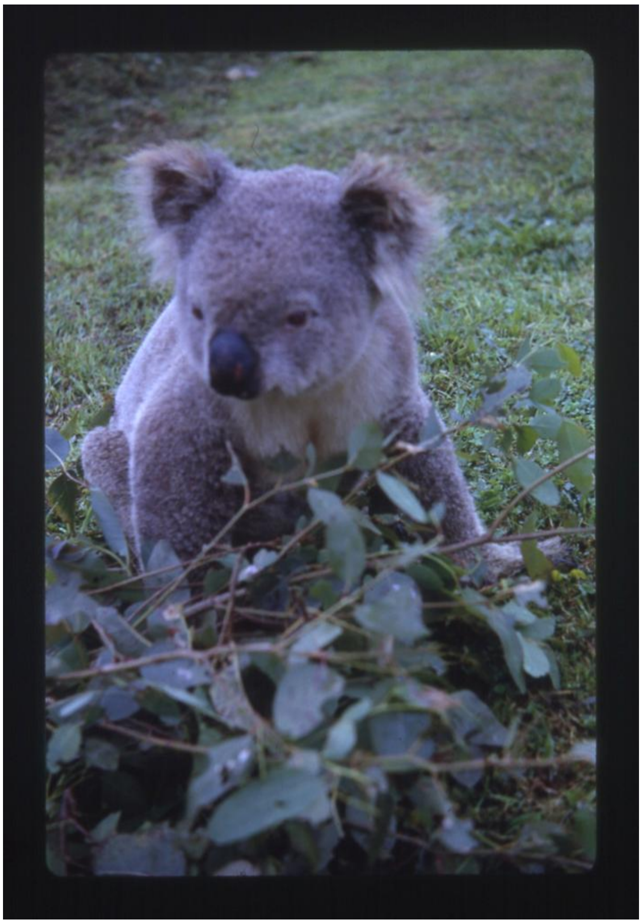
Conservation of Forest Habitats: Examining tree species preferences and habitat quality of a low-density koala population, South East NSW



Heather Gow-Carey

International Bachelor of Science (Geosciences)

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Cover Photo: A rescued koala from the South Coast region in the 1960's. This animal was cared for and re-released into the Kooraban area. Photo courtesy of Rhonda Ayliffe.

The information in this thesis is entirely the result of investigations conducted by the author, unless otherwise acknowledged, and has not been submitted in part, or otherwise, for any other degree or qualification.

Signed:

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Abstract

The koala (*Phascolarctos cinereus*) is an arboreal mammal with specific niche habitat requirements that is exposed to increasing threats and compounding pressures from habitat loss across its range. An investigation of overall habitat quality was conducted for a low-density koala population on the South Coast of NSW which is potentially on the brink of localised extinction. Data for this investigation was provided from faecal pellet surveys which have attempted to quantify the number of koalas remaining in the area however there has been limited assessment of habitat requirements and tree species preferences.

By conducting a G-test for Independence of strike rates and a statistical analysis of tree usage and availability individual tree species preferences were derived. This was then applied spatially to model the extent of adequate habitat using the Inverse Distance Weighted Interpolation technique within ArcMap 10. From a fragmentation assessment of the size and configuration of habitat patches in relation to active koala survey points, the overall quality of the habitat was investigated. It was found that there is a large proportion of adequate habitat across the region, especially within close proximity to known locations of koalas. The trees that are being utilised differ substantially to those listed as primary feed trees for the region, highlighting the need for localised assessment of habitat requirements in order to create informed plans of management.

Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction and Background

1.1. Introduction

The koala (*Phascolarctos cinereus*) is an iconic Australian species that is recognised throughout the world. Despite such a high international standing, koalas are under increasing pressures across Eastern Australia, with many populations on the brink of localised extinction. The recent national listing as ‘Vulnerable’ under the *Environment Protection and Biodiversity Conservation Act 1999* for koala populations in Queensland, New South Wales and the Australian Capital Territory, is finally recognition of the uncertain future for this species.

Since the arrival of Europeans, koalas have experienced a sharp decline in both population size and distribution. Hunted almost to extinction in the early 1900’s (Phillips 1990; Melzer *et al.* 2000), intervention and legislation have assisted the recovery of a number of koala populations. However, compounding threats from disease, predation, road deaths and conflicts with land use and habitat are again putting pressure on the remaining koala populations, many of which now exist in fragmented and isolated habitat along the East Coast of Australia (Lunney *et al.* 2009).

