assessment of the distribution and abundance of koalas at KFP will be driven by four primary research questions:

1. Which survey method is better adapted to detect and estimate the koala population at KFP, and how do these methods compare in terms of survey effort?
2. What is the distribution and abundance of koala at KFP?
3. Do koala display any tree species preference in KFP?
4. What environmental variables affect the distribution of koala across the landscape at KFP?

This study will not compare the density estimates obtained by each method directly as distance sampling provide a calculated density estimate from direct observations while the SAT provides measures of the relative abundance from the detection of scats. Rather, the study will assess the koala detection function and survey effort that will be compared as a relative, but standardised, measure of their distribution across the landscape.

In doing so, this study first provides the context that forms the foundation behind the research questions stated previously. Wildlife surveys and their applications for koala population management are first reviewed, before providing further details on the species and its status in Southeast Queensland (SEQ). The methodology and study area are outlined before presenting the results of the study. Finally, the results are discussed in relation to previous research and the implications of this project are summarised by referring back to the original research questions.

CHAPTER 2: Wildlife surveys review

2.1 Wildlife surveys

Methods for estimating animal abundance have been extensively developed during the past century, where advances in computer technology allowed testing the robustness of different survey techniques with the integration of statistics (Cassey and McArdle 1999; Rhodes *et al.* 2006b; Seber 1986; Thomas *et al.* 2002; Tyre *et al.* 2003). In the past 20 years, wildlife managers in particular have been responsible for providing accurate population estimates, and the literature relating to methods for assessing population size is constantly growing (Cassey and McArdle 1999; Lunney *et al.* 2002; McAlpine *et al.* 2008; Rhodes *et al.* 2006a; Schwarz and Seber 1999). Appropriate survey methods depend primarily on the size of the species and its biology. For example, if the species is cryptic and nocturnal it is usually difficult to detect, therefore the methodology must be adapted to cater for such characteristics (Schwarz and Seber 1999).

When estimating the size of a population within a prescribed area, three approaches can be applied: total counts, partial counts and the use of an index. Total counts of individuals are a popular method for surveying large mammals and have been applied in the assessment of caribou populations in Canada and elephants in South Africa, where aerial-based census methods allowed the determination of the total numbers of individuals (Morley and Van Aarde 2007; Zimmerman *et al.* 2002). It is relatively simple to conduct a census and results are easily interpretable (Clancy *et al.* 1997; Sinclair *et al.* 2006; Zimmerman *et al.* 2002). Total counts are still used to assess large mammals with clumped dispersion patterns such as the African buffalo (*Syncerus caffer*) and the African elephant (*Loxodonta africana*), where estimates have high variance and large confidence limits (Clancy *et al.* 1997; Sinclair *et al.*

2006). However, this method presents a high risk of inaccuracies due to impractical sampling effort over large areas, and complete data are often not accessible (Hounsome *et al.* 2005; Seber 1986; Zimmerman *et al.* 2002). Therefore, when animals are not all equally visible and the observer's ability to see all individuals can bias the survey, samples of the population are better suited to provide estimates of total population (Seber 1986; Sutherland 2006). These estimates are more accurate as they provide a measure of the confidence associated with the results (Marques *et al.* 2001). Subsets are obtained by partial counts and are widely used to assess terrestrial mammals whereas individuals are usually surveyed using distance sampling based on line-transects (Ellis and Bernard 2005; Marques *et al.* 2001; Marshall *et al.* 2008; Pollard *et al.* 2002). Indices based on animal signs such as track and scat counts are often used to survey large carnivores and herbivores (Funston *et al.* 2001; Stander 1998) and are generally successful in studying cryptic species and their relative habitat use (Sinclair *et al.* 2006; Sutherland 2006). Koala distribution, for example, has been examined using presence-absence of scats in New South Wales and Queensland (Phillips and Callaghan 2000; Phillips *et al.* in press).

Reliability is the key factor to an estimate and depends on accuracy and precision. Accuracy is defined by how close an estimate is to the true population size, while precision is determined by the similarity of repeated estimates to each other (Hounsome *et al.* 2005). The calculation of the 95% confidence limits of a population estimate allows the determination of the estimate precision, which can be improved through repeated counts (Sutherland 2006). The most accurate estimates are obtained by methods relying on the count of animals, or their signs, where the estimate of individuals per unit area allows the calculation of the total population (Buckland *et al.* 1993; Marshall *et al.* 2008; Schwarz and Seber 1999; Seber 1986). Partial counts enable a population subset to be obtained, allowing the whole population to be measured without the constraint of counting all individuals (Schwarz and Seber 1999).

Visual animal identification, hence detectability, is influenced by environmental factors related to the study area, species behaviour, resources available and observer experience. These factors can easily bias the survey resulting in inaccuracy (Sinclair *et al.* 2006; Wilson *et al.* 1996). Any errors in the calculation of population estimates could affect the species' conservation through the application of inappropriate management actions (Sutherland 2006). Divergence in koala surveys in Australia, for example, are directly impacting on the conservation of the species due to inconsistencies in population estimates (Melzer *et al.* 2000).

When designing the sampling strategy, it is necessary to determine if the absolute or relative density is needed, whether any data on the species itself are required, and which sampling unit is better suited for the survey (Sutherland 2006). Sampling units consist of random or systematic plots, where strips, lines, points or quadrats can be selected to measure the population within a study area. To ensure precision, sampling units should minimise variation by being applied systematically across the landscape (Buckland *et al.* 2000). Transects are used to sample units with closed boundaries (bounded counts) such as in strip transects or with open boundaries (unbounded counts) such as in line-transects (Buckland *et al.* 1993; Marques *et al.* 2001).

When direct observations are not possible, counting animal signs provides a relative measure or "index", a measure often used to study secretive species (Schwarz and Seber 1999; Sutherland 2006). The index assumes a constant ratio between the sign and the species. If the index doubles, so does the population estimate (Schwarz and Seber 1999). Indices such as species' scats are widely used to track changes in population size and are useful for comparing data over years (Kendall *et al.* 1992; Sinclair *et al.* 2006). The koala is an elusive species difficult to detect through visual observations, thus the use of sampling methods based on faecal pellet counts or presence-absence of scats have recently been used instead of direct observations (Lunney *et al.* 2009; McAlpine *et al.* 2008; Phillips *et al.* 2000; Phillips *et al.* in press; Rhodes *et al.* 2008). In summary, different methods have been intensively developed to estimate animal population size to match their underlying assumptions, and fit the biology of the species of interest (Cassey and McArdle 1999; Catling *et al.* 1997).

Nonetheless, the estimation of animal abundance is limited by two recurring issues. Firstly, the population occupies an area too large to be surveyed accurately despite the use of sample counts; secondly the species is not distributed in the surveyed sample unit (Royle and Nichols 2003). Therefore, the selection of an appropriate sampling method involves a trade-off between the efficiency of each method, and the characteristics of the study site where an increased effort improves the accuracy of the survey (Focardi *et al.* 2002; Gaidet-Drapier *et al.* 2006). Despite the numerous techniques available, it is important to remember that no method is bias free and the selection of a robust sampling methodology is crucial to ensure the collection of meaningful data (Buckland *et al.* 2000; Marshall *et al.* 2008).

Distance sampling is a common sampling method relying on direct observations, allowing the calculation of population estimates as long as the primary assumptions of the method are met. The assessment of koala populations in Southeast Queensland by DERM is based on distance sampling (Dique *et al.* 2004), despite the difficulties to detect koalas in closed canopy (Munks *et al.* 1996; Sullivan *et al.* 2004).

2.1.1 Distance sampling

Distance sampling requires counting individuals, or groups of individuals, by measuring accurate perpendicular distance from the sampling unit, usually consisting of line-transects (Thomas *et al.* 2002). This method is widely used for the systematic sampling of open populations and is generally suitable for assessing conspicuous terrestrial and marine mammals (Buckland *et al.* 1993; Seber 1986; Thomas *et al.* 2002). Distance sampling consists of unbounded counts where the observer records animals seen from the line, either by foot, vehicle, horseback, boat or plane (Buckland *et al.* 1993; Seber 1986; Thomas *et al.* 2002). The encounter rate, or the number of observations per distance travelled, allows the estimation of relative density based on the overall detection function for each species (Buckland *et al.* 1993; Cassey and McArdle 1999; Marshall *et al.* 2008; Schwarz and Seber 1999). The comparison of animals detected on the line to those detected at greater distance enables the computation of a detection function that ranges between 0 and 1 (Buckland *et al.* 1993; Sutherland 2006). The estimate of the population size is then obtained by multiplying the average density per sampling unit (line-transect) by the total population area (Buckland *et al.* 1993).

The detection distance is typical depicted by the distance sampling curve, where the detectability decreases the further one moves from the transect centreline (Fig. 2.1) (Thomas *et al.* 2002). The area below the curve represents the probability of detection of an animal within the surveyed area (Buckland *et al.* 1993).

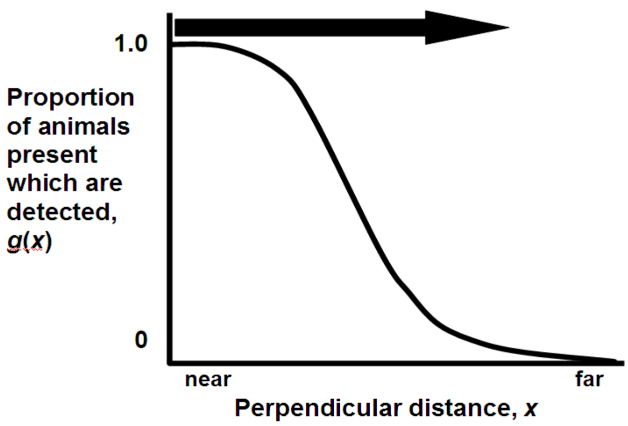

Figure 2.1 Distance sampling curve showing the detectability function where all animals on the line are seen with a probability 1, detectability decreases with increasing distance from the line (Buckland *et al.* 1993)

Distance sampling is well suited for surveying vertebrates in open habitats by direct counts as well as for recording indices of mammal activity such as scats and tracks along the transect (Sutherland 2006). The assessment of deer abundance for example, is often based on distance sampling surveys of dung, where the gravity centre of the pellet group or dung is accurately measured from the line (Focardi *et al.* 2002; Marques *et al.* 2001). Distance sampling is a relatively simple and cost effective method (Marques *et al.* 2001; Marshall *et al.* 2008) but relies on four fundamental assumptions (Buckland *et al.* 1993; Buckland and Turnock 1992; Focardi *et al.* 2002):

1) animals on the transect line are all detected
2) animals do not move before detection
3) distances are measured accurately
4) detections are independent events

The first assumption is central to distance sampling and unbiased estimates can be calculated only if these assumptions are met (Thomas *et al.* 2002). Line-transect design is based on the key requirement of systematic coverage of study areas regardless of population density where the placement of a grid of lines across the study area is ideal (Buckland *et al.* 1993).

Buckland *et al.* (1993), provides an extensive review of distance sampling design and requirements while Laake *et al.* (1993), developed the software DISTANCE allowing the computation of the data. The key elements presented by Buckland *et al.* (1993) rely on the assumption that animals will remain undetected in distance sampling and that the detectability decreases with increasing the distance from the line. The fundamental concept central to the theory is the detection function where $g(0) = 1$: i.e. at zero meters all the animals on the line are detected with a probability of 1. To derive robust estimates, a minimum of 60 to 80 observations are required across the study area (Buckland *et al.* 1993).

Distance sampling has been successfully applied to study ungulates (Ellis and Bernard 2005; Focardi *et al.* 2002; Gaidet-Drapier *et al.* 2006; Marques *et al.* 2001), primates (Ancrenaz *et al.* 2004; Buij *et al.* 2003; Marshall *et al.* 2008; Nekaris *et al.* 2008; Wich *et al.* 2008), badgers (Hounsome *et al.* 2005), small African carnivores (Martinoli *et al.* 2006) and marsupials including the koala (Catling *et al.* 1997; Clancy *et al.* 1997; Dique *et al.* 2003c). These different studies evaluated the precision and accuracy of distance sampling and compared the efficiency of the different methods used to conduct a line-transect survey (aerial, foot, bicycle, car). In general line-transects surveyed on foot resulted in the most accurate surveys. However, some limitations arose due to the difficulty in detecting cryptic species in dense habitat (Marshall *et al.* 2008).

2.1.2 Distance sampling limitations

A common limitation of the method is the number of independent sightings required for the estimation of a detection function. The sample size should be a minimum of 60-80 observations for the area sampled to accurately model detection functions (Ancrenaz *et al.* 2004; Marshall *et al.* 2008). A smaller sample size could bias the results by not providing enough variance (Buckland *et al.* 1993). Therefore estimating the size of low-density populations could be difficult where observers can walk hundred of kilometres with only a few sighting events (Marshall *et al.* 2008). Increasing sampling effort can compensate for this bias, however for some cryptic species occurring in dense habitats the problem remains, due to low visibility reducing the detectability (Ellis and Bernard 2005).

Focardi *et al.* (2002) and Hounsome *et al.* (2005), compared distance sampling to mark-recapture methods and found that distance sampling estimates were less precise than mark-recapture estimates when studying the density of ungulates and badgers (*Meles meles*). While distance sampling was more efficient it was less appropriate than mark-recapture for estimating species occurring at low-density in closed habitats (Focardi *et al.* 2002, Hounsome *et al.* 2005). They concluded that density estimates were biased when using distance sampling due to the variability of the detection function reflecting the difficulty of observing mobile animals such as ungulates and badgers even at short distances, where animals often moved to hide in the bush before being detected by the observers. Accessibility of line-transects was also identified as an issue in dense habitats (Focardi *et al.* 2002, Hounsome *et al.* 2005).

Marshall *et al*. (2008) evaluated distance sampling when studying a population of primates in Tanzania and concluded that the violation of assumptions was difficult to avoid, particularly in dense habitats. The most problematic limitations consisted of detecting animals existing at low densities and accurately measuring the distances from the centre of groups of primates. Buij *et al.* (2003), surveyed low densities of orang-utans in Borneo and found that the cryptic species was difficult to detect by distance sampling. They concluded that distance sampling was time-consuming and suggested indirect surveys based on nest or dung signs rather than direct observations. Sullivan *et al.* (2002), advocated the use of faecal pellet count to survey koalas due to detection difficulties within the canopy and Munks *et al.* (1996) concluded that koalas were hard to detect by visual observations.

Thus, the use of indirect methods is recommended for surveying elusive species occurring at low density, such as the koala. The use of such methods allows the determination of population relative estimates and distribution within a study site (Stephens *et. al* 2006; Sullivan *et al.* 2004).

2.1.3 Indirect methods

The urgent need to monitor threatened and endemic species contrasts with the difficulties of studying them (Blaum *et al.* 2008; Stephens *et al.* 2006). Indirect sampling methods offer a number of advantages over direct methods and Caughley (1977), has advocated the use of indices in dealing with many ecological problems. Signs can be easily identified in diverse habitats and sampling is not as labour intensive as direct methods (Sadlier *et al.* 2004). Indirect methods based on presence-absence or counts of signs are more suitable, as they provide relative estimates of population size (Schwarz and Seber 1999; Stephens *et al.* 2006). Indirect methods have largely been applied to study carnivorous species such as cheetahs (Houser *et al.* 2009), foxes (Sadlier *et al.* 2004), leopards (Janecka *et al.* 2008), tigers (Karanth *et al.* 2003), grizzly bears (Kendall *et al.* 1992) and marsupials such as gliders (Ward 2000), quokkas (Hayward *et al.* 2005) and koalas (Lunney *et al.* 2000; McAlpine *et al.* 2008; Munks *et al.* 1996; Phillips and Callaghan 2000; Phillips *et al.* 2000; Rhodes *et al.* 2006b; Sullivan *et al.* 2003).

Indices provide a passive method for estimating wildlife densities. The value of indices is based upon the premise that a fixed amount of sampling effort gives the fixed proportion of the population and the rate of proportionality should be constant (Norvell *et al.* 2003; Schwarz and Seber 1999). An index of density is always associated with true abundance, where the value of the index usually increases with population density (Wilson *et al.* 1996). For example, the number of tiger (*Panthera tigris*) tracks along transects in India provided a useful index to compare changes in population density between years (Karanth *et al.* 2003). Kendall *et al.* (1992) concluded that signs such as scats and tracks were powerful to survey low density populations of grizzly bears (*Ursus arctos*) in the USA.

Presence-absence of scats is applied in this study as the indirect method used to survey koalas, as previous studies have demonstrated the efficiency of this method in detecting this elusive species (Lunney *et al.* 2009; McAlpine *et al.* 2008; Phillips and Callaghan 2000; Phillips *et al.* 2000; Rhodes *et al.* 2005).

2.1.4 Presence-absence scat surveys

Indices of relative abundance and population size are often based on the presence or absence of scats if the species has characteristic dung and occurs at low density (Ellis and Bernard 2005; Hayward *et al.* 2005; Kendall *et al.* 1992). Ungulates and carnivores have been successfully studied using presence-absence methods (Campbell *et al.* 2004; Ellis and Bernard 2005; Houser *et al.* 2009; Marques *et al.* 2001). It is easier to record these signs than direct observations of the species to determine site occupancy (Sutherland 2006) and the method has the detection probability directly included into the estimation calculation (Royle and Nichols 2003). Presence-absence of scats is recorded by plot-based searches and constitutes a non-invasive method to study cryptic species (Gallant *et al.* 2007; Lunney *et al.* 2000; Marques *et al.* 2001).

The aim of presence-absence surveys is to establish if a site is occupied by a specific species (Wintle *et al.* 2004). It is essential to make the distinction between not being able to detect a species presence in an occupied site (false negative), and the absence of species in an unoccupied site (true negative). False positive consists of recording the species as present when it is in reality absent (Tyre *et al.* 2003). Typically in presence-absence surveys, a large number of sites are investigated by a standardised monitoring technique where site variables are measured, resulting in a habitat model (Tyre *et al.* 2003). Surveys result in a binomial classification at two different levels: the probability that the species is present within the site and the probability that the species occupies a habitat as part of their home range (Royle and

Nichols 2003; Tyre *et al.* 2003). The data consist of detection and non-detection events permitting a reduced-effort approach that are able to cover large areas in a relatively short amount when compared to direct observations methods (Royle and Nichols 2003). This approach is applied in this study where koala presence-absence is assessed according a standardised protocol.