Throughout NSW, the loss and degradation of habitat has been identified as the most considerable threat to koalas (DECC 2008). As they are arboreal folivores which feed largely on species from the *Eucalypt* genus, koalas are considered to be “specialised mammalian herbivores” (Shipley *et al.* 2009, p. 276). Although they have been seen to utilise a number of different eucalypt species across their range, most koala populations only consume very few species within each localised community. Each population is known to use between one to three species on a regular basis, with preference being further shaped by the influence of leaf nutrients and toxicity (Moore & Foley 2000).

As koalas are limited in their ability to adapt to changes in their environment because they have such niche habitat requirements, there are a number of direct implications for the conservation and management of populations. Many studies have been undertaken to assess the existing habitat of koala populations across Australia, though one small and low-density population has not been investigated to the same extent. This thesis is focused on determining the tree species preferences and overall habitat quality of a koala population on the Far South Coast of NSW.

These remaining koalas are extremely unique in that they are considered to be one of the last remaining endemic populations throughout Australia with a moderate to high level of genetic diversity (DECCW 2010). Despite a range of management initiatives by both government and the local community over the past 20 years, the long-term decline of koalas throughout this region has not been halted (Figure 1.1). It has been estimated that probably only one population of less than 50 individual animals now exists (DECCW 2010).

These koalas have had a very long and controversial management history. Their known extent covers multiple tenures and land-use areas, which has resulted in a range of studies from various industry and government organisations. The Office of Environment and Heritage (OEH) have been undertaking extensive koala surveys for the past 5 years in an attempt to quantify and define the extent of the current population. Through the use of faecal pellet surveys, the OEH has compiled a comprehensive database provided for use in this project.

This thesis has generated significant interest from both the CMA and the OEH with results having the potential to be used in practical applications for the conservation and management of koala habitat throughout the region. During the time frame in which this thesis was completed, the Southern Rivers CMA was awarded a Federal grant from the 2011-12 Biodiversity Fund to “conserve, connect & rehabilitate habitat of iconic threatened fauna species: koala & long-nosed potoroo” (SRCMA 2012, p. 3). The priorities for the implementation of this grant are habitat conservation and rehabilitation across more fertile zones and to essentially enhance the overall quality of koala habitat. This thesis has the potential to assist in conservation planning to carry out these goals.

While several localised studies across this region have sought to determine the most utilised tree species, few have investigated actual tree species preferences. Furthermore, there have not been any successful attempts to map and quantify the extent of suitable koala habitat. This study seeks to address this knowledge gap.

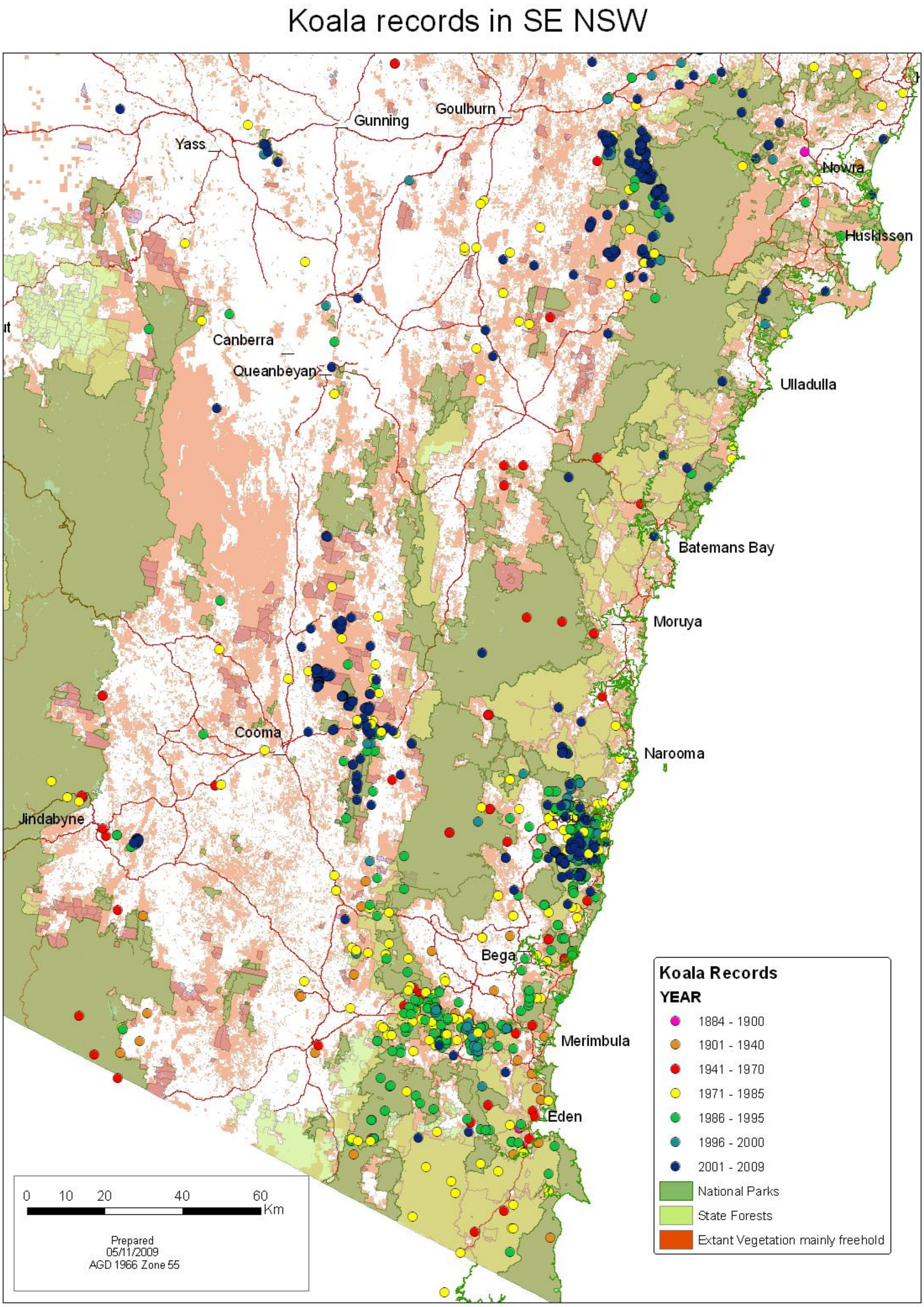

Figure 1.1: Location of koala records on the south coast of NSW, highlighting the decline in range and density over the past 100 years. Data collected from the NSW Wildlife Atlas (from DECCW 2010)

1.2. Study Objective

The koalas of the NSW South East are at critical numbers due to the threats of habitat loss and fragmentation. An understanding of tree species preferences and habitat configuration is vital for conservation; hence the overall objective of this project is to assess the extent and quality of koala habitat with the aim to create more informed management decisions.

1.3. Aims

The key aims to be addressed are:

1) To determine preferred local tree usage species (primary, secondary and supplementary) at a landscape scale.

2) To create a ranked predictive habitat map for koalas based on areas of vegetation that includes a high proportion of identified koala usage species.

3) To examine the extent and configuration of habitat patches in relation to known koala populations at a landscape and patch scale in order to assess habitat quality and determine whether there is enough habitat to sustain the existing population.

1.4. Background and Literature Review

Considerable literature exists regarding the role of conservation and management for the protection of koala habitat throughout Australia, which forms the basis for this study. While the literature covers an extensive range of topics, this review will address several key issues which most commonly arise in the literature. These issues include: the importance of the conservation of forest habitats, the vulnerability of koalas, habitat requirements, tree species preferences, the fragmentation model and the challenges of fragmentation on the koala. Although the literature presents these themes in a variety of contexts, the primary aim of this review is to assess these issues in relation to the koala habitat of the South Coast of NSW.

1.4.1. The Importance of Conservation Planning for Forest Habitats

A functional healthy ecosystem provides a range of biodiversity benefits, not only for koalas but for multiple species that rely on forest habitats (NRMMC 2009). This notion is echoed through a number of articles that examine the challenges of conservation and management across spatial scales and tenures. As koalas are an arboreal mammal, they are naturally restricted to the woody Eucalypt forests of southern and eastern Australia (Melzer *et al.* 2000).

Across their range, koalas are found throughout multiple tenures including National Parks, State Forests, Council Reserves and private land. While there is protection offered in National Parks and to a certain extent within State Forests, there are limited management strategies in place for other areas of habitat. This has resulted in a number of studies investigating the extent of habitat on private land, and assessing the challenges of interdisciplinary approaches to land management and conservation across these regions (McAlpine *et al.* 2007a; Lunney *et al.* 2000a; Stratford *et al.* 2000; Clark *et al.* 2000; Phillips 2000a).

In a fragmented and multi-use landscape, the challenge of conservation at a species level is dramatically enhanced, and the koala symbolises these conflicting land-use values. Koalas prefer Eucalypt species growing on river flats with nutrient rich soil. Unfortunately, these areas of higher quality soils are also the most preferred for agricultural use and consequently, the clash between the needs of the koala and those of the farming communities has resulted in a sharp decline in numbers throughout the Bega Valley (Jackson 2007; Lunney & Leary 1988).