Habitat selection and dispersal affect occupancy patterns, hence the ability to detect trends in abundance from presence-absence surveys (Rhodes *et al.* 2006b). Consequently, the sample size needs to be large enough to ensure the detectability of cryptic species (Wilson *et al.* 1996). The effectiveness of binary presence-absence methods to monitor the relative abundance of species has been demonstrated by Blaum *et al.* (2008) to small carnivores species in the Kalahari region of South Africa, by searching for tracks along sand transects. Furthermore, Royle and Nichols (2003) concluded that occupancy surveys derived through presence-absence methods are advantageous as they offer reduced effort while allowing accurate surveys of large-scale areas. The flexibility of the method has been highlighted by Tyre *et al.* (2003) with studies done on birds, frogs and invertebrates but the authors suggested repeated surveys on a subset of sites to obtain relative abundance estimates before drawing conclusions on site occupancy.

The preceding sections have shown that sampling techniques are continuously evolving as scientists endeavour to improve survey efficiency (Cassey and McArdle 1999). However, the compatibility and ability to compare new methods with established techniques is often poorly understood. For example, the Spot Assessment Technique (SAT) developed by the Australian Koala Foundation (Phillips and Callaghan in press) to assess koala tree preference by determining the presence-absence of faecal pellets is an indirect method used more recently to assess the relative density as well as distribution of koalas by looking at tree species preference across the landscape (McAlpine *et al.* 2008; Phillips *et al.* 2000; Rhodes *et al.* 2008). Koala populations are scattered across Australia in dense habitats and their elusive nature presents a challenge to survey the species efficiently through conventional census methods (Phillips 2000; Sullivan *et al.* 2002). An understanding of the species ecology is therefore necessary to inform the selection and use of appropriate survey methodologies that can be implemented at the appropriate scale (Seber 1986).

2.2 Koala background

Estimating koala (*Phascolarctos cinereus*) population size at a regional, state and national level is an ongoing problem (Phillips 2000). This folivorous arboreal marsupial is cryptic, with low detectability characteristics and occurs widely across Australia with a patchy distribution (Lunney *et al.* 2009; Melzer *et al.* 2000; Phillips 2000). The species exists mainly at low densities in fragmented areas where its conservation status is insecure as a result of habitat loss and fragmentation (Phillips 2000). Differences in opinion surrounding the national population estimate are affecting koala conservation through disagreements on the actions undertaken to improve the species status, thereby slowing down the conservation process (Penn *et al.* 2000; Phillips 2000). Estimated koala numbers vary between 45,000 (AKF 2009) to one million (Melzer *et al.* 2000; Phillips 2000; Sullivan *et al.* 2002) and this lack of accuracy jeopardises the conservation of this iconic species. Furthermore, koalas are listed variably under different conservation categories across different states resulting in confusing information for wildlife managers and policy makers. The global conservation status of species is determined by the IUCN, where seven conservation status categories range from Least Concern to Extinct with three threatened categories requiring conservation actions: Critically Endangered, Endangered and Vulnerable (IUCN 2010). The koala is classified as a species of Least Concern (status reviewed in 2008), and despite alarming declines in New South Wales and Queensland, the global population is considered secure

(IUCN 2010; Phillips 2000). The koala is also significant at a cultural level for Australian, and international communities. Its conservation is valued despite the regional variation in status across states (Stratford *et al.* 2000).

In Victoria and South Australia, the koala is believed to be widespread with high densities contained locally due to fragmented habitat. In New South Wales koalas are listed as "Vulnerable" to "Locally Extinct" and in Queensland "Common" to "Vulnerable" depending on regional variation (Melzer *et al.* 2000). In the Southeast Queensland (SEQ) bioregion koala are listed as "Vulnerable" under the *Nature Conservation Act 1992* and "Near Threatened" in the *National Action Plan for Monotremes and Marsupials* (Melzer *et al.* 2000). Despite the evidence of regional conservation requirements, the species does not meet the criteria to be listed under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), which would allow the species to be considered as Vulnerable under IUCN criteria. Habitat loss, disease, road traffic and predation from dogs as a result of urban development pose a serious threat to koala survival, demonstrated by their numbers declining in many regions (Dique *et al.* 2003b; DERM 2009; McAlpine *et al.* 2006; Melzer *et al.* 2000; Phillips 2000). These declines have reached significant levels in some areas, particularly in Southeast Queensland where some populations declined by more than 50% in the past five years (DERM 2009).

The conservation of the population in Southeast Queensland is therefore critical as the Queensland sub-species *Phascolarctos cinereus adustus* has higher genetic diversity compared to the sub-species *P.c. victor* in Victoria, which is facing inbreeding depression (Fowler *et al.* 2000; Melzer *et al.* 2000; Wilmer *et al.* 1993). However, despite an urgent need for reliable population estimates, koala surveys are still not standardised and surveys often lack financial support and adequate sampling design (Cork *et al.* 2000).

2.2.1 Koala ecology

Koala feed primarily on tree species of the genus *Eucalyptus* and show tree species preferences throughout their range (Phillips and Callaghan 2000; Rhodes *et al.* 2006b; White 1999). *Eucalyptus microcorys* and *Eucalyptus tereticornis* have been found to be the species preferred by koalas in QLD and their importance for koala habitat quality is highlighted in different studies (DERM 2009; Phillips *et al.* in press; White 1999). Koalas have evolved physiological traits allowing them to feed almost exclusively on the leaves of eucalypts, which contain toxic compounds and provide a nutrient-poor diet (Ellis *et al.* 1998). Tree selection relies on the koala's ability to assimilate the secondary compounds within the leaves, resulting in koalas resting approximately 80% of the day due to their low metabolic rate. The species' home range is directly related to *Eucalyptus* species availability and leaf toxicity, and can vary from 2ha to 300ha depending on populations and land fragmentation (Ellis *et al.* 2009). White (1999) found that home range varied between 5.3 and 91.4ha in rural Southeast Queensland and Dique *et al.* (2003b) found that koalas on the Koala Coast (SEQ) dispersed an average of 3.5 km from their natal home range. The home range of male koalas is significantly larger than that of females, as males patrol within their territory continuously to locate females and deter other males from establishing dominance (Ellis *et al.* 1998; Phillips *et al.* 2000).

The availability of food trees is a key element influencing koala dispersal patterns however, non-food tree selection also plays an important role due to the koalas physiological requirements for diurnal shelter and protection (Ellis *et al.* 1998). To minimise energy costs, individuals travel by night and rest during the day in closed-canopy trees (Hindell and Lee 1987). It is suggested that the spatial distribution of koalas results from a combination of the foraging strategies and complex social interactions (Ellis *et al.* 1998; Hindell and Lee 1987).

Koalas show tree species preference and site fidelity, linked to soil nutrients and foliar nutrients availability (Phillips and Callaghan 2000). The presence of koalas is correlated with high levels of nitrogen, phosphorus and potassium in the soil, as well as high leaf moisture concentrations in arid regions (Munks *et al.* 1996). Studies have also demonstrated that koalas have a preference for larger trees when available, providing more resources and shelter than smaller trees (Hindell and Lee 1987). According to Ellis *et al.* (1998), koalas maintain a complex social system with overlapping home ranges but no sharing of food trees; a food tree is rarely used twice by the same individual or by other koalas. Ellis *et al.* (2009), found that 86% of trees were used only once by koalas at Blair Athol in Queensland. Koalas have been observed selecting a tree where they smelt the base of the tree before climbing it, suggesting that koalas used olfactory cues at the base of the tree to identify a potential food tree and hence leaf palatability (Ellis *et al.* 2009).

2.2.2 Koala distribution

Koalas range from North Queensland to South Australia where their entire distribution has experienced changes following European settlement (Fig. 2.2). It is believed that the koala's former range has contracted by more than 50% (Phillips 1990; Phillips 2000; Sullivan *et al.* 2003b). The clearing of eucalypt forest combined with intensive hunting in the 1800s and outbreaks of disease resulted in the near extinction of the species in the southern range by the 1930s (NRMMC 2009; Phillips 2000). Important translocation programmes within different areas of Victoria and South Australia re-established koalas, while reintroduction efforts enabled new areas such as Kangaroo Island to be colonised (Melzer *et al.* 2000). The success of these translocation programmes allowed koalas to spread through available habitats resulting in the depletion of food resources, and inbreeding in some areas as a result of locally overabundant fragmented populations (Melzer *et al.* 2000; NRMMC 2009). In New South Wales koalas are patchily distributed with local extinctions in the southern and western range

(Melzer *et al.* 2000). Habitat loss resulted in the disappearance of half of the population range in the state (Phillips 1990). Queensland populations are widely distributed in the wet forests and woodlands, scattered across the state (Melzer *et al.* 2000). The Southeast bioregion supports the largest concentration of koalas in Australia and these populations remained abundant despite the spread of disease and hunting. However, they are now severely threatened by ongoing development pressure and rapid declines have been observed (DERM 2009; Penne et al. 2000; Phillips 2000; Sullivan et al. 2004).

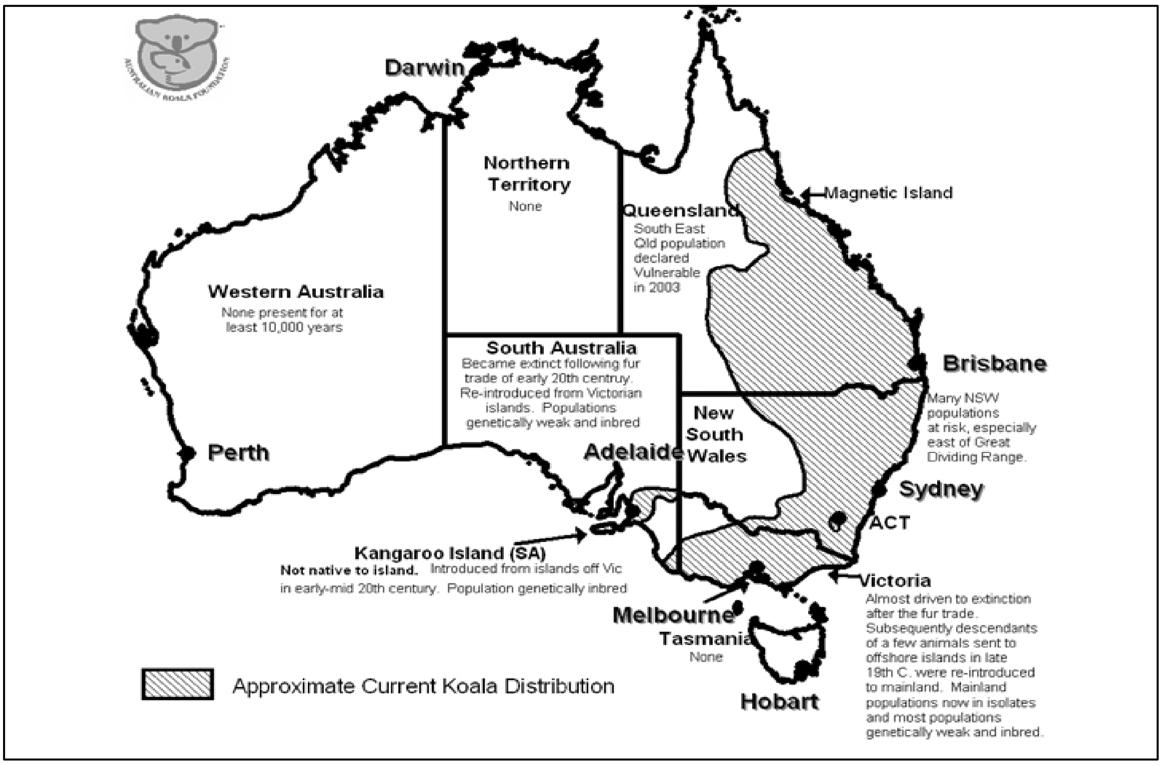

Figure 2.2 The current distribution of koala established by the Australian Koala Foundation showing koala different conservation status across States (Sourced from AKF 2004)

2.2.3 Koala in Southeast Queensland

The Southeast Queensland region is experiencing the fastest rate of development in Australia (Dique *et al.* 2003b). Over the last 20 years, approximately 55,000 new residents per year were recorded for this area (DERM 2009). The urbanisation pressure impacts directly on koala populations where habitat loss resulting from forest clearing is the driving factor behind declines (Melzer *et al.* 2000; Sullivan *et al.* 2003a; Woodward *et al.* 2008). In 2008, the Koala

Taskforce was established by the Premier of Queensland in response to these declines to evaluate koala conservation efforts in Southeast Queensland. The goals of the Koala Taskforce were to map koala habitat in SEQ and to identify threats to the koala population (DERM 2009). One of the regions the most affected by koala declines is the Koala Coast, situated 20 km southeast of Brisbane. This region covers an area of ~ 375 km^2, and is considered significant as it contains a high number of koalas (~6200 individuals in 1999) that are believed to be genetically different from other populations (DERM 2009; Wilmer *et al.* 1993). The Koala Coast, which incorporates the mainland portion of Redland City, the eastern portion of Logan City and the south-eastern portion of Brisbane City, is geographically isolated and lies within an expanding urban matrix (DERM 2009) (Fig. 2.3).

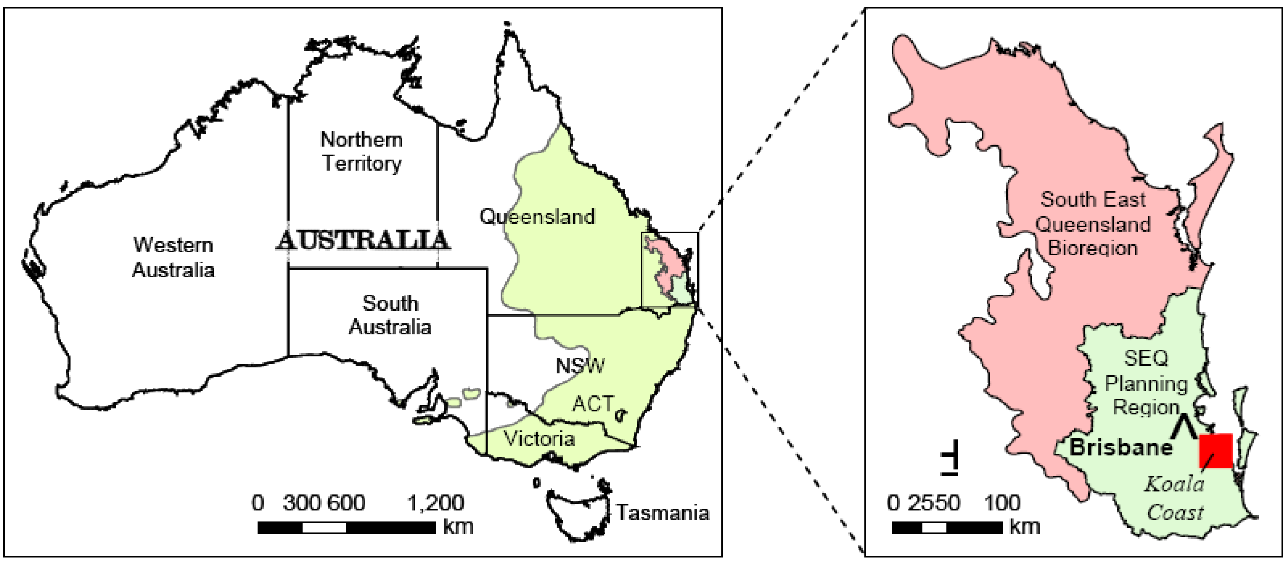

Figure 2.3 The Koala Coast location within the Southeast Queensland bioregion (DERM 2009)

The conservation of this population is important as genotypic diversity is an essential criterion for conservation (Fowler *et al.* 2000). The high genetic variation found in koalas occurring in Queensland is still poorly understood, therefore conserving the species in this particular area is fundamental under the precautionary principle (Melzer *et al.* 2000). According to Houlden *et al.* (1996), the Southeast Queensland koala DNA is considered to be distinct enough to declare these populations significantly different from New South Wales and Victoria populations.

The Koala Coast is experiencing extensive bushland clearing, dramatically reducing koala habitat (Dique *et al.* 2003a). Recent surveys indicated that the population declined in the last decade where numbers dropped from 6246 individuals in 1999 to 4611 in 2008 (DERM 2009). Despite this alarming trend, surveys in this region are based solely on direct observations from strip and line transects (Dique *et al.* 2004; Dique *et al.* 2003c; DERM 2009). Knowledge of the sensitivity of the assumptions of this technique (Marshall *et al.* 2008), questions the accuracy of the results and highlights the lack of information about koala distribution and abundance within this region. Supplementing direct observations with presence-absence of scats surveys conducted simultaneously provide information on koala distribution, habitat utilisation and relative density allowing appropriate conservation plans to be developed. Consequently, the National Koala Conservation Strategy (NKCS) in the Draft National Koala Conservation and Management Strategy 2009-2014 – Consultation Draft, recognised that reliable population estimates based on techniques discerning tree species are necessary and that more research is required on koala survey methods (NRMMC 2009).

2.2.4 Koala threats and conservation issues

The national koala population is considered secure under the *EPBC Act* 1999 despite severe declines in Southeast Queensland, local extinctions in New South Wales and inbreeding problems in Victoria (Melzer *et al.* 2000; Penn *et al.* 2000; Phillips 2000). These differences in conservation status demonstrate a poorly coordinated national conservation effort. The evidence of genetic differences between northern and southern populations further highlights the need to conserve the species across its range (Penn *et al.* 2000).

Development of land in the last two centuries has resulted in habitat loss and fragmentation due to extensive clearing of native forest. The loss of forest is the number one threat for koalas through destruction and fragmentation of habitat (McAlpine *et al.* 2006b). Habitat fragmentation has also been suggested to be responsible for the spread of disease (*Chlamydia*) in koala populations (Cork *et al.* 2000). Their remaining numbers are threatened by domestic dog predation, proliferation of roads resulting in an increase of kills through collision with cars, *Chlamydia*, a disease affecting the reproductive tract of females, drought and bushfires (Melzer *et al.* 2000; Phillips 1990; Rhodes *et al.* 2006b). The Southeast Queensland region has already lost more than 60 % of native vegetation cleared for development (Catterall and Kingston 1997), directly impacting on koala populations (Peterson *et al.* 2007). In such rapidly urbanising areas, studies have showed that the main threats to koala populations after habitat loss consisted of traffic mortality and predation by dogs (Dique *et al.* 2003a; Phillips 1990). These issues have been identified as having a major impact and the National Koala Conservation Strategy proposes the restriction of dog ownership and the introduction of slow traffic speed zones in koala habitats (ANZECC 1998).