Through a range of scientific studies, there is extensive knowledge about the biological and ecological components of the koala but this often falls short of being able to integrate knowledge into policy and management (McAlpine *et al.* 2007a; Stratford *et al.* 2000; Clark *et al.* 2000). There has been concise evidence that plans of management must target local wildlife areas and avoid the use of a single conservation strategy covering the broader populations (McAlpine *et al.* 2008; Crowther *et al.* 2009). This identifies the need for a localised analysis of the South Coast koala habitat across multiple tenures to assess the area in its entirety in order to facilitate an informed decision-making process.

1.4.2. Vulnerability of Koalas

Worldwide, many species are in decline due to the combination of multiple threats (Rhodes *et al.* 2011; Davidson *et al.* 2009). The vulnerability of the koala exemplifies this notion, as in order to enact conservation and management, we must have an understanding of its ecology in the context of the compounding pressures on the species. Habitat loss and fragmentation through human land use have been recognised as key threats for a large proportion of forest-based fauna, including koalas (Rhodes *et al* 2006; Lindenmayer *et al.* 2000).

The multitude of threats to the koala has been examined by a number of studies. Direct risks include dog attacks (Pullar & Phan 2008; Lunney *et al.* 2005; Laurance & Cochrane 2001), vehicle collisions (Rhodes *et al.* 2011; Pullar & Phan 2008, Dique *et al.* 2003a) and disease (Pullar & Phan 2008; Pincock 2007; Jackson 2007, Melzer & Huston 2001). Along with environmental dangers such as bushfire and prescription burns (DECCW 2008; Matthews *et al.* 2007; Lunney *et al.* 2005; Whelan *et al.* 2002), drought (Seabrook *et al.* 2011; Lunney & Leary 1988), climate change (Anon 2011; Adams-Hosking 2011; Williams 2009) and Eucalypt dieback (Jurskis 2005; Jaggers 2004). These threats have been explored under the National Koala Conservation and Management Strategy 2009–2014 (NRMMC 2009) and the NSW Recovery Plan for the Koala (DECC 2008).

In a fragmented landscape, koalas experience increasing vulnerability from these threats as there are limited options for migration or adaptation (Lunney *et al.* 2005; Laurance &

Cochrane 2001). The koalas of the South East coast are exposed to a majority of these threats, consequently revealing the need for a comprehensive analysis of the fragmentation of habitat to assess the future viability of this population.

1.4.3. Habitat Requirements

Habitat suitability for arboreal folivores is largely determined by the availability of suitable food species and the ease of access to shelter (Callaghan *et al.* 2011). Australia's eucalypt forests are harsh and complex environments and the foraging of arboreal mammals is extremely limited by both the low nutrient value and the high toxicity of the foliage (Moore *et al.* 2010; Stalenberg (Honours thesis 2010); Moore *et al.* 2004; Moore & Foley, 2000). As koalas have very few natural predators, they do not require extensive shelter and therefore many studies have concluded that food requirements are the primary factor of habitat quality (Hindell & Lee 1987, Ellis *et al.* 1999, Phillips & Callaghan 2000, Lunney *et al.* 2000b).

Throughout eastern Australia, only four mammal species feed on eucalypt leaves. While the common brushtail possum (*Trichosurus vulpecula*) and the common ringtail possum (*Pseudocheirus peregrinus*) feed on a range of foods such as gum, pollen, nectar and insects; only the koala and the greater glider (*Petauroides volans)* are strictly folivorous, dependent to forage on a range of species from the Eucalypt genus to fulfil their nutrient requirements (eg. Shipley *et al.* 2009; McAlpine *et al.* 2008; Moore *et al.* 2004; Moore *et al.* 2003; Pausas *et al.* 1995).

With such niche dietary requirements, Shipley et al (2009) argues that the koala is "one of the most specialised mammalian herbivores" (p. 276). Although it has been found that across their range koalas have been seen to utilise up to 120 species of eucalypts and 30 non-eucalypts; at each localised koala community very few species are actually consumed (further explored in Moore & Foley 2000). This variability between koala populations has highlighted the need to develop site specific lists of tree species that satisfy koala habitat requirements.

1.4.4. Tree Species Preferences

The literature states that, for koalas, the delineation of suitable habitat usually includes tree presence, abundance and use as key indicators of habitat quality (McAlpine *et al.* 2008; Jaunchowski *et al.* 2008; Callaghan *et al.* 2011). As the prime component of koala habitat is the presence of specific Eucalypt species, there is a need for adequate identification of these species at a landscape scale.

A range of studies investigating the utilisation of tree species by koalas have been conducted, revealing that while there are many classifications identifying suitable species but in many cases the most critical species have been overlooked (Phillips *et al.* 2000, Phillips & Callaghan 2000). Largely these ‘classifications’ are based on anecdotal or equivocal data that has not been formally quantified, even then, confusion still exists concerning the importance of some tree species to koalas. Anecdotal generalisations about tree species preferences serves to highlight the need for finer scale understandings of the role that individual species play in the quality of koala habitat (Phillips *et al.* 2000).

There are several tree species classifications that refer to the South Coast koala population (SEPP 44; Phillips 2000b; DECC 2008 – see Appendix 1). These divide tree species into primary, secondary and supplementary feed species on the basis of how extensively they are being used by koalas.

From Phillips 2000b:

> *‘Primary food trees exhibit a level of use that is significantly higher than that of other Eucalyptus spp. while also demonstrating a mode of utilisation by koalas that is independent of density … Secondary and/or Supplementary food trees … invariably exhibit (on average) a significantly lower level of use than a primary food tree while also demonstrating evidence of more complex variables associated with their use, generally by being both density and/or size class dependent … Note: Supplementary food trees arguably represent a third tier in the koala food resource. In common with secondary food tree species they exhibit a level of utilisation that is also size class/density dependent. However, the levels of utilisation of supplementary food tree species are generally lower than that of a secondary food tree species, and possibly dependent upon the presence of the latter in the first instance. Interestingly, supplementary food tree species invariably tend to be stringybarks but with significant variation in the use of some species across their range.’*

With the presence or absence of these key koala tree species as the crucial element of habitat quality, a number of studies have investigated the need for a localised classification of most utilised species (Phillips *et al.* 2000; Moore & Foley 2000; McAlpine *et al.* 2008). Though for the application of habitat modelling and conservation planning at a landscape scale, a classification of *preferred* usage tree species, as opposed to those species that are simply the most widely used is essential (Callaghan *et al.* 2011). Habitat preference models are able to quantify animal-habitat relationships by a statistical comparison of both habitat use and availability (Beyer *et al.* 2010). In order to assess the habitat quality of the South Coast koalas, a ranking of the most preferred tree species is necessary to model and measure the extent of suitable habitat.

1.4.5. Habitat Modelling

In order to examine the area of adequate habitat across a region, predictive habitat modelling is undertaken at a scale that is suitable to the organism of focus. As the home range of an individual koala is from 50-150 ha, a landscape scale of 100s-1000s ha is seen as a suitable area of habitat assessment (McAlpine *et al.* 2007b). There have been a range of studies that have sought to quantify the habitat variables that are most of use to koalas, including climate, soil, forest structure, tree species, chemical composition of leaves, exotic and native predators, disturbance history and topography (eg. Kavanagh *et al.* 1995; Bryan 1997; Cork *et al.* 2000; Lunney *et al.* 2000b; McAlpine *et al.* 2008; Jaunchowski *et al.* 2008; Callaghan *et al.* 2011).

While there has been no complete consensus on the value of these variables in predicting koala habitat, there has been consistent support in these studies that the presence or absence of key Eucalypt species, and the underlying influence of substrate are the two prime predictors of habitat quality. Furthermore, McAlpine *et al.* (2008) emphasise that models of species habitat and distribution cannot be generalised from region to region due to the diversity of koala habitat across its range. This identifies the need for localised habitat modelling to best predict and assess the extent of habitat available to the koalas throughout the study area.

1.4.6. The Fragmentation Model

In an ever expanding human-modified environment, the expansion of development and demand for natural resources has caused the loss and fragmentation of a range of forest environments. Fragmentation is the process where patches of habitat are separated into smaller and increasingly isolated fragments (McGarigal & Cushman 2002; Fahrig 2003; McAlpine *et al.* 2006a). The effects of fragmentation should be thought as of distinctly separate from habitat loss, though the consequences of both factors combine to have specific negative impacts on the biodiversity of an ecosystem (Fahrig 2003; McGarigal & Cushman 2002; Lindenmayer *et al.* 1999).

The process of fragmentation creates remnant habitat fragments (*patches*) that result in heterogeneous landscapes made up of smaller and isolated patches of suitable habitat situated within a matrix of less suitable habitat (Brady *et al.* 2011; Nikolakaki 2004; Haila 2002; McAlpine *et al.* 2007b).