The complex debate on how best to conserve koala results in diverse management actions and research programmes. However the species conservation status is still at the centre of disagreements between the Australian government, conservation groups, scientists and communities (Cork *et al.* 2000). The koala is an iconic species symbolising the need to conserve wildlife habitat. However, the fact that the species is not protected at a national level is problematic (Clark *et al.* 2000a). Cases with such ecological complexity require multidisciplinary cooperative efforts, which are often difficult to achieve (Stratford *et al.* 2000). The main policymakers producing management plans are the four governments presiding over the areas where koalas exist, even though the Federal government drafted the National Koala Conservation and Management Strategy 2009-2014 to complement State legislations (Clark *et al.* 2000b; NRMMC 2009). The document identifies the threat to koalas and includes an implementation plan supervised by a national coordinating team to provide a national framework for conserving the species. Long-term, desired and short-term outcomes are presented. For Southeast Queensland koala populations, the plan proposes to prevent ongoing koala decline through the rehabilitation of cleared habitats, rather than preventing continuing development of koala habitats. The plan also proposes to promote future land use and development compatible with the survival of the species. However, it does not recommend the cessation of clearing critical koala habitats. Despite these recommendations, the documents have not been well received by all parties and the Australian Koala Foundation has already raised some concerns regarding the document (NRMMC 2009).

The conflict between human land requirements and koala habitat use is one of the main problems affecting the conservation of the species as more than 50% of forest occupied by koalas has been cleared for development (Cork *et al.* 2000; Penn *et al.* 2000; Phillips 2000; Rhodes *et al.* 2006a). Koalas are sensitive to habitat fragmentation and they frequently have to cross non-forest corridors to access high quality habitat where the risk of mortality is high (McAlpine *et al.* 2006b). According to Phillips (2000), the koala could become an endangered species in the next decade due to the rapid rate of habitat loss. Habitat availability is fundamental and should be prioritised for conservation, however is not prioritised in the NKCMN plan (Bryan 1997). Koalas are often found in fertile areas where they face pressure from urban development such as farming areas or private land. Therefore the conflict concerning koala habitat involves high stakes. In Southeast Queensland, the Southeast Queensland Forests Agreement was signed in 1999 and aimed to manage forests sustainably, and increase the size of reserve areas. The current reserve system is now less fragmented, however shows biases for wet rainforest due to greater attention from public, and therefore fails to protect dry eucalypt forest and associated fauna. Furthermore, biodiversity conservation plans do not acknowledge conservation on private lands by focussing on public lands (McAlpine *et al.* 2007).

Cork *et al.* (2000) recommend that habitat models in koala conservation should acknowledge human activities as well as environmental factors. Here, the ecological scale is critical to conservation, where working at more than one scale at a time is vital to understanding cumulative impacts (McAlpine *et al.* 2008). Conservation priorities need to be identified through conservation planning with the integration of biodiversity and land use strategies, which depend on decision makers priority settings. Action should be applied at the local level rather than at a national level (McAlpine *et al.* 2006a; Rhodes *et al.* 2008). Regional environmental sustainability advocates biodiversity conservation, nonetheless still favours economic growth in practice (Peterson *et al.* 2007). Even at this level the koala warrants concerted conservation efforts as an iconic wildlife species. The koala is believed to bring billions of dollars to the Australian government through tourism revenue and the financial importance of this charismatic species to tourism industry has been proven (Hundloe and Hamilton 1997). However, the economic benefit of clearing koala habitat for development is stronger than the survival of the species as no drastic measures have been yet taken to ensure its conservation at the national level.

The key issue in koala conservation lies in the lack of national standards to determine population estimates (Phillips 2000). Regional distribution and abundance patterns should be identified for all regions experiencing declines, followed by spatial analysis of habitat quality, connectivity to improve conservation strategies and koala threats modelling (Bryan 1997; McAlpine *et al.* 2006a). Protecting the conservation status of the koala on a national level requires data currently missing due to difficulties to survey the species on its total range.

Therefore with the legislation failing to protect the koala under federal law, developers will continue to extensively exploit and reduce koala habitat (Melzer *et al.* 2000).

2.3 Koala surveys

Determining the national koala population size is labour-intensive and logistically difficult to realise due to non-standard methodologies (Meltzer *et al.* 2000). However at a regional scale the lack of estimates is an issue for conserving the species (McAlpine *et al.* 2008; Rhodes *et al.* 2008). This emphasises the need for reliable regional estimates of koala populations, which are regarded as being more valuable for conserving the species than national estimates (McAlpine *et al.* 2008).

A unique national survey was undertaken in 1986, where the Australian National Parks and Wildlife Service coordinated the assessment of koala populations across South Australia, Victoria, New South Wales, ACT and Queensland (Phillips 1990). Community reports of sightings, intensive systematic searches, faecal pellet distribution, community surveys, koala responses to taped calls and spotlighting were combined to estimate koala numbers with the help of hundreds of volunteers (Melzer *et al.* 2000). The survey, limited by the large geographic scale, and biased by the lack of volunteer experience in detecting koalas, still provided useful information on koala distribution and tree species preferences (Phillips 1990).

Previous assessments of koala abundance have used a combination of strip and line-transect sampling, presence or absence of scats and community-response surveys (Curtin *et al.* 2002; Dique *et al.* 2004; Dique *et al.* 2003b; Ellis *et al.* 1998; Lunney *et al.* 2000; McAlpine *et al.* 2006a; Melzer *et al.* 2000; Phillips *et al.* 2000; Rhodes *et al.* 2005; Rhodes *et al.* 2006b; Sullivan *et al.* 2004). Koala distribution is mainly determined by community-response surveys and presence-absence of scat assessments, while population density estimates are based on strip and line transects (Dique *et al.* 2004). The Australian Koala Foundation argued that there was a tendency for surveys to overestimate koala numbers, as local estimates are usually extrapolated over larger areas. Because koala populations are not distributed equally over the landscape, their numbers could be much lower in reality than estimated, however method such as distance sampling accounts for this issue by providing a detection function (Sutherland 2006).

2.3.1 Direct observations

Direct observations are usually made by following line or strip transects, and by applying distance sampling to estimate koala population size in Southeast Queensland and is the current technique in use by DERM (Dique *et al.* 2004). Dique *et al.* (2003a) compared strip and line transects methods in Southeast Queensland, concluding that line transects were better suited to survey koalas as they were logistically effective and more accurate. Koalas were surveyed during the day in Pine Rivers Shire (SEQ), a high density koala area where two observers walked a total of 134 line transects separated by 150m between each transect covering 14 sites. A total of 82 koalas were from 22 study sites within an area of 77, 000ha, to provide an estimate of 4584 koalas with a 95% confidence interval (Dique *et al.* 2003a). In a different survey conducted by Sullivan *et al.* (2002) in a low-density area in western Southeast Queensland, traditional survey techniques such as transect counts were often biased by missed observations, affecting the final estimate. Therefore, they suggested that faecal pellet counts from quadrats search were better suited to determine relative abundance (Sullivan *et al.* 2002), in agreement with previous studies by Munks *et al*. (1996).

A number of recent studies assessing the koala distribution in Southeast Queensland and Northern New South Wales confirmed this suggestion by applying the Spot Assessment Technique, an indirect plot-based method applied to determine presence-absence of koala scats under their preferred tree species (McAlpine *et al.* 2006a; McAlpine *et al.* 2008; Phillips and Callaghan 2000; Phillips and Callaghan in press; Phillips *et al.* 2000; Rhodes *et al.* 2008; Rhodes *et al.* 2006b). This technique has the potential to derive a standardised method of koala detection and will be evaluated in this study.

2.3.2 The Spot Assessment Technique

The Spot Assessment Technique (SAT) developed by the Australian Koala Foundation (Phillips and Callaghan in press), assesses the distribution of koala by determining their tree species preference. This indirect sampling method is based on a binary variable, presence or absence of faecal pellets, and determines the level of koala activity by studying the extent of tree use across the landscape. The SAT provides critical information by estimating the relative abundance of koala while simultaneously delivering an index of their habitat preferences (Phillips and Callaghan in press). The method also enables a relatively rapid cost-effective assessment of a high number of sample sites. The SAT is suited to surveying koalas as the species is territorial with strong site fidelity, and has characteristic faecal pellets with a eucalypt odour, which are relatively easy to identify in the field (Fig. 2.4) (Phillips and Callaghan in press; Triggs 1996).

Figure 2.4 Koala faecal pellets are easy to identify as they have an oval shape and strong eucalypt odour

Since its development, the technique has been widely applied to assess koala distribution and habitat use (McAlpine *et al.* 2008; Phillips and Callaghan 2000; Rhodes *et al.* 2008; Rhodes *et al.* 2006b). This method is based on the systematic sampling of study sites selected by an unbiased approach. The advantages of the SAT are clear and this method offers an easily reproducible and efficient technique to accurately identify koala distribution and assess their relative abundance over large-scale areas (Phillips and Callaghan in press).

2.4 Conclusion

The variety of wildlife survey methods offers each advantages and disadvantages. In many situations the most efficient method will be determined by as sound knowledge of the survey subjects ecology. Intensive systematic searches are only a suitable option when habitat is limited, which is impossible over a large geographical scale. For koala, existing broadscale population estimates rely on extrapolation of local densities, based on the assumptions that similar habitat types would contain the same density of koalas (Melzer *et al.* 2000). However, according to Sullivan *et al.* (2004), *ad hoc* estimates retard effective koala conservation projects and national standards with regionally compatible survey methods need to be put in place.

CHAPTER 3: Methods

3.1 Background

In order to evaluate the koala detection ability of the Spot Assessment Technique (SAT) versus that of distance sampling, a koala survey was undertaken at Karawatha Forest Park (KFP), where a low-density koala population is believed to exist as no current data are available. KFP is situated in the Southeast Queensland bioregion where the species is listed as Vulnerable under Queensland law, due to the threat posed by intensive development occurring in the region.

Field assessments were completed between October 2009 and January 2010, where 33 permanent plots were intensively surveyed using a combination of both SAT and distance sampling methods. Animal ethics approval was granted by the Griffith University Animal Ethics Committee. Koalas are active all year round and their habitat selection is not reported to vary seasonally (McAlpine *et al.* 2008), therefore there were unlikely to be any seasonal biases by conducting the survey only over the summer.

3.2 Study Site

This study was conducted at Karawatha Forest Park (KFP) in Brisbane, southeast Queensland (Latitude -27.632° S, Longitude 153.084° E). This urban forest park situated south of Brisbane and managed by the Brisbane City Council (BCC), is covered by dry sclerophyll *Eucalyptus* forest and isolated wetland habitats, and at 900ha is of one of the largest areas of remnant bushlands in Brisbane City, surrounded by residential area. Karawatha Forest Park, is a lowland intact forest containing significant areas of koala food and habitat trees such as: *Eucalyptus tereticornis, E. propinqua, E. microcorys, E. resinifera, E. tindaliae* and

Corymbia citriodora (Butler 2007; DERM 2009; Hero 1999). The site contains vegetation communities which include endangered species such as *Eucalyptus seeana* and *Eucalyptus tereticornis*, mapped by DERM at the 1:100000 scale. The soils types vary from sandy loam to rocky sandstone and are mainly infertile (Butler 2007).

The park is believed to contain more than 300 plant species and supports a variety of native mammal species (Bond and Jones 2008) including the koala (Carrick 1999). Hero (1999) estimated that KFP supported over 69 koalas based on extrapolations of population estimates from the nearby Daisy Hill Reserve, situated on the other side of the Pacific motorway about 10km from KFP. Recreational activities such as motor biking and cycling as well as dog walkers have been observed within the park (Healy 2009). KFP is surrounded by urbanisation and main roads, isolating the existing koala population and limiting their dispersal to other remnant habitats.

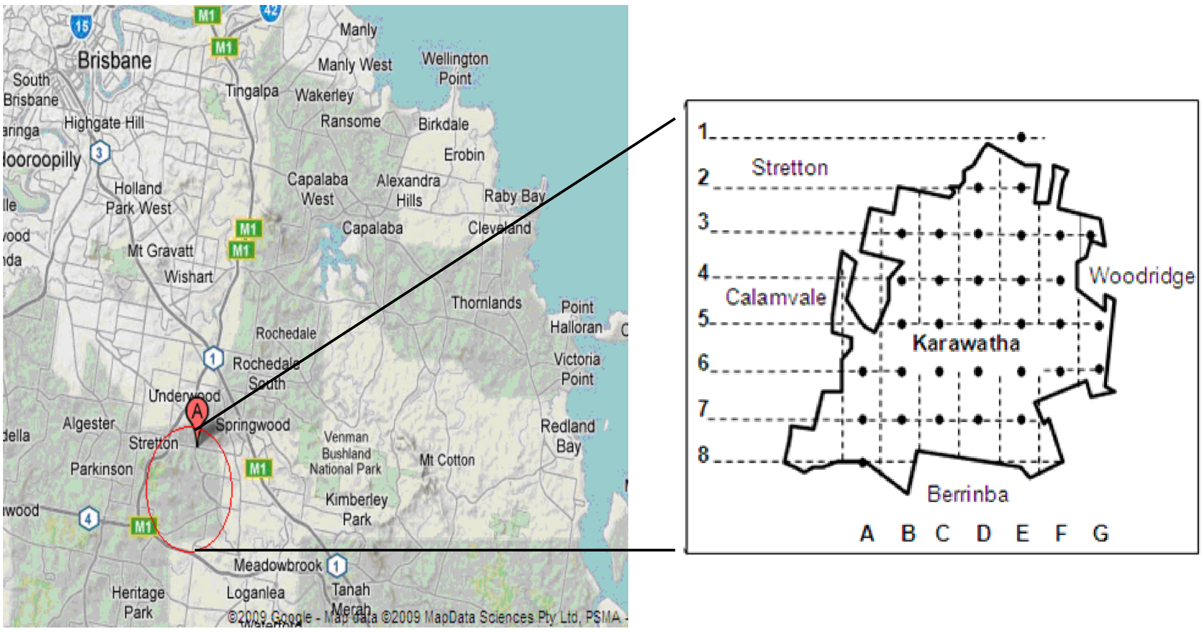

Figure 3.1 Location of Karawatha Forest Park in Southeast Queensland (Sourced from Google map and Ogden 2009)

3.3 Experimental design

The study used an existing network of trails and survey plots that were established in 2007 at KFP as part of the PPBio (Program for Planned Biodiversity and Ecosystem Research) Australasia initiative by Griffith University (Hero *et al.* in press). The PPBio grid consists of a systematic network of 33 permanently marked plots, where each plot samples an effective area of ~1ha (250m x 40m) across 900ha, approximately 3km by 3km. Each 250m plot transect follows the topographical contours in order to minimise elevational biases within the plot (Hero *et al.* in press). This systematic approach allows an unbiased sampling of the 33 plots where each plot is independent of the others (Butler 2007; Hero *et al.* in press). Spatial autocorrelation was tested at 500m distance intervals using Moran's I Index. For each of the plot, a vegetation database has been compiled where every tree along the transect has been identified and DBH recorded (diameter at breast height) measured (Butler 2007).

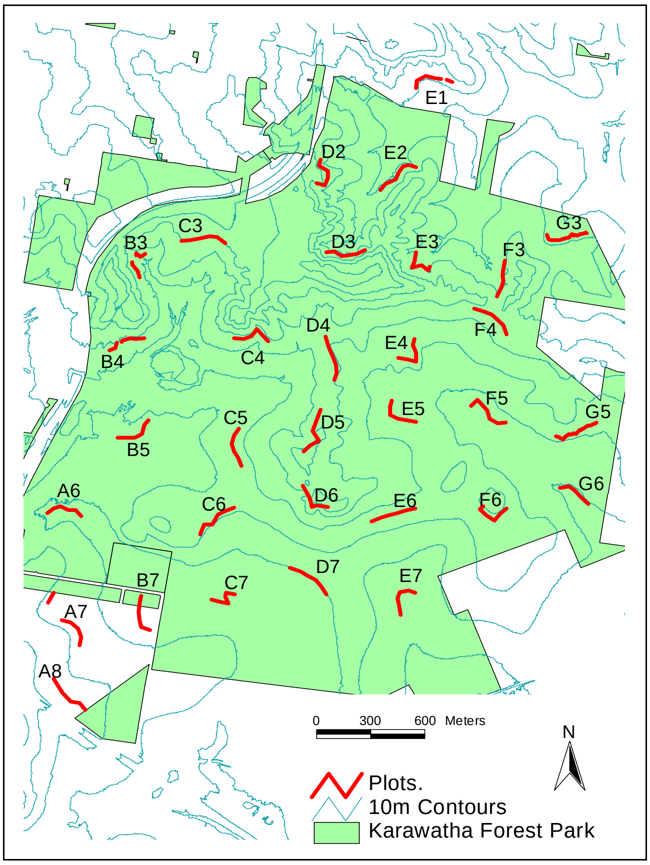

Figure 3.2 Map of the 33 plots location within KFP (Sourced from PPBio)

Both methods used a standardised detectability function allowing the comparison of results by survey effort. The frequency of occurrence of faecal pellets at each plot provided a measure of the relative abundance of koala within the landscape but also facilitated the interpolation of data points to generate a nominal distribution map enabling the identification of koala concentration areas. These areas were then related to existing environmental data from previous studies at KFP (Butler 2007; Hughes 2008).

3.4 Vegetation surveys

A complete vegetation survey on each of the 33 plots was performed in 2007 with a summary of tree species abundance for each plot (Butler 2007). The tree DBH data were updated in 2009 and therefore allowed an accurate analysis of the relationship between tree DBH and koala distribution. Butler (2007) identified four genera of koala food trees including 18 species of *Eucalyptus*, three species of *Angophora*, five species of *Corymbia* and two species of *Lophostemon*. The tree tag numbers were listed in a database containing information on tree species, DBH, location of each tree from and along transects. Trees with a DBH greater than 30 cm were tagged within the full 1ha plot while these with a DBH > 10cm < 30cm were tagged from 0.5ha (Butler 2007). The combination of this information permitted efficient navigation within each plot, and allowed for rapid tree identification during SAT. The different environmental variables measured such as soil topography, soil nutrients, fire history, canopy cover and biomass were already available from the PPBio KFP database (Butler 2007; Hughes 2008).

3.5 Koala surveys

Koala surveys were first conducted on the 33 plots. Each plot was surveyed sequentially from north to south by following the plot line-transect, then by performing the SAT at the transect mid-point in a radius of approximately 30m. Once the 33 plot surveys were completed, the twelve grid transects were surveyed by distance sampling. After surveying the 250m transect, the observers walked back to the transect midpoint (at 125m) to identify a focal tree. Focal trees were those closest to the midpoint with a DBH greater than 10cm. Once each focal tree was located, observers completed the Spot Assessment Technique by searching for koala scats around the base of the tree for approximately two minutes. The majority of trees situated on the plots were already identified and have been uniquely tagged. The observers carried the vegetation database while sampling and were be able to rapidly identify tree species and DBH by referring to the tag number in the database. An illustration of the three methods employed in this study is summarised (Fig. 3.3).

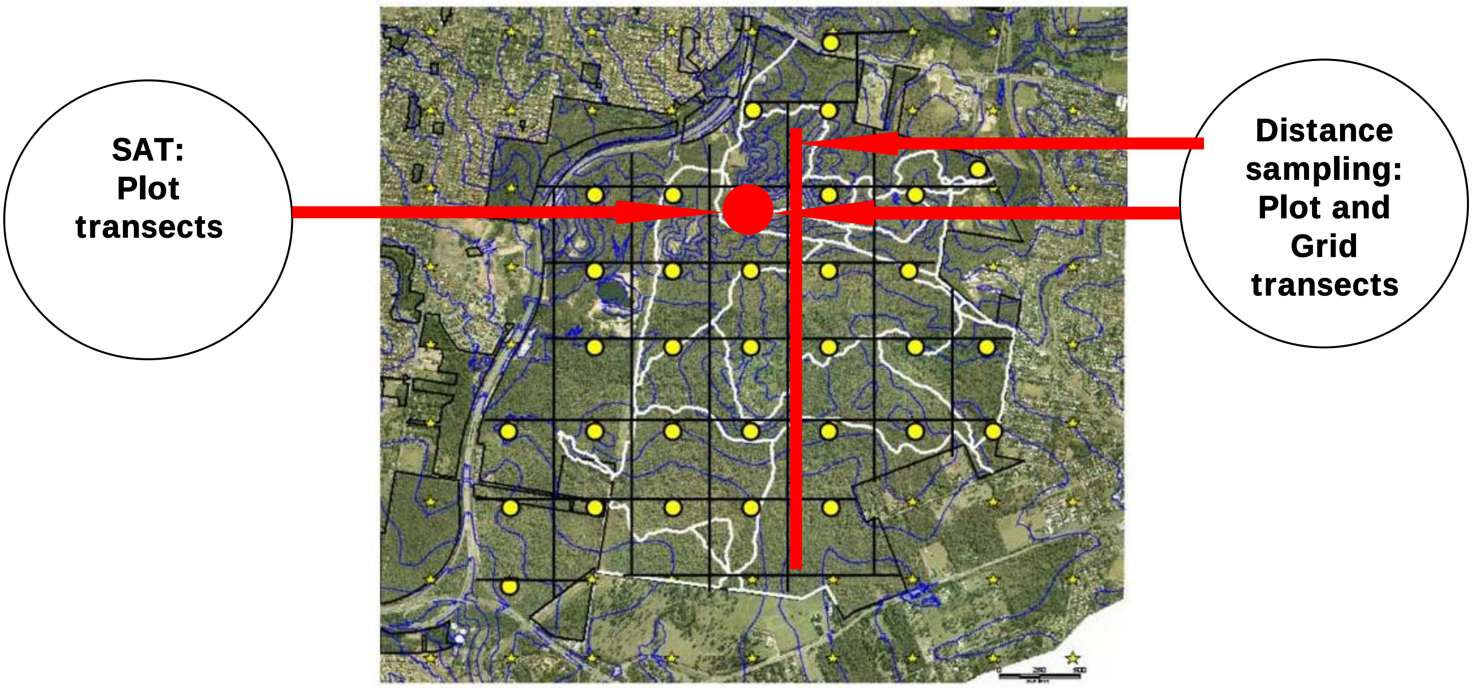

Figure 3.3 Survey design for SAT and distance sampling interpolation on KFP grid (Sourced from PPBio)

3.5.1 Distance sampling

The basic measurements performed in distance sampling surveys are represented in Figure 3.4 where the study area of size *A* is sampled by a straight line of length *L*. The observer *Z* measures the perpendicular distances y_i to the animal *X* as well as the sighting angle θ_i. The detectability is assumed to decrease with increasing distance *W* away from the transect midline (Buckland *et al.* 1993).

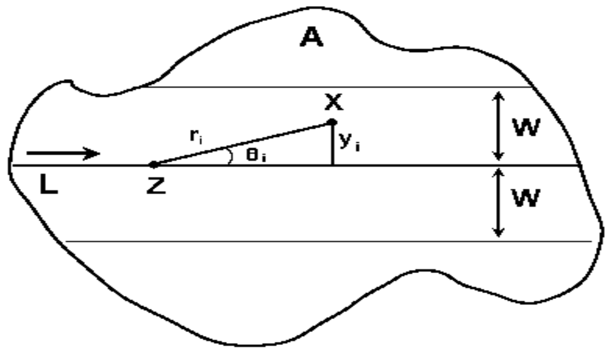

Figure 3.4 Distance sampling measurement from a line-transect where the observer records the perpendicular distance of the animal from the line within the study area (Buckland *et al.* 1993)

Diurnal distance sampling methods were performed on each 250m plot transect as well as on the twelve grid transects by calculating the detection function from the line-transects. One of the observers navigated along the line with a GPS while the other observer looked for koalas in the canopy along each transect. For all koalas detected through visual observations the perpendicular distance from the line was accurately recorded using a laser rangefinder. The height of each koala in the tree was also measured and the angle was recorded from the line. Each plot transects was surveyed for approximately 24 minutes on a period of 15 days, while the 12 grid transects were surveyed for an average of 4h per day in the afternoon for 7 days.

3.5.2 The Spot Assessment Technique

The SAT was systematically applied at a distance of 125m on each of the 33 plots, completed after the distance sampling surveys on each plot. The closest tree grater than 10cm DBH to the transect midpoint at 125m was flagged as the focal tree and searched for the presence of koala scats by the two observers. The characteristic koala scats (Triggs 1996) provided a reliable index of koala presence for each (McAlpine *et al.* 2008). An additional 29 surrounding trees greater than 10cm DBH were also sampled in a radius around the focal tree (Fig. 3.5). A tree was defined as a woody plant species with a DBH greater than 10 cm excluding cycads, palms and grass-trees (Phillips *et al.* 2000). The two observers searched for koala scats within a 1m radius at the base of each tree for a maximum of 2 person minutes per tree, or until scats were detected. Untagged trees (i.e. those < 10cm DBH but further than 11m from the midline) were identified and DBH measured. The SAT was performed for an average of 1h by the two observers and 45min when volunteers were assisting the observers. To avoid any biases, the scats identified by the volunteers were checked by the experienced observers before being confirmed as koala presence. A presence was recorded for each plot once one or more scats were found and each tree where scats were found was noted.

Koala activity levels for each plot were calculated as the percentage of trees with scats within the 30 trees sampled. The total number of trees with scats was divided by the total number of trees searched per plot, thus indicating the koala activity and tree use across KFP (Phillips and Callaghan in press). Active plots were defined by any level of activity and variation in activity level was assumed to be normally distributed (Phillips *et al.* 2000).

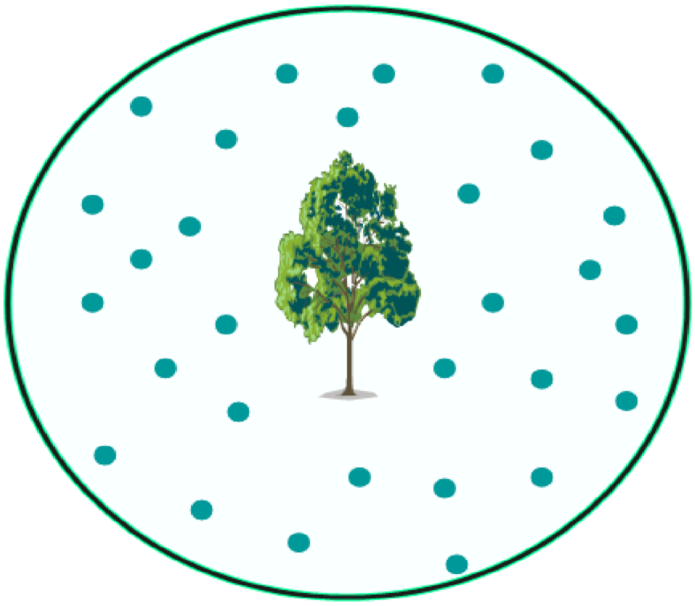

Figure 3.5 The SAT design where 29 trees are sampled in a radius around the focal tree

3.6 Limitations

Some limitations were associated with both methods. For distance sampling, the common limitations reviewed previously (see 2.1.2 Distance sampling limitations) were anticipated while searching for koalas by visual observations, thus direct observations on the plot and grid transects were standardised for each plot regardless of the weak visibility of the species in the canopy. The SAT method presents few limitations, however one possible limitation could arise through the identification of a non-koala scat as a sign of koala presence. Brushtail possums and koalas share scat similarities such as a characteristic oval shape and a similar pellet size (Triggs 1996). However, observers were aware of these similarities before starting the fieldwork and carefully examined all scats found by referring to a fieldbook (Triggs 1996) and by breaking the scat to capture any eucalypt odour and presence of eucalypt leaves, before scoring a koala presence.

3.7 Data Analysis

Statistical analyses were performed using SPSS (ver. 17.0) and Primer (ver. 6.1.10). Significance was measured at α=0.05. The statistical analyses applied to each research question are reported below. The estimation of koala population density could not be performed using the DISTANCE software (Laake *et al.* 1993) due to the extremely low sample size yielded by direct observations. The data derived from indirect observations (SAT), permitted the determination of the relative density of koalas within KFP and their distribution. These data also permitted the analysis of the distribution of the discriminatory ability of different environmental variables to explain the patterns in relative koala habitat use. The SAT data also enabled an assessment of koala tree species preferences based on active plots.

Question 1:

Which survey method is better adapted to detect and estimate the koala population at KFP, how do these methods compare in terms of survey effort?

Results obtained for distance sampling and the SAT were presented in two different tables where distance sampling observations are reported with all the related measurements.

The SAT provided a measure of koala activity, expressed as a proportion and calculated by the number of trees with pellets divided by the total number of trees in the plot according to Phillips *et al.* (in press):

$$A = \frac{n_p}{n_{tot}} \times 100$$

Where activity level is represented by A, the total number of trees with faecal pellets by n_p and the total number of trees sampled in each plot by n_{tot} (Phillips *et al.* in press).

The SAT results were presented showing the different activity levels for each plot with scats detected, highlighting the plots with high activity level.

The detectability functions of the two methods were compared in terms of sampling effort, statistically tested using a chi-square goodness of fit of the observed and expected frequencies, the data satisfying the assumptions of independent observations. Sampling effort allowed the comparison of both methods by categorising data, totalling the number of hours spent applying the SAT with the number of hours spent walking along the transects and the km covered. The presence-absence of scats was recorded according to the SAT's protocol allowing the calculation of koala activity level by dividing the number of trees with scats by the total number of trees sampled per plot. Distance sampling and the SAT were not compared in terms of direct observations as these methods have been designed to sample two different things, relative abundance for the SAT and density estimates for distance sampling.

Question 2:

What is the distribution and abundance of koala at KFP?

The population size of koalas at KFP was analysed using descriptive statistics. The low sample size (n=2) obtained for the distance sampling results didn't allow the computation of the data with DISTANCE and therefore relative density was established solely on the basis of the SAT results.

A map was then prepared in ArcGIS interpolating the SAT results and modelling the distribution of koalas within KFP. The different numbers of trees with scats per plots were represented by dots of different size overlaid. Two maps prepared by GHD for DERM and the Australian Koala Foundation (AKF) were also included showing different interpretations of koala habitat quality in KFP. The SAT layer was then applied to analyse koala distribution in relation to the different habitat quality areas. GHD used data obtained from koala sighting events, landcover classification and field verification verifying the habitat model, where habitat is categorised into Bushland of high, medium and low value, Suitable for Rehabilitation, Other Areas of Value and Non-Habitat (DERM 2009). The AKF based the habitat ranking primarily on QLD Herbarium's Remnant Regional Ecosystem mapping (Version 5) and the availability of koala primary food tree species, and categorised habitat into Primary Habitat Class, Secondary Habitat Class, Non-Remnant, Planted and Regrowth (Lunney *et al.* 2000).

Question 3:

Do koalas display any tree species preference in KFP?

Koala tree preference was determined by the results obtained through the SAT surveys. The activity level of each plot (the proportion of tree species used by koalas per plot) allowed the analysis of different tree species used by koalas. The results were *arcsine* transformed and analysed in Primer (ver. 6.1.10). The 30 trees sampled on each plot were explored using NMDS to ensure that the trees sampled and those on the rest of the plot were not significantly different in terms of the vegetation communities. This analysis was completed to confirm that the samples were representative of the entire plot. A two sample t-test was performed between *Eucalyptus* trees and non-*Eucalyptus* trees used by koalas to test if koalas did prefer *Eucalyptus* species (Phillips and Callaghan 2000).

In order to standardise the selectivity of tree species preferred by koalas, the Jacob's index was used (Jacobs 1974). A Jacob's index value was calculated for each tree species used by koalas based on the SAT data, standardising the relationship between the relative proportion of tree species used by koalas and their availability per plot. The Jacob's Index was used to standardised koala tree preferences and the relative abundance of individual trees at KFP (Jacobs 1974):

$$D = \frac{r - p}{r + p - 2rp}$$

The Jacob's index is used to compare the utilisation of a habitat relative to its availability and in context of this study explains the relationship between koala tree species use and the availability of these trees within KFP (Giessing *et al*. 2006; Hayward 2006). The proportion of each tree species used by koalas = r (based on SAT results) and the proportion of each tree species used by koalas in the entire habitat = p. Jacob's index scores range between -1 and +1 where the -1 values indicate maximum avoidance and the +1 values maximum preference (Hayward 2006).

In order to test if koalas preferred tree species with a larger DBH as found in previous studies (Phillips and Callaghan 2000; Lunney *et al.* 2000) a two sample t-test of the DBH of trees with scats and the DBH of trees without scats was performed. A multivariate analysis of variance (MANOVA) was also performed on SPSS to identify interactions between DBH size category and the number of plots and trees with scats (Zar 2010).

Question 4:

What environmental variables affect the distribution of koala across the landscape at KFP?

A multivariate analysis of koala presence, as determined by SAT results, and 20 different environmental variables, available from the PPBio database, at each plot was conducted to determine which variables (fire frequency, vegetation variables, soil variables and land topography) explained any variance in koala distribution using Primer (ver 6.1.10).

Due to the high number of zeros when koala were absent from a plot, the data were normalised by applying a log x + 1 transformation. The environmental data were normalised and assembled in an Euclidean similarity matrix with variables ranked according to Spearman's rank correlation to test for colinearity between variables (McAlpine *et al.* 2008). A Bray-Curtis similarity matrix was constructed based on the presence-absence of koala for each plot and a non-metric multidimensional scaling (NMDS) 2D representation was used to establish a relationship between koala presence and the 20 different environmental variables among the 33 plots using 100 iterations.

The importance of the environmental variables in determining koala distribution was analysed using BIOENV, which tested the correlations of environmental gradients and multivariate results. The analysis was confined to isolating the five variables that best explained the distribution of koala in KFP by the rank correlation method. In order to obtain a P value, a permutation test was repeated 100 times with alpha set at 0.05. BIOENV was run multiple times to determine which combination of variables explained the most variation in koala activity levels.

CHAPTER 4: RESULTS

4.1 KFP koala population

Fieldwork established the widespread presence of koalas within KFP by detecting koala scats on 42% of the plots. Direct observations, however were revealed to be labour intensive for a very low return as only two koalas were detected on the plot transects. The cryptic nature of the species compromised the calculation of population estimates, and the small number of observations precluded the computation of any robust distance sampling estimates. The SAT surveys detected the presence of koala on 14 of the 33 plots, with activity levels ranging from 3% to 20% among individual plots.

4.2 SAT versus distance sampling

4.2.1 Distance sampling results

Distance sampling on the plot line-transects detected a total of two koalas, found on the same day on two adjacent plots (Table 4.1). The individuals were assumed to be females or juveniles due to their small size however the observation of the pouch or male sternal scent gland was not possible due to the position of the animals within the tree.

Distance sampling on the plots was performed prior the SAT, where the 33 plots were surveyed in 15 days of fieldwork with an average of 24 minutes ± 0.93 seconds of foot survey along the transect for each of the 33 plots (Table 4.4). The koalas were detected within known food trees of a large size and were fairly close to the transect midline.

Table 4.1 Koalas detected using distance sampling method on KFP 33 plots

Plot nbr	Tree species	Tree tag	Tree DBH (mm)	Time of the day	Koala height in tree (m)	Tree height (m)	Distance from observer (m)	Angle to koala	Distance along transect (m)	Distance from transect (m)
D4	*E. racemosa*	none	334	12:45	14.3	20.1	4.7	67°	22.5	2.1
E4	*E. major*	160	211	15:20	9.4	14.5	11.3	29°	4.7	5.3

Figure 4.1 Koala detected in KFP

The 11 grid transects were surveyed during 7 days of intensive search during the afternoon with a total effort of 26.5 hours (Table 4.4). No koalas were detected on any of the grid transects.

4.2.2 SAT results

In total 973 trees from 36 different species were sampled following the SAT protocol. These trees comprised 17 different species of *Eucalyptus* and 19 species of non-*Eucalyptus* (Table 4.2). Scats were found within 1m of the base of 39 trees (4% of trees sampled) in 14 plots. Activity levels varied among plots with a mean of 9% ± 1.5%. Only half of the plots had activity levels of 10% or greater. The highest activity level recorded was of 20% (6 trees with scats on a plot), and the lowest was of 3% (1 tree with scat on a plot) (Table 4.3).