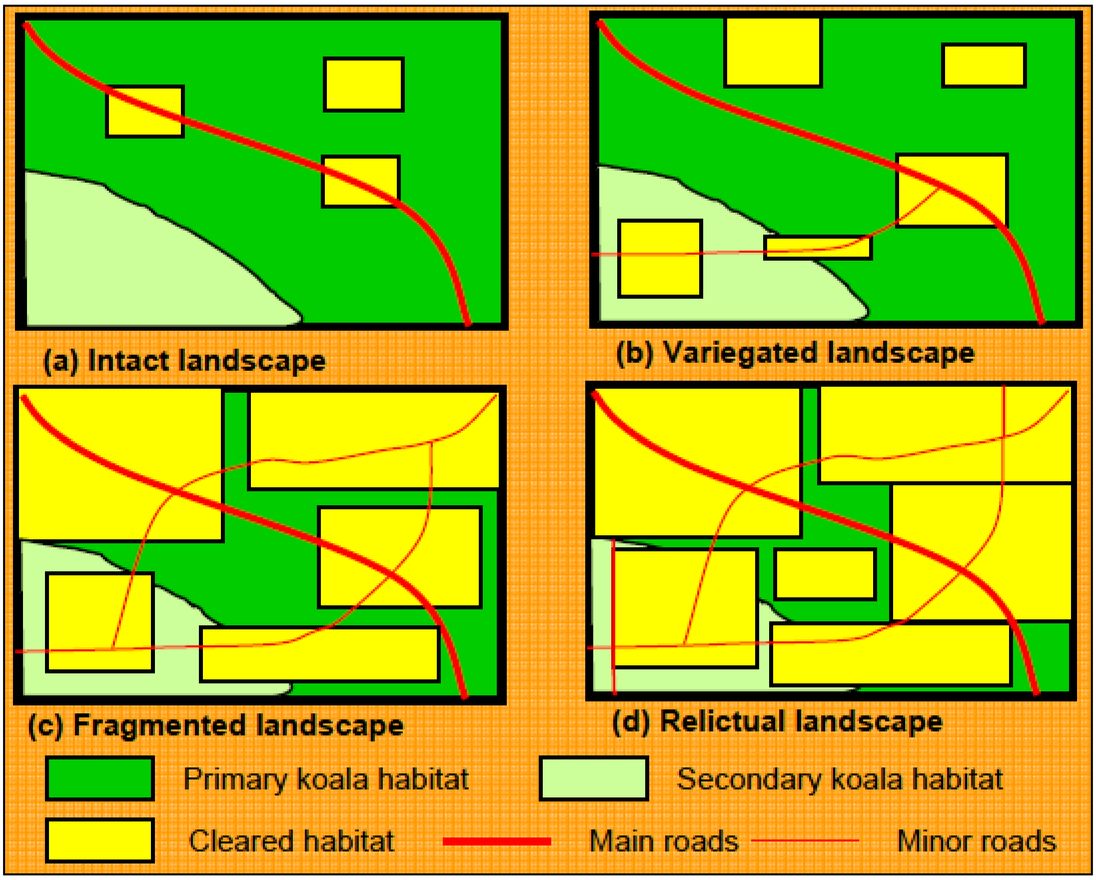

Figure 1.2: Conceptual model of landscapes with different levels of habitat destruction and subdivision by roads. Each landscape is characterised by the amount of remaining habitat, human land use and road density. (McAlpine *et al.* 2007b: Modified from McIntyre and Hobbs, 1999)

The “fragmentation model” is the most widely used landscape model to examine the effects of biodiversity decline through the destruction of habitat (Figure 1.2). It has been criticised as its use is restricted by certain ecological applications due to its failure to recognise the overlap between habitat and the surrounding regions which in themselves may be important resources (Bradey *et al.* 2011). Fischer and Lindenmayer (2006) further summarise the limitations of this model that is principally based on the island biogeography theory (MacArthur and Wilson 1967). As the model relies on the distinct separation of ‘habitat’ from the rest of the landscape, for many purposes it can be considered to be over simplistic, creating conservation plans that do not highlight the underlying ecological processes or neglect to assess species-specific differences.

The fragmentation model is considered suitable for application to this project due to the sharp contrast between remnant native vegetation and the surrounding cleared agricultural land. This recognises the koala’s specialised habitat requirements as outlined above, and as it is focusing on a single species it will be able to address the conservation outcomes as outlined by Fischer & Lindenmayer (2006), based on Diamond (1975).