Table 4.2 Summary of the different tree species sampled and resulting number of scats found with species identified by DERM as koala food trees indicated in bold

Tree species sampled	Number of trees sampled	Koala scats	Tree species sampled	Number of trees sampled	Koala scats
Acacia complanata	*4*	0	*Eucalyptus tindaliae*	98	13
Alphitonia excelsa	*2*	0	***Eucalyptus resinifera***	59	4
Acacia concurrens	*11*	0	*Eucalyptus carnea*	63	3
Banksia sp.	*1*	0	***Eucalyptus propinqua***	23	3
Acacia leiocalyx	*2*	0	*Eucalyptus dura*	34	2
Allocasuarina littoralis	*25*	0	*Eucalyptus baileyana*	32	2
Angophora leiocarpa	*4*	0	*Eucalyptus fibrosa*	25	2
Corymbia citriodora	*6*	0	*Eucalyptus racemosa*	54	2
Corymbia gummifera	*3*	0	*Eucalyptus acmenoides*	66	2
Corymbia henryi	*20*	0	*Corymbia intermedia*	100	2
Acacia implexa	*2*	0	***Eucalyptus tereticornis***	19	1
Callistemon sp.	*3*	0	*Eucalyptus seeana*	15	1
Corymbia trachyphloia	*50*	0	*Lophostemon suaveolens*	46	1
Dead	*47*	0	*Angophora woodsiana*	39	1
Eucalyptus crebra	2	0			
Eucalyptus grandis	2	0			
Eucalyptus major	20	0			
Eucalyptus microcorys	18	0			
Eucalyptus planchoniana	6	0			
Eucalyptus siderophloia	23	0			
Lophostemon confertus	16	0			
Melaleuca sp.	31	0			
Tea Tree	2	0			
TOTAL	300	0		673	39
Total trees sampled					973
Total non-eucalypt species					192
Total eucalypt species					781

Eucalyptus species dominated trees used by koalas in KFP, with *Lophostemon suaveolens* being the unique non-eucalypt species used by koala. Tree species sampled that were well represented among plots were *Corymbia intermedia* (n=100) and *Eucalyptus tindaliae* (n=98). The majority of the trees with scats were found under *Eucalyptus* species (n=35) with *Eucalyptus tindaliae* being the species the most used by koalas (n=13) (Table 4.2).

Table 4.3 SAT results and koala activity levels in 14 plots in KFP

Plots with scats	Activity Level per plot	Trees with scats per plot	Tree species with scats
E3	**3%**	1	*Eucalyptus resinifera*
F3	**20%**	2	*Eucalyptus tindaliae*
		2	*Eucalyptus carnea*
		1	*Corymbia intermedia*
		1	*Eucalyptus baileyana*
C5	**6%**	2	*Eucalyptus tindaliae*
C4	**10%**	1	*Angophora woodsiana*
		2	*Eucalyptus tindaliae*
D4	**20%**	2	*Eucalyptus dura*
		3	*Eucalyptus tindaliae*
		1	*Eucalyptus carnea*
E5	**10%**	2	*Eucalyptus tindaliae*
		1	*Eucalyptus tereticornis*
D6	**3%**	1	*Eucalyptus dura*
D5	**10%**	1	*Eucalyptus baileyana*
		1	*Eucalyptus resinifera*
		1	*Corymbia intermedia*
F6	**13%**	1	*Eucalyptus fibrosa*
		2	*Eucalyptus propinqua*
		1	*Eucalyptus fibrosa*
E7	**6%**	1	*Lophostemon suaveolens*
		1	*Eucalyptus seeana*
D7	**6%**	2	*Eucalyptus racemosa*
B6	**13%**	2	*Eucalyptus resinifera*
		2	*Eucalyptus acmenoides*
C6	**3%**	1	*Eucalyptus propinqua*
A7	**3%**	1	*Eucalyptus resinifera*
Mean activity level/ Total trees with scats	**9% ± 1.5%**	**39**	

While activity levels ranged from 3% to 20 % with a mean activity level of 9%, the two koalas were detected by distance sampling. One of these plot E4, did not contain any scats under the trees sampled at the middle point of the transect. Therefore 15 plots out of 33 can be considered as active or used by koalas based on the results from both methods. Two plots (D4 and F3) were found to contain an activity level of 20% while four plots (E3, D6, C6 and A7) contained the lowest activity level of 3%. The two koalas were observed on D4 and E4, with D4 containing both visual observation and scats found at the transect middle point (Fig. 4.2).

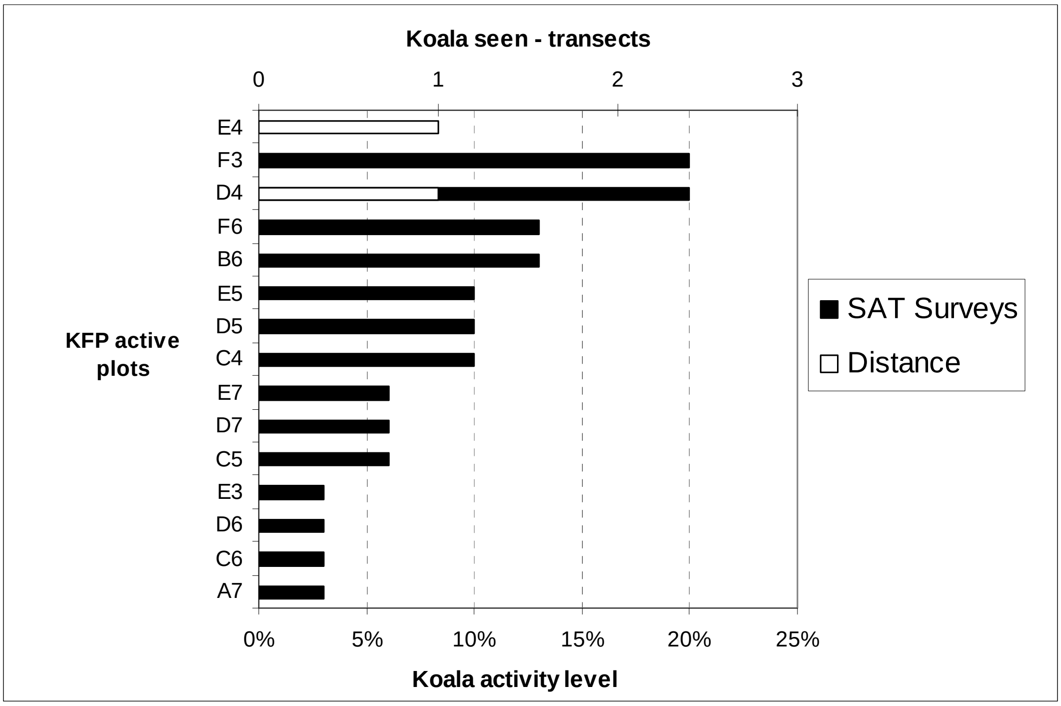

Figure 4.2 Koala activity levels and visual observations where activity level is calculated from the number of trees with scats divided by the total number of trees sampled per plot

4.2.3 Comparison between methods

The primary aim of this study was to compare distance sampling to the SAT to detect koalas as a function of the total sampling effort. The relative success of each method was determined by a measure of the detection success of koala presence. The SAT surveys comprised 29.66 hours of sampling effort for the 33 plots, while distance sampling surveys were completed in 13.45 hours. Distance sampling was therefore more efficient at the plot scale. On the grid transects level, distance sampling required a total 26.5 hours of fieldwork (Table 4.4).

Table 4.4 Search effort and koala detection results using the SAT method and distance sampling on the plot and grid transects

	SAT n=33	**Distance sampling (plot transects) n=33**	**Distance sampling (grid transects) n=11**
Total time spent (hours)	29.66	13.45	26.5
Average sampling effort per plot/grid (min) ± SE	54 ± 1.83	24 ± 0.93	240 ± 10.30
Total distance covered (km)	1.32	8.25	24
Total number of koala detections (presence)	14 plots with scats and 39 trees	2 koalas	0 koala

The proportion of koalas detected (using signs and visual observations) through the two methods differed significantly indicating that the SAT methods were more effective at detecting koala presence than both distance sampling approaches (χ^2 (15) = 5.89, P < 0.05). Despite distance sampling of plot transects being more efficient in terms of sampling effort, these detected only a small number of koalas.

4.3 Koala distribution and population estimates

4.3.1 Koala population estimates

The cryptic nature of the species resulted in only two koalas being detected and therefore did not allow visual observation results from either plot or grid transects to be computed into DISTANCE. Thus, koala population estimates based on these methods remains unknown for KFP. At a crude level the density of koala can be calculated as koalas per hectare based on the area covered in plot transect surveys, resulting in a density of 0.06 ha^{-1} (2 koalas/33 ha). The small sample size precluded the calculation of any confidence limits around the density estimate.

4.3.2 Koala distribution

The systematic placement of plots throughout KFP enabled the detectability of koala to be analysed spatially across the landscape. Results derived from the SAT were used to produce a map in ArcGIS showing the distribution of the koala population as a function of trees with scats within KFP (Fig. 4.3). Results were analysed for spatial auto-correlation using Moran's I index in ArcGIS, revealing that there was no autocorrelation in the activity level data (Moran's I = -0.05, z = -0.19, $P > 0.05$).

Inverse distance weighted interpolation was used to determine cell values using linearly weighted combinations of a set of sample points, relying on the inverse of the distance raised to the power. The interpolated surface consisted of the different koala activity levels resulting in the graduated contour map which predicted koala activity. The different koala activity levels demonstrated that koala distribution is largely restricted to the central area of KFP with the avoidance of areas on the periphery to the northwest and south (Fig. 4.3).

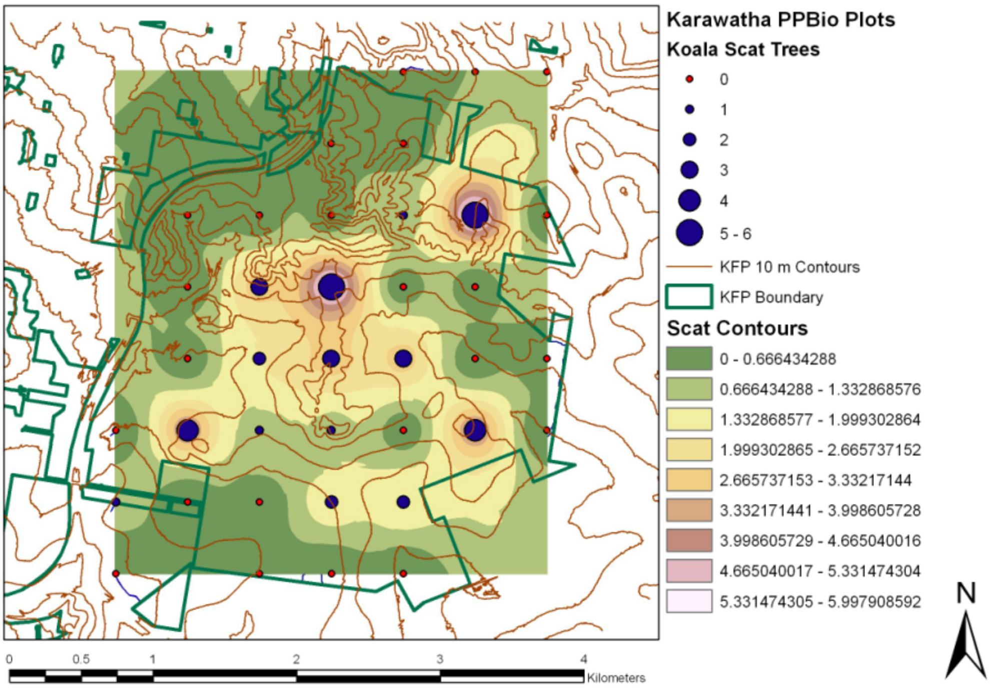

Figure 4.3 Koalas distribution within KFP modelling scat presence where blue dots illustrate the different activity levels

There was also a high congruency of koala distribution determined by SAT methods and habitat quality within KFP, revealed by the DERM and Australian Koala Foundation (AKF) koala habitat mapping (Fig. 4.4 and Fig. 4.5). The DERM map prepared by GHD shows that KFP consists mainly of High Value Bushland and Medium Value Bushland, based on the proportion of primary food tree species and vegetation cover (Fig. 4.4). The majority of koala activity (64%) was located in the High Value Bushland area, confirming the significance of KFP habitat for koalas. The AKF map shows that KFP is mainly consisting of Secondary Class B habitat, potentially explaining the low mean activity level of 9%.

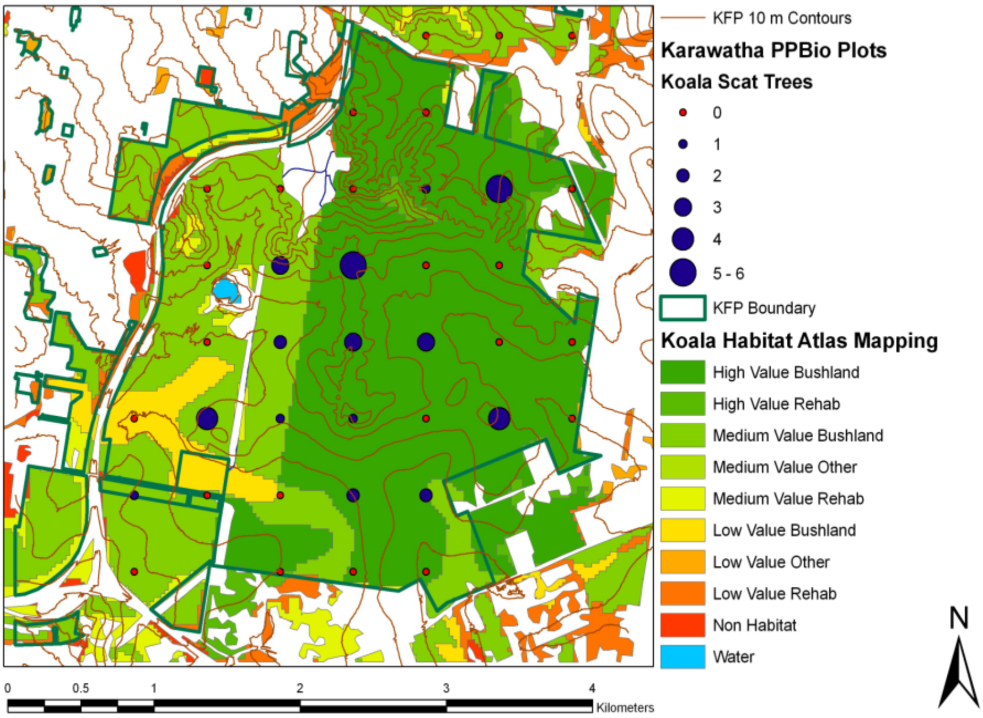

Figure 4.4 Koala distribution and habitat mapping within KFP according to GHD habitat ranking (Sourced from DERM)

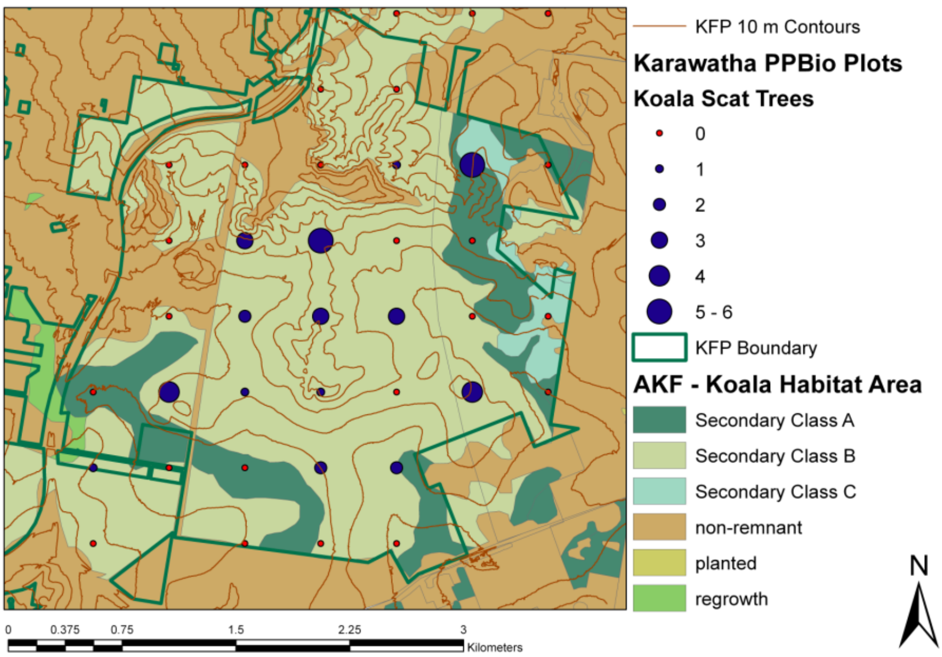

Figure 4.5 Koala distribution and habitat mapping within KFP according to the Australian Koala Foundation habitat ranking (Sourced from AKF)

4.4. Koala tree species use

Koala tree species preference was assessed by relating the total tree species availability on the plots. Thirty-nine different tree species were identified on the different plots, *Lophostemon suaveolens* being the most common and *Glochidion sumatranum* being the rarest (Fig. 4.6). Fourteen species were used by koalas in KFP of which two of them have been previously identified as koala food trees. The four species identified by DERM as koala food trees (*Eucalyptus microcorys*, *E. tereticornis*, *E. resinifera* and *E. propinqua*) are present in KFP under different frequencies.