Due to the fragmentation model being reliant on the overall landscape mosaic and the extent of suitable patches, the configuration of these patches must be considered when designing management strategies for koalas. This can be undertaken by examining the spatial characteristics of the patches in regards to their size, shape and connectivity (Jaunchowski *et al.* 2008; McAlpine *et al.* 2006a; Lindenmayer *et al.* 1999). Habitat connectivity has been defined as the extent to which an individual can travel between patches within the overall landscape network (Kindlmann & Burel 2008; McGarigal & Cushman 2002; Fahrig 2003). If the size of a patch is not sufficient to sustain a population of a given species then they must be able to disperse to survive, illustrating the importance of connectivity in the conservation of koala habitat across a fragmented landscape. Connectivity is not assessed in the aims of this study, though further research could identify the connectivity of remnant habitat patches and assess the proposed locations of wildlife corridors.

1.4.7. Challenges of Fragmentation on Arboreal Fauna

While habitat loss has substantial negative effects on biodiversity, there are a number of independent consequences of fragmentation that are experienced by a range of arboreal mammals (Lindenmayer *et al.* 1999). Literature has shown that these effects are largely more complex and varied than the direct loss of habitat and must be analysed to assess localised effects (McAlpine *et al.* 2006a; Fahrig 2003; Jaunchowski 2008; McGarigal & Cushman 2002).

It is largely the case that many forest dwelling mammals are particularly sensitive to habitat loss and fragmentation as these species are characterised by a limited ability to move freely through the land use matrix (McAlpine *et al.* 2006a; McAlpine & Eyre, 2002). Faunal populations can become increasingly isolated as fragmentation occurs, resulting in the collapse of populations (Laurence 2008). This is due to many forest species being hesitant to cross extensive areas of cleared land to access new resources or shelter. The koala can move between trees where the canopy overlaps however, they must frequently come to the ground to move between habitat patches (Dique *et al.* 2003b; Rhodes *et al.* 2006.

Many previous studies of koala habitat have focused on the habitat quality at the vegetation community level, associated with soil quality and nutrient levels of foliage (eg. Bryan 1997; Lunney *et al.* 1998; Lunney *et al.* 2000b; Moore *et al.* 2004; Moore & Foley 2005). These studies have neglected to extend the habitat analysis into the effects of configuration on fine-scale habitat factors. McAlpine *et al.* (2006a) identifies that the threats and challenges to koala populations vary spatially as “the koala has experienced population declines and local extinctions across its geographic range” (p.154).

McAlpine *et al.* (2006a & 2006b) further outlines the importance of forest area and configuration in relation to local habitat factors for the koala, concluding that the configuration of habitat throughout the land use matrix at a number of scales must be understood to ensure adequate koala conservation. This element is vital to the final aims of this project as it reinforces that conservation is not as straightforward as mapping the distribution of habitat and protecting these regions, the independent effects of fragmentation are variable and must be assessed to draw conclusions regarding the overall habitat quality of the study area.

Chapter 2 Species and Study Site

2.1. Study Location

The study site is approximately 71 000 ha located between 150º 13'E, 36º 30'S and 149º 87'E 36º 64'S on the Far South Coast of New South Wales. This area covers a number of National Parks, State Forest and private land including sections of Kooraban, Gulaga, Wallaga Lake, Biamanga, Mimosa Rocks National Parks; Bermagui, Mumbulla and Murrah State Forests; and Bermagui Nature Reserve (Figure 2.1). The area is dominated by a temperate climate, characterised by warm summers and moderate rainfall levels with the warmest month being January and the coolest is July. Average temperature ranges from 8.8ºC to 21.6ºC. Rain occurs throughout the year with higher falls during the summer months with an average of 603.2 mm annually.

Throughout the region, three Palaeozoic meta-sedimentary successions occur, dated to be of the late Ordovician to late Devonian: a coastal zone of turbiditic sublitharenite and slate, an inland zone of indurated quartzarenite, pelite and chert and a thin succession of quartzarenite to sublitharenite, with red siltstones and shales and minor conglomerates and gritstones with sequences (Scott 1999). Furthermore, nutrient rich fluvial sediments and alluvial deposits are found along the river and creek flats of the region (Tozer *et al.* 2010). The topography varies from coastal flats and narrow floodplains to hilly areas with the peak of Mumbulla Mountain reaching an altitude of 773 m in the south and Gulaga (Mount Dromedary) reaching 806 m in the north.