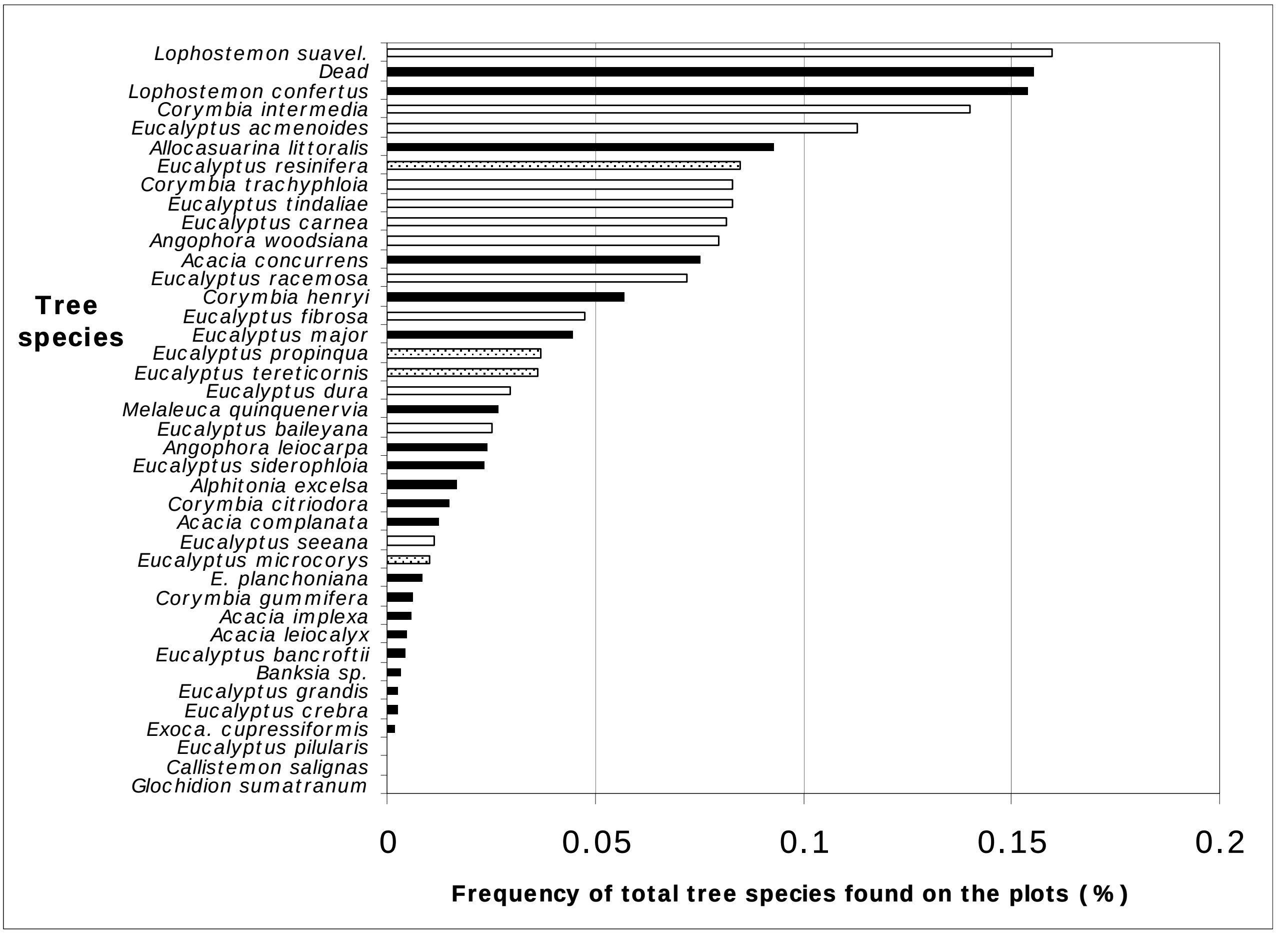

Figure 4.6 The total tree species availability found on the 33 plots, the white bars showing trees used by koalas in KFP and the shaded bars showing tree species recognised as koala food trees by DERM in QLD

4.5 Koala tree use plot representation

To determine if the trees species with scats were representative of the rest of the plot tree species, the proportion of the 14 trees species used by koalas was calculated for the whole plot as well as for the 30 trees sampled in each of the 33 plots. Dissimilarity matrices for plot similarity using tree species were calculated using a Bray-Curtis measure. The graphical NMDS description of the variation or distance trajectory between trees sampled, indicated with a s, and rest of the plot was explored (Fig. 4.7).

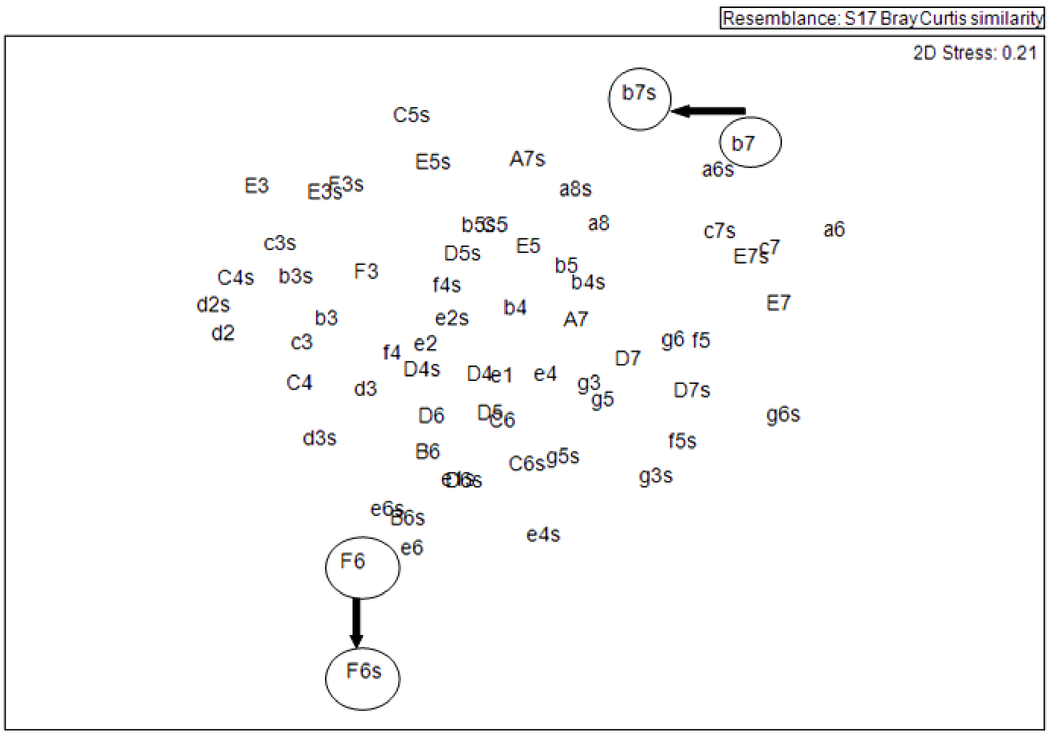

Figure 4.7 Representation of the proportion of trees species used by koalas on the plots totality where plots with the letter *s* represent the trees sampled

The matrix distance between sampled trees and all trees on the plot, for example the distance between F6 and F6s, was reported in SPSS where the distance for koala plots ($\bar{x}$ = 0.684, SE= 0.026) was tested against the distance for non-koala plots ($\bar{x}$ = 0.709, SE= 0.030). The non-significant results (t (13) = -0.837, P > 0.05) indicated that the tree species used by koalas did not differ significantly in terms of representativeness on the total plot.

Fourteen different tree species were found to be used or preferred by koalas. *Eucalyptus tindaliae* was found to be the species the most used (n=13) with 98 trees sampled on 13 plots. *Corymbia intermedia* was the most widespread and abundant species within the trees sampled, with 100 trees sampled on 28 plots, but only 2 trees were used by koalas (Table 4.5). Koala recognised food tree species by DERM are highlighted in bold.

Table 4.5 Tree species sampled used by koalas

Tree species	No. of plots with tree species present	Number of trees sampled	N° of trees with scats
Eucalyptus tindaliae	13	98	13
Eucalyptus resinifera	22	59	4
Eucalyptus carnea	20	63	3
Eucalyptus propinqua	9	23	3
Corymbia intermedia	28	100	2
Eucalyptus dura	7	34	2
Eucalyptus baileyana	9	32	2
Eucalyptus fibrosa	5	25	2
Eucalyptus racemosa	12	54	2
Eucalyptus acmenoides	19	66	2
Eucalyptus tereticornis	5	19	1
Lophostemon suaveloens	10	46	1
Eucalyptus seeana	8	15	1
Angophora woodsiana	10	39	1

The availability of these fourteen tree species in relation to their availability across all plots was explored to ensure that the abundance of trees species preferred were not biasing the tree species preferences shown. Results confirmed that there was no bias in the analysis (Fig. 4.8).

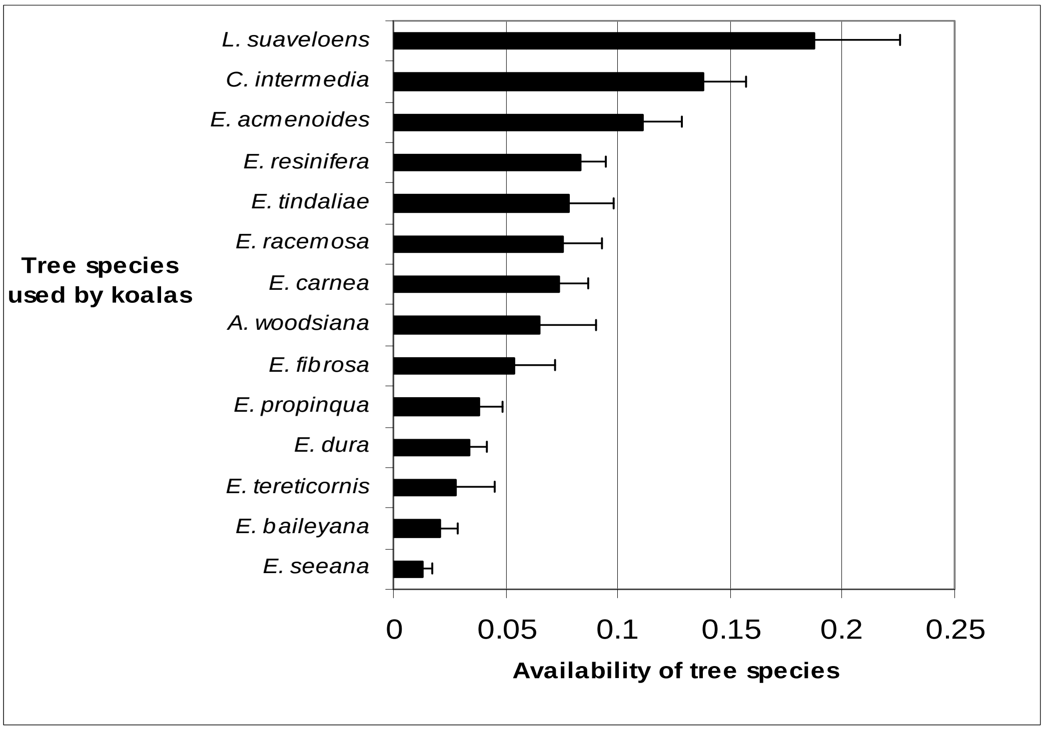

Figure 4.8 Mean ± SE tree species availability on the 33 plots

A higher number of scats were found under eucalypt trees, where 35 trees with scats from different *Eucalyptus* species and 4 trees from non-*Eucalyptus* (see Table 4.5). The use of *Eucalyptus* species was significantly higher ($t(9) = 1.833$, $P < 0.05$). *Eucalyptus tindaliae* dominated the trees used by koalas comprising 33% of all trees with koala scats. Results confirmed the higher use of *Eucalyptus* species by koalas within KFP and demonstrated the importance of *Eucalyptus tindaliae* for koala conservation. The preference of tree species used by koala across the landscape is explained in greater detail.

4.6 Jacob's index tree preference measures

The Jacob's index was used to standardise koala tree species preferences and the relative abundance of individual trees at KFP. Results indicated that *Eucalyptus tindaliae*, *E. dura*, *E. propinqua*, *E. seeana*, *E. resinifera* and *E. baileyana* were preferred. *Eucalyptus acmenoides*, *Angophora woodsiana* and *Lophostemon suaveloens* were avoided (Table 4.6).

Eucalyptus tindaliae was present on 7.7% of the 33 plots, however was clearly preferred by koalas (31% of use). *Eucalyptus resinifera* was present on 8.3% and also preferred (12.8% of use) whereas *Lophostemon suaveloens* was present on 18.7% but used at 2.5% only (Table 4.6). The scores were not statistically tested in the absence of mean values for Jacob's index values for each individual species as sampling occurred only once for each plot.

Table 4.6 Tree species preferences using the Jacob's index from active plots where koala food tree species recognised by DERM are highlighted in bold

Tree species	Tree preference preferred or avoided	Jacob' index scores	Proportion of species used by koalas ± SE (%)	Proportion of species available in total habitat ± SE (%)
E. tindaliae	+	0.68	30.7 ± 4.3	7.7 ± 2.0
E. dura	+	0.41	7.6 ± 3.1	3.3 ± 0.8
E. propinqua	+	0.35	7.7 ± 3.3	3.8 ± 1.0
E. seeana		0.31	2.5 ± 1.5	1.3 ± 0.4
E. resinifera		0.23	12.8 ± 4.4	8.3 ± 1.1
E. baileyana		0.10	2.5 ± 0.9	2.1 ± 0.7
E. carnea		0.02	7.7 ± 1.1	7.3 ± 1.3
E. fibrosa		-0.02	5.1± 1.5	5.3 ± 1.7
E. tereticornis		-0.03	2.5 ± 0.9	2.7 ± 1.7
E. racemosa		-0.20	5.1 ± 2.9	7.5 ± 0.2
E. acmenoides	-	-0.39	5.1 ± 1.5	11.1 ± 1.7
A. woodsiana	-	-0.45	2.5 ± 0.9	6.5 ± 2.4
C. intermedia		-0.49	5.1 ± 1.1	13.7 ± 1.9
L. suaveolens	-	-0.79	2.5 ± 1.5	18.7 ± 3.8

Tree species preference is indicated by bars over zero, while bars below zero indicate tree species used by koalas but not preferred.

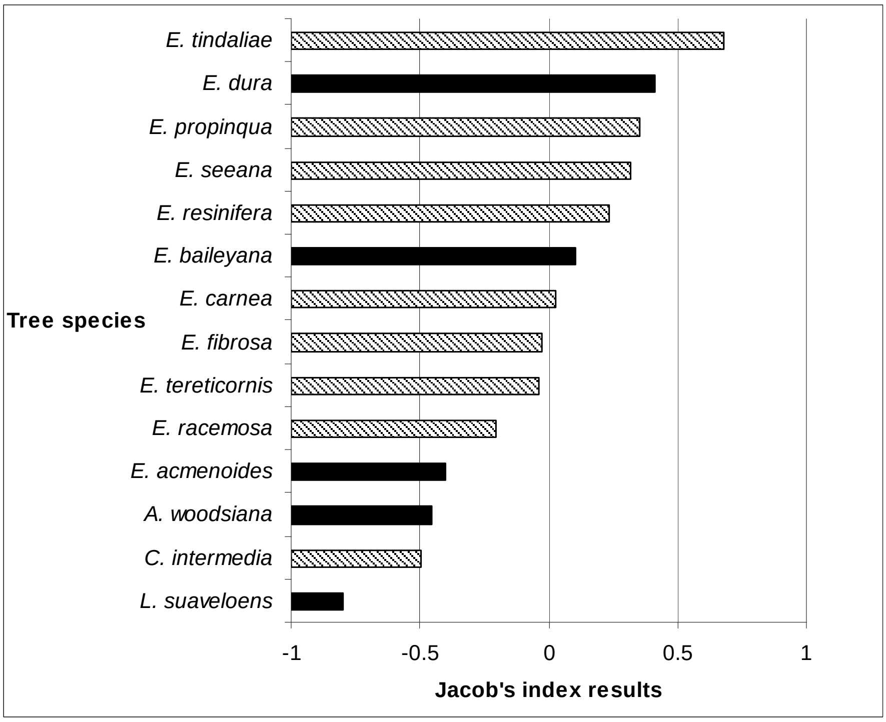

Figure 4.9 The Jacob's index results indicating koala tree preferences, the stripped bars showing koala food and habitat trees recognised by DERM

4.7 Tree size and koala tree selection

Tree size, as measured by the DBH, has been found to influence koala tree selection in KFP, where the majority of scats were found within the 200-300mm DBH category (Table 4.7). The overall distribution of DBH size classes was found to be larger in the 200-300mm category, containing 28% of all trees sampled, indicating a congruency in scats and number of trees in this category.

Table 4.7 The different DBH categories found in the 39 trees used by koalas

DBH Category (mm)	**100-200**	**200-300**	**300-400**	**400-500**	**500-600**	**600-700**	**700-800**
Mean DBH per category (mm) ± SE	150.1 ± 2.1	236.5 ± 1.8	322.1 ± 2.1	403.4 ± 3.1	516.1 ± 4.6	650.9 ± 34.0	738.2 ± 98.0
E. tindaliae			3	3	2	2	2
E. carnea				2		1	
C. intermedia		1	1				
E. tereticornis		2					
E. dura	1	1		1			
E. baileyana		1	1				
E. resinifera	1	4					
E. fibrosa			1			1	
E. propinqua		1	1				
L. suaveloens	1						
E. seeana			1				
E. racemosa	1			1			
E. acmenoides		2					
Total trees	5	11	8	8	2	3	2
% of trees sampled	12.8	28.2	20.5	20.5	5.1	7.7	5.1
% of trees available on total plots	35.9	25.4	20.1	11.3	3.7	2.3	2.1

The relationship between koala tree preference and DBH revealed that koalas used trees with significantly greater mean DBH ($\bar{x}$=364.58 ± 26.13) than those not used by koalas ($\bar{x}$=275.00 ± 4.52) (t (38) = 3.428, $P < 0.05$).

The proportion of trees sampled within each DBH category and koala use of these trees showed a moderate non-significant regression ($P < 0.05$) between trees with a larger DBH and koala use (R^2= 0.182) (Fig. 4.10).

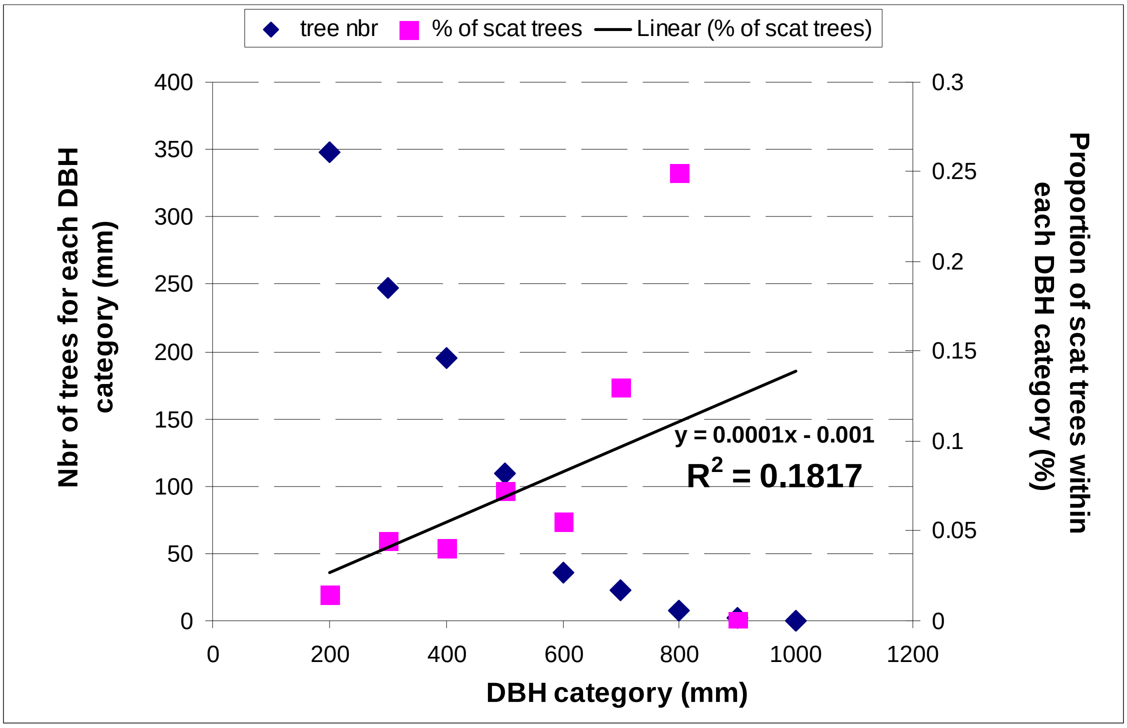

Figure 4.10 Tree DBH koala preference indicated by the SAT results showing a moderate regression between the number of trees with scats and DBH size

The multivariate analysis of variance (MANOVA) testing interactions between plots, trees with scats and DBH indicating a significant effect of tree DBH on trees with scats and plots with scats V= 0.970, F (64, 1878) = 3.392, $P < 0.05$). The assumptions of normality within groups and homogeneity of variance were satisfied.

4.8 Environmental determinants of koala distribution

Plot similarity in terms of tree species composition was first performed showing no clear difference amongst plots either used by koalas, or not used, indicating homogeneity of tree species composition across the 33 plots. Activity while concentrated in the central portions of the reserve was not confined to any particular area of KFP. Plots were explored graphically using non-metric multi-dimensional scaling (NMDS) where plots used by koalas were differentiated from those not used by an upper-case letter (Fig. 4.11). Results confirm that koalas were able to access a wide range of habitat in KFP by plots not being clustered together.

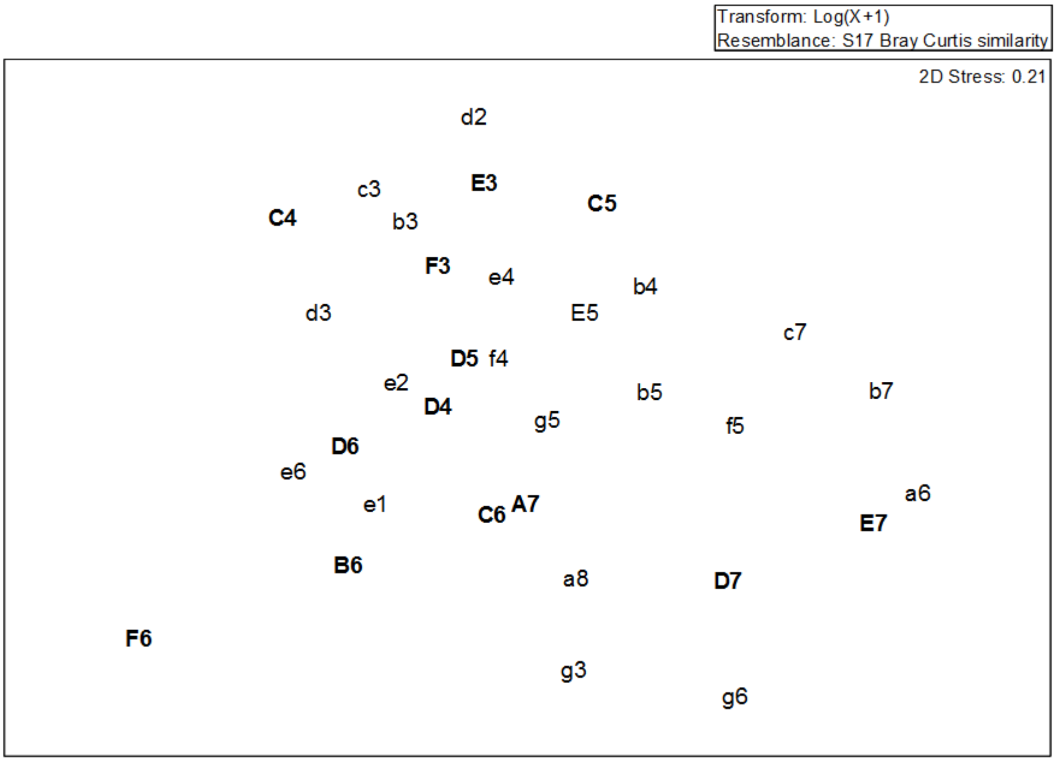

Figure 4.11 NMDS representation of the 33 plots similarity in tree species composition. Plots with koala activity are indicated by bold typeface and uppercase letters

Multivariate analysis revealed a difference in plots used by koalas as determined by vegetation (tree species richness and biomass), soil composition (soil phosphorus and sodium concentrations) and land elevation. It can be observed that the two high koala activity level plots (F3 and D4) and three medium activity level plots (D7, C4 and E5) were clustered together, indicating an effect of these five variables on koala distribution (Fig. 4.12). The combination of these five different variables only partially explained the patterns in koala activity within KFP (Spearman's correlation = 0.245) despite this being significant ($P < 0.05$) (Table 4.8).

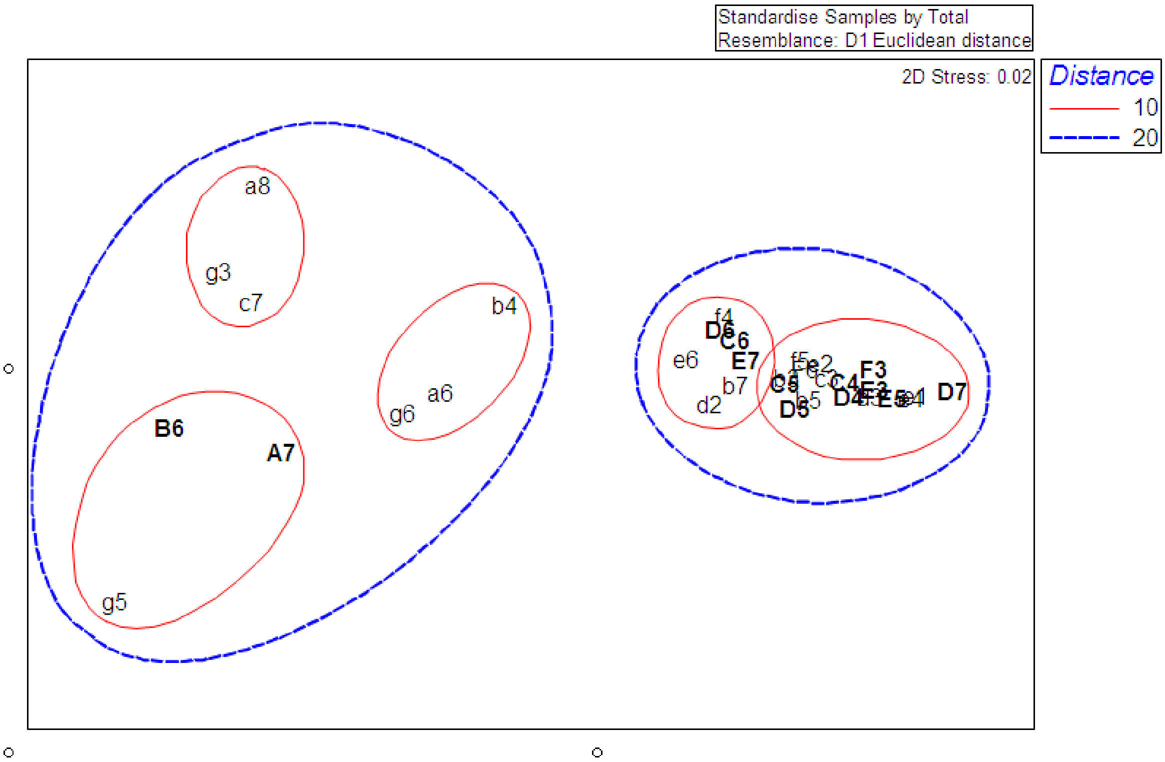

Figure 4.12 NMDS showing a cluster of plots containing koala high and medium activity levels in responsible to soil and vegetation variables

Table 4.8 The different environmental variables used for the 33 plots in a multivariate analysis

Environmental variables tested in multivariate analysis		**Explanatory variables (R = 0.25) (P = 0.04)**
1	Aspect degrees	Elevation
2	Slope	Biomass
3	Elevation	Soil sodium (mg/kg)
4	Fire frequency	Soil phosphorus (mg/kg)
5	Canopy cover	Plot tree species richness
6	Biomass	
7	Soil pH	
8	Soil Electrical conductivity	
9	Soil calcium (mg/kg)	
10	Soil potassium (mg/kg)	
11	Soil magnesium (mg/kg)	
12	Soil sodium (mg/kg)	
13	Soil phosphorus (mg/kg)	
14	Soil cation exchange capacity (cmol +/kg)	
15	Soil carbon (wt %)	
16	Soil nitrogen (wt %)	
17	Soil nitrate (mg/kg)	
18	Soil ammoniacal nitrogen (mg/kg)	
19	Mean plot tree DBH	
20	Plot tree species richness	

The relationship between mean plot trees DBH was explored previously with tree species preference and was found to have an effect on koala trees selection. However in multivariate analysis, this variable did not contribute to explaining the distribution of koala activity.

4.9 Conclusion

The results were able to address the four research questions. The success of SAT methodology in detecting koala distribution was expected and the study validated the hypothesis by demonstrating the weakness of visual observations in detecting a cryptic species such as the koala. The distance sampling protocol was carefully followed in order to avoid any biases and to detect as many koalas as possible. Koala distribution, tree species preference and habitat use added valuable components to the study and allowed a better understanding of koala ecology in KFP. These results will be discussed in greater detail in the following chapter.

CHAPTER 5: Discussion

5.1 Koala presence detection and comparison of methods

This study was successful in detecting koalas from 42% of the plots, confirming the existence of a low-density koala population in KFP. Despite intensive direct observation surveys, only two koalas were detected by following the line-transects and distance sampling procedures. While previous studies using distance sampling have been able to estimate koala populations (DERM 2009; Dique *et al.* 2004; Dique *et al.* 2003b), the results from this study highlighted the poor level of accuracy obtained from this method, particularly for low density populations, resulting in the inability to estimate koala population size with any confidence.

The sample size obtained by direct observation is remarkably low. This finding corroborates the study by Lunney *et al.* (2000), where 119 sites were surveyed in NSW and no koala were seen, but 31% of the sites contained koala scats. In order to understand why distance sampling yields poor data, particularly in low density situations, it is fundamental to understand that the accuracy of a sampling method relies on how well it meets its primary assumptions (Clancy *et al.* 1997). When reviewing the principal requirement of distance sampling to ensure accuracy, a minimum of 60 to 80 observations (Buckland *et al.* 1993), it appears clear that the method is not well adapted to surveying koalas existing in low density due to the difficulty to see them from the line and detect a high number of individuals.

The first koala detected on plot D4 was the result of intense observations after one of the observers first detected the arm, then the rest of its body hidden behind a branch with its body well camouflaged in the upper canopy by its grey fur at a height of 14 meters. Dique *et al.* (2003c), recognised in their Southeast Queensland koala population assessment that the height of koalas in trees has the potential to bias the survey due to the difficulty to see the animal. In order to observe the animal in KFP, the observers had to position themselves away from the transect by taking another angle after performing all distance sampling measurements. The koala remained immobile while the observers approached to assess the health and condition of the animal. The small size of the animal suggested a female (Ellis *et al.* 2002a), however the observation of the pouch was not possible due to its position in the tree. Scats were found at the base of the tree.

The second koala was detected the same day on plot E4, adjacent to D4. This time the animal was alert, potentially because of its relatively low position (9m) in the tree. The fact that no scats were found beneath the tree could indicate that the animal placed itself in the tree late in the morning, or climbed the tree when hearing the observers approaching. Ellis *et al.* (1998), found in their study in Blair Athol, Central Queensland, that koalas defecated between 6pm and midnight when they were most active. The *Eucalyptus major* where the koala was found was situated in an open grassy area, and therefore the detection of the animal was relatively easy as its body was conspicuous in the small tree. The small size of the koala suggested a juvenile, no pouch could be detected. The two animals were detected on the same day in the same area, an open woodland patch situated within the central portion of KFP. The use of the habitat in this area was confirmed during a pilot nocturnal spotlighting survey. The observers detected two other koalas in the same area, feeding on a *Eucalyptus tindaliae* and a *Eucalyptus racemosa*, the larger size of the animals and absence of pouch suggesting the presence of males.

While the direct observation results confirmed the presence of koala in KFP, the accuracy of previous surveys relying on distance sampling in low density populations is questionable (DERM 2009; Dique *et al.* 2004). In this study distance sampling was subject to violations of the central assumptions where koalas were revealed to be quasi-undetectable in closed habitats and where the minimum sample size of 60-80 observations, allowing the accurate calculation of population estimates, appeared to be an unrealistic expectation. The low numbers of koalas detected from the plot transects could possibly be attributed to the relatively small area surveyed. It would therefore have been expected to detect more koalas on the extensive grid transects. However no animals were detected at all, despite a greater sampling effort, preventing the estimation of the population size. This finding confirms those of previous studies where reliable estimates of low-density koala populations could not be established (Cork *et al.* 2000; Lunney *et al.* 2000; Sullivan *et al.* 2002).

The indirect SAT methods used in this study were more successful in detecting the presence of koala. The detection of koala scats under 39 trees from 14 plots facilitated the analysis of koala distribution and habitat use. The mean koala activity level of 9% ± 1.5% found at KFP is low when compared to similar assessments in Southeast Queensland (Phillips *et al.* in press) and in NSW (Phillips and Callaghan 2000; Phillips *et al.* 2000), where the mean activity level was higher than 30 %. The low value found at KFP confirms that the koala population exists at low-density.

The comparison of the methods validated the hypothesis, and highlighted the poor level of precision obtained by direct observations in estimating populations existing at low-density. Distance sampling is therefore not appropriate to survey low-density koala populations. Current koala population estimates in Southeast Queensland rely solely on distance sampling methods (DERM 2009). Had the results obtained in KFP from distance sampling methods been used in isolation, the conclusions that a non-existent koala population could easily be reached, resulting in potentially dramatic consequences for the conservation of the species.

Scat surveys are more appropriate in detecting the presence of koalas however still cannot provide the critical information needed to list the species as Vulnerable, based on the number of koalas in a given area (Melzer *et al.* 2000). Therefore there is an urgent need for decision makers to allow some flexibility in the conservation status classification process and legislation mechanism by acknowledging the fact that reliable estimates of koala numbers are difficult to obtain, and that relative abundance and distribution over time should be considered as contributing factors. Koala numbers are declining in Southeast Queensland (Phillips 2000), and there is an urgent need for standardised methods, able to detect but also evaluate koala distribution, to be incorporated into koala conservation plans.

5.2 Koala distribution and estimates

The results indicate that there was no spatial autocorrelation in the SAT data among the different plots at KFP, validating the assumption of independence of observations, critical for statistical analysis. The Moran's I index confirmed that 500m was a sufficient distance when surveying koalas existing at low density. Phillips *et al.* (in press) however, found high levels of spatial autocorrelation in their results assessing estimates and distribution of medium to high density koala populations in Coombabah and Coomera-Pimpama areas, where grids consisted of 250m and 300m respectively. The strong spatial autocorrelation in these areas was interpreted as confirmation of site fidelity and ranging patterns, where koala activity levels were 32.5% and 30.4 % respectively. Both Coombabah and Coomera-Pimpama are identified as medium to high density koala populations, with density ranging from 0.22 koalas/ha to 0.23 koalas/ha (Phillips *et al.* in press). A reduction of the grid size at KFP would not have affected this pattern, although may have provided a finer resolution of the distribution within the reserve.

The SAT data obtained in KFP were used to create a koala distribution map for KFP and showed that the 14 active plots were contained in the central part of the reserve. The plots with medium and high activity levels are adjacent suggesting a preference for this area of the forest, validated by the observations of the two koalas detected through distance sampling in the same central habitat. Peripheral areas remained absent of any indication of koala presence although preferred trees species were evenly distributed through the 900ha, suggesting that koalas avoid these edge areas. Bond and Jones (2008), emphasised the indirect impacts of traffic noise and pollution creating a disturbance effect on fauna occupying the edges of forest remnants, which could explain the absence of koalas from these areas.

The importance of KFP habitat was highlighted in the koala habitat map produced by GHD for DERM, demonstrating that KFP consists of approximately 2/3 of High Value Bushland, hence critical koala habitat. 64% of the different activity levels detected in this study are located in the High Value Bushland, reinforcing the importance of conserving this remnant patch of forest. However AKF map showed that KFP consists mainly of Secondary Class Habitat, due to the fact that established koala food tree species, *Eucalyptus microcorys* and *Eucalyptus tereticornis* are not abundant in KFP. AKF Primary Habitat criteria requires habitat containing more than 50% of one of these two species (D. Mitchell, pers. communication). *Eucalyptus tindaliae* is recognised as a Supplementary tree species by AKF, not as primary food tree species (D. Mitchell, pers. communication). The low value found for the mean activity level in KFP could be reinforced by the AKF habitat ranking, where koalas are not abundant in KFP due to the habitat not consisting of Primary Class food tree species. However, it has been recognised that tree species preferences vary regionally (Phillips and Callaghan 2000), the habitat should possibly be classified as having a higher value. The fact that the widely recognised species such as *E. microcorys* and *E. tereticornis* were not used extensively by koalas in KFP despite being present in low numbers indicate that they were not preferred in KFP. More studies should be undertaken on koala tree preferences in KFP by sampling all the trees on the plots using the SAT, which could provide a more in depth analysis of koala tree species preferences.

Despite these inconsistencies, KFP remains a critical habitat by allowing the conservation of its current koala population. As landscape fragmentation in the region increases with development it can act as a refuge to other koalas, provided through corridors connecting remnant habitats. Koala distribution show that bushland within the central part of KFP are areas of high conservation importance and should remain protected. Koalas exhibit home range overlap as part of their social structure (Phillips 2000), and it could therefore be expected that their distribution was clumped within KFP despite the fact that males are solitary and disperse further than females (McAlpine *et al.* 2006a). The central distribution of koalas suggests that favourable environmental variables are influencing their distribution, but also that koalas have potentially taken refuge in the middle part of KFP to distance themselves from urbanisation areas. In fact main roads, a highway and housing, surround KFP probably impacting on koala selection of habitat areas. McAlpine *et al.* (2006a), highlighted the fact that koalas are particularly sensitive to forest fragmentation due to reduced movement possibilities, koalas rarely crossing large cleared areas. Thus, roads limit koala dispersal and isolate the species in remnant patches of forest (Dique *et al.* 2003a; McAlpine *et al.* 2006a). KFP provides two wildlife underpasses and one overpass allowing wildlife to disperse to Kuraby Bushland and where a diversity of mammals was found to be using these passages. However no koalas have been recorded using these (Bond and Jones 2008).

KFP remains a recreational Forest Park, with the consequence that domestic dogs on leashes are still allowed in the area, increasing some disturbance effects on koalas (Dique *et al.* 2003a). Studies have established significant declines in small koala population due to domestic dog predation and road kills on the Koala Coast (Dique *et al.* 2003a). To ensure the conservation of the species within the area, the Brisbane City Council should consider prohibiting domestic dogs from the park. Dog owners have been observed letting their dogs run freely on numerous occasions, where koalas on the ground moving between trees could be highly vulnerable (McAlpine *et al.* 2006a).

The SAT results from this study provide the baseline data to allow trends in relative abundance to be established by measuring population changes in KFP over the years. By comparing the number of active plots and the range of activity levels over time, it will be possible to determine if the population is increasing or decreasing. However, population estimates should be rapidly established to better manage the koala population and highlight the species status conservation requirements. Estimates could be achieved by applying the faecal standing-crop method (FSCM) developed by Sullivan *et al.* (2002). This technique allows estimates to be established by calculating pellet abundance, daily pellet production and maximum pellet age (Sullivan *et al.* 2002). Despite the fact that the method requires time and increased effort to determine these three factors, it is more appropriate than direct observations in determining estimates at a small scale such as in KFP. This method could be easily applied in KFP as the location of the different trees on the plot is already provided by the PPBio database and from the SAT surveys completed in this study. Changes in odour and in colour are the two criteria allowing the determination of pellet age where fresh pellets have a strong eucalypt odour and old pellets have lost their odour and shiny patina. Pellets are considered as fresh even after two to four weeks, however weather conditions can affect decay rate and assessments should be completed in the dry season if possible (Sullivan *et al.* 2002).

The KFP koala survey allows the recognition of this small koala population regionally and appropriate management plans can now be implemented by the Brisbane City Council. The loss of any local sub-population is important as it contributes to the extinction process (Caughley 1994). The KFP koala population is the typical example of the small-population paradigm, where a small population is facing extinction by inbreeding depression, genetic drift and stochastic influences (Caughley 1994). The isolation effect of the urbanisation surrounding KFP is not allowing the koalas to disperse further. Although the wildlife overpass allows some mammals to cross the major barrier created by Compton Road (Bond and Jones 2008), this passage has not been designed for koalas as it doesn't contain any large tree species, potentially limiting the ability of koalas to cross. A larger wildlife corridor linking KFP to the larger koala population on the Koala Coast should be considered, allowing gene flow to circulate between the two isolated populations.

5.3 Koala tree species preference

Koala tree species preferences vary regionally and depend on tree species availability, soil composition and hence leaf nutrients concentration, leaf moisture and habitat quality (Ellis *et al.* 2002b; Lunney *et al.* 2000; Moore and Foley 2000; Phillips and Callaghan 2000). As anticipated, koalas in KFP predominately favoured *Eucalyptus* tree species. Phillips *et al.* (2000), found similar results from the Port Stephens area in NSW, where *Eucalyptus robusta* and *Eucalyptus parramattensis* made up the bulk of koala diet but the genera *Corymbia*, *Melaleuca* and *Angophora* were also used, but not significantly (Phillips *et al.* 2000). Studies have demonstrated that koalas used non-eucalypt tree species when their preferred trees species are not available as shelter from weather conditions and protection against predators (Ellis *et al.* 2009; Lunney *et al.* 2000; Phillips *et al.* 2000).

Phillips *et al.* (2000), highlighted inconsistencies in other studies on the ability to attribute tree species preferences to koalas. They concluded that while it is recognised that koalas favoured only a few tree species in an area, there was some divergences on which tree species these were (Hindell and Lee 1987; Phillips 1990; Phillips and Callaghan 2000). Koala tree species preferences in Queensland have previously been determined and *Eucalyptus microcorys* and *Eucalyptus tereticornis* appear to be the most preferred trees species (Ellis *et al.* 2002b; Lunney *et al.* 2000; Phillips *et al.* in press; Tucker *et al.* 2008; White 1999). The presence of these two species in KFP was relatively rare in comparison with *Eucalyptus tindaliae*, *Eucalyptus resinifera* and *Eucalyptus carnea* (Butler 2007). While fourteen different tree species were used by koalas in KFP comprising, eleven *Eucalyptus* species and three non-*Eucalyptus* species, no scats were found under *Eucalyptus microcorys*, present on 1% of KFP and mainly distributed on the edges. One tree with scats only was found to be a *Eucalyptus tereticornis,* available on 3% of KFP. It was expected that these two species would have show a significantly higher level of usage. The fact that they are poorly represented in KFP could explain this lack of usage, despite 19 *Eucalyptus tereticornis* being sampled and 18 *Eucalyptus microcorys.*

While the significantly higher use of *Eucalyptus tindaliae* in KFP suggests that this species can be classified as koala primary food tree within the reserve, *Eucalyptus resinifera* also showed a higher level of use than other species. Furthermore, although *Eucalyptus tindaliae* was preferred, *Eucalyptus resinifera* was slightly more abundant throughout KFP. The species is available at 7.7% ± 2.0% and distributed on 18 plots, hence 54% of the total plots, and were used at 30.7 % ± 4.3% by koalas. The tree species preferences determined from this study were considered to be representative of the area given that the 30 trees surveyed for scats consisted of an unbiased sample of the complete tree community from each plot.

The Jacob's index has not been used in previous studies assessing koala tree preferences. Previous assessments relied on "strike rate" based on the SAT where the total number of trees on the plots are sampled (Phillips and Callaghan 2000; Phillips *et al.* 2000), utilisation rate determined by the SAT, geological and vegetation variables (Lunney *et al.* 2000), and radio-tracking (Ellis *et al.* 1998; Rhodes *et al.* 2005; Tucker *et al.* 2008; White 1999; Woodward *et al.* 2008). The Jacob's index has been widely used to analyse prey species preferences in African carnivores, and habitat selection by birds in Germany (Giessing *et al.* 2006; Hayward 2006; Hayward *et al.* 2006) and appeared ideal for studying koala tree species preferences in KFP in the absence of radio-tracking feasibility. This method of assessment provides a range of tree species preferred or avoided and the results highlighted koala preference for *Eucalyptus tindaliae* with a maximum score of 0.68, confirming the importance of this species for koalas in KFP. The determination of koala primary food tree species is fundamental to conserving and managing koalas on a regional scale by facilitating critical habitat mapping, however identifying habitat quality is a complex process.

Tree DBH has been shown to be important for koala tree selection and the findings of this study are in accordance with previous studies, where koalas showed an overall preference for larger trees (Hindell and Lee 1987; Lunney *et al.* 2000; Phillips and Callaghan 2000). Although the majority of koala scats were found under trees in the 200-300mm category, this can also be due to the fact 28% of the trees sampled fall within this category. Larger trees are less abundant in KFP, due to a history of logging (Ogden 2009), and therefore the majority of trees are found in the smaller DBH categories, potentially limiting the availability of preferred trees for koalas and explain the relatively low activity levels (Lunney *et al.* 2000).

Koala tree selection is highly dependent on a range of explanatory variables such as soil nutrients, leaf terpene levels, patch size and landscape configuration. Therefore the analysis of environmental variables is fundamental when investigating koala habitat use (Ellis *et al.* 2009; Phillips and Callaghan 2000).

5.4 Koala habitat use and explanatory variables

It is only recently that studies have investigated the relationship between koala distribution and habitat variables on a landscape scale (Cork *et al.* 2000). Koala habitat modelling on the regional scale has been applied in different studies in QLD and NSW (Lunney *et al.* 2002; McAlpine *et al.* 2006a; McAlpine *et al.* 2008; Rhodes *et al.* 2005; Rhodes *et al.* 2006a). Different koala habitat selection models highlight the fact that high quality koala habitat is determined by food availability and foliage palatability, which is directly dependent on environmental variables (Moore and Foley 2000).

In KFP, a distinct relationship between five environmental variables and koala distribution emerged from multivariate analysis. Firstly, after demonstrating that all plots were relatively homogenous in terms of tree species distribution and that koalas could access all of KFP, the results showed that soil composition (nutrient concentrations), land topography and vegetation variables (biomass, canopy cover, tree species richness, and mean tree DBH) affected koala distribution at the mesoscale. The plots with medium and high activity levels were clustered in the NMDS representation, indicating that these different variables were influencing koala habitat selection. Five explanatory variables: soil elevation, plot tree biomass, soil concentration of sodium, soil concentration of phosphorus and tree species richness only partially explained ($R = 0.254$) the variation in koala distribution. Mathew *et al.* (2009), found a strong relationship between soil elevation and fertility and koala presence in NSW catchments. The relationship between elevation and the presence of koalas in the current study was moderate, however played a role in koala habitat selection. Butler (2007) found that elevation and variation in soil nutrients were key discriminatory variables influencing the patterns of tree assemblages in KFP. Butler (2007) also showed that *Eucalyptus tindaliae* was the dominant species on ridge tops within KFP, providing support to the importance of elevation as an explanatory variable for koala distribution in this study. The combination of these results suggests that koalas could select ridge tops to access their primary food tree species.

Biomass and plot species richness also played a role in determining the presence of koala, where it was expected that koalas would select areas with a higher biomass, providing higher food availability and shelter. No other studies have included biomass in analyses investigating the influence of environmental variables on koala distribution. Plot tree species richness could be also be interpreted as a logical explanatory variable for koala presence where plots with higher tree species richness offer more options for koalas to feed and rest. It was also expected that nitrogen, potassium and phosphorus would act as explanatory variables as previous studies have identified these variables as important in koala tree selection (Cork *et al.* 2000; Ellis *et al.* 2002b; Moore and Foley 2000; Munks *et al.* 1996). However, results demonstrated that sodium and phosphorus soil concentrations were selected as soil variables influencing koala distribution. Studies have highlighted that koalas were sensitive to a threshold foliage concentration of nitrogen, potassium and phosphorus, highly correlated to soil nutrient levels (Hindell and Lee 1987; Moore and Foley 2000). While only phosphorus concentration was identified as a discriminatory variable in this study these nutrients were measured only from the soil and not from the leaves. Therefore, a more detailed study exploring leaf nutrients in relation to soil nutrients should be undertaken in KFP to provide a better understanding of koala tree selection.

5.5 Conservation implications

In summary, this study has demonstrated several critical findings for the conservation of koala regionally. Principally, distance sampling was not appropriate for establishing estimates of koalas existing at low density. Conversely the study revealed that 42% of KFP plots contained koala scats, indicating that koalas were mainly distributed in the central area of KFP with *Eucalyptus tindaliae* being of their primary food tree species. KFP has been classified as High and Medium Bushland Value (DERM 2009), demonstrating the importance of this patch of forest as habitat for koala conservation. Finally, this study found that elevation, biomass, tree species richness, soil level of phosphorus and sodium affected koala distribution across KFP.

These results allow for future conservation plans to be implemented regionally. Firstly, low-density koala assessments based on distance sampling should be replaced by presence-absence of scats surveys in order to avoid inaccurate estimates. The SAT can be applied on a broader scale to validate the results of this study in an area of conservation significance, such as the Koala Coast, where there is an urgent need to protect the species from further decline. Applying the SAT across this region will enable the determination of koala distribution and tree species preferences, hence the determination of critical koala habitat. The recent SEQ Koala Habitat Assessment and Mapping Project (DERM 2009), aimed to map, and rank koala habitat across Southeast Queensland, including the Koala Coast region. This project is in concordance with the conclusions of this study for future koala conservations plans. Mapping koala habitat is critical for threatened species, thus the Koala Habitat Atlas has been created to respond to the urgent need to identify koala habitat (AKF 2009). It should be noted that there are still inconsistencies in the mapping procedure which may result in some areas being overlooked for koala conservation. However it was not the intention of this study to review these alternatives mapping approaches.

Data from KFP koala assessment will be provided to the Australian Koala Foundation to enclose KFP in the Koala Habitat Atlas and recognise the existence of this small koala population. Secondly, our results provide a better understanding of koala biology and adaptation to fragmented habitats. Understanding how koalas respond to urbanisation is important, as the probability for such isolated populations to escalate in the future is high with the current rate of development. The importance of primary food tree species was highlighted in this study as well as tree DBH size, confirming the need to retain large trees and primary tree species for koala habitat restoration.

Priorities for the conservation of biodiversity under the federal system consist of focussing on regions with poor legal protection for native species, threatened species and habitats. The National Reserve System has been put in place by the Government to ensure the protection of ecosystems with the objective to develop a "comprehensive, adequate and representative" system of protected reserves, referred to as "CAR" (Bryan 2002; Peterson *et al.* 2007). The southeast Queensland bioregion is recognised as important for its biodiversity value and for ensuring conservation plans for threatened species (Peterson *et al.* 2007). However, the koala cannot benefit from appropriate management measures without being recognised at a national level by being listed as Vulnerable under the *EPBC Act* 1999. It is only a question of time before the listing occurs, with new scientific data demonstrating annual declines in koala populations (DERM 2009). Until such time, studies such as the KFP koala assessment are important to help conserve the species in fragmented areas where no data are yet available.

CHAPTER 6: CONCLUSION

6.1 Management recommendations

The clearing of native vegetation resulting in the fragmentation of habitat remains the number one problem for koala population management (Cork *et al.* 2000; McAlpine *et al.* 2006b; Melzer *et al.* 2000). Clearing has a direct impact on koala food availability, hence the species long-term persistence (McAlpine *et al.* 2006b). Modelling is a powerful tool allowing future projections of koala declines in the near future and has been widely used in recent studies (Lunney *et al.* 2002; McAlpine *et al.* 2006b; Rhodes *et al.* 2005; Rhodes *et al.* 2006a). McAlpine *et al.* (2006b), modelled koala presence and a range of explanatory variables such as habitat patch size, proportion of primary tree species, nearest neighbour distance between forest patch and density of sealed roads. They found that landscape configuration, habitat quality and area of forest habitat were key factors for koala survival and that regional environmental plans often overlooked these factors in land use planning and fauna conservation (McAlpine *et al.* 2006b).

Lunney *et al.* (2002), demonstrated the importance of metapopulation structure, with regional koala habitat management critical for small populations such as the KFP koala population. Thus, knowledge of metapopulation dynamics is critical to maintain small populations, obtained through sustained monitoring programmes. Regular field surveys based on the SAT should be implemented as surrogate measure of relative abundance instead of relying on information based on extrapolations, with regional population viability analysis (PVA) undertaken to understand population changes (Lunney *et al.* 2002). By modelling threats such as clearing of remnant bushland areas, the evaluation of appropriate management options can then be done.

Implementing protection measures for KFP itself will not be sufficient for long-term conservation of the koala population. The urbanisation of the land surrounding the forest patch needs to be managed in accordance with the species survival requirements by incorporating traffic speed regulations, domestic dog management and sealed road management. We recommend modelling the presence of koalas at KFP with similar variables to those used by McAlpine *et al.* (2006b); forest patch size, spatial configuration, distance to next patch, density of sealed roads, distance to housing, to understand the importance of the land use matrix for the KFP koala population.

6.2 CONCLUSION

This project contributed to koala conservation by comparing the suitability of distance sampling to presence / absence methods (SAT) in the assessment of koala distribution and abundance. Distance sampling has been, and continues to be widely used to estimate koala abundance (Dique *et al.* 2003c; DERM 2009), despite the fact that applying the method without supplementing it with other techniques may result in inaccuracy for the assessment of a cryptic species such as the koala. With the current rate of urbanisation, the use of inappropriate sampling techniques that are unable to accurately estimate koala numbers and provide little information on the distribution patterns and habitat use by koalas can result in the loss of koala habitat in SEQ with dramatic consequences for their survival (Meltzer *et al.* 2000). By undertaking a direct comparison of the techniques within an existing urban remnant to assess the accuracy of both the SAT technique and distance sampling, this project has helped to address the lack of standardisation in surveying koalas. This project established a methodological approach to assessing the relative distribution and abundance of koala at a mesoscale. The development of the techniques at KFP can be applied to other areas in the future, where koala populations are known to occur at higher densities to compare these patterns. The PPBio systems based approach to biodiversity monitoring will facilitate this given that the system is modular, and standardises survey protocols (Hero *et al.* in press). Future studies can therefore identify any number of sites to further validate the method but also to improve existing koala population habitat use.

The project also benefited the long-term conservation of Karawatha Forest Park koala population by understanding koala habitat use, which will allow the development of appropriate conservation plans. Monitoring koala scats in KFP on the plots each year can provide a cost/effort efficient method to estimate the relative abundance of the species, suitable for long-term monitoring. These baseline surveys also make it possible to monitor the future trends in low density populations that will enable natural resource managers to implement appropriate regional management strategies.

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