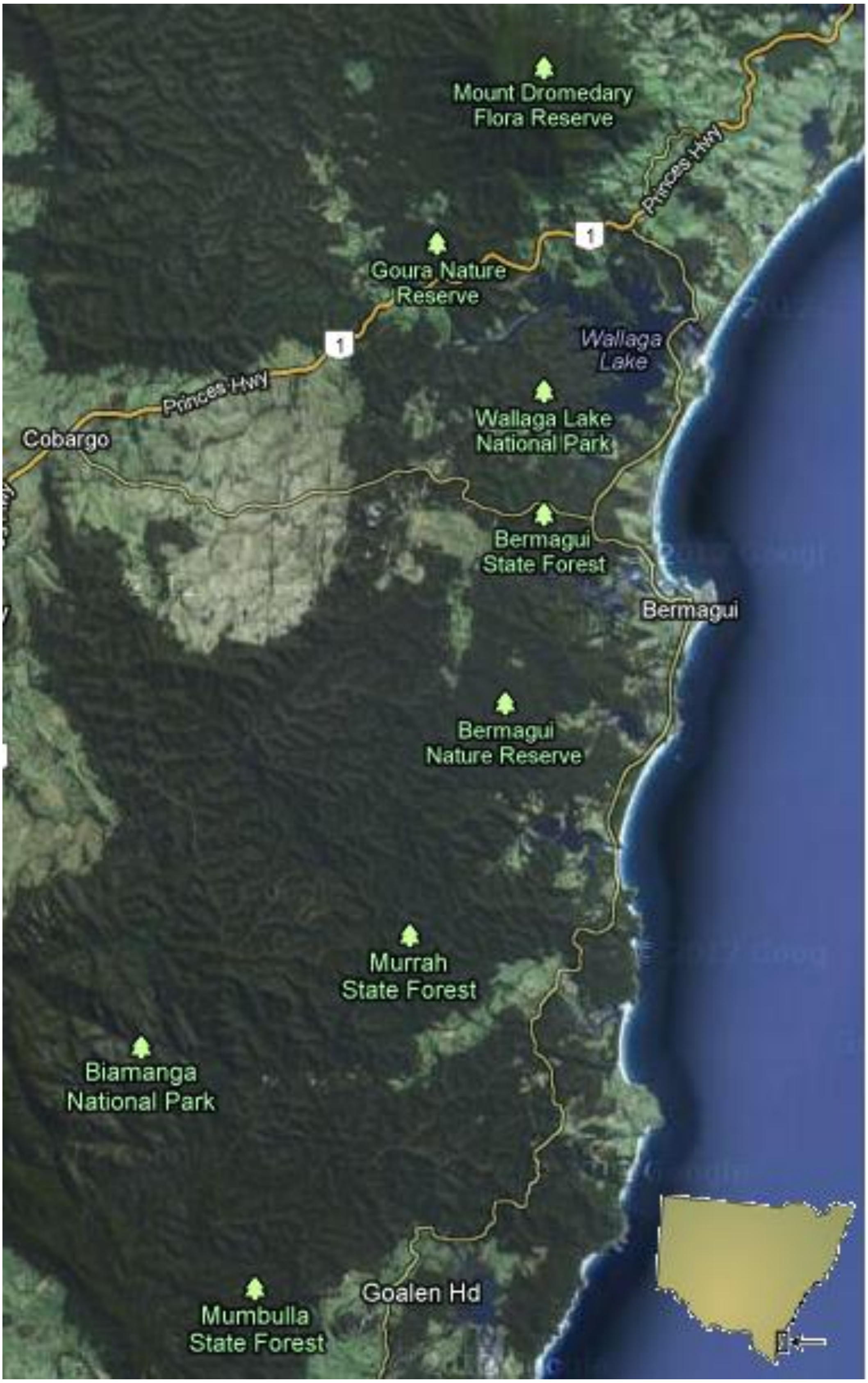

Figure 2.1: Satellite imagery of the study area (© 2011 Google).

Before European settlement, the vegetation of the lowland slopes was largely tall open forests of spotted gum (*Eucalyptus maculata*), forest red gum (*E. tereticornis*), and woollybutt (*E. longifolia*), with a moderately dense sclerophyllous understorey (Lunney & Leary 1988). A large proportion of these regions were cleared for farming, and consequently the remaining dry open sclerophyll forest is restricted to the rugged, less fertile areas often associated with the Ordovician meta-sediments. These forests are dominated by silver-top ash (*E. sieberi*), yellow stringybark (*E. muelleriana)*, blue-leaved stringybark (*E. agglomerata*), white stringybark (*E. globoidea*), along with rough-barked tree (*Angophora floribunda*) and woollybutt (*E. longifolia*). These vegetation communities are often found with a rather open understory of acacia and black she-oak *(Allocasuarina littoralis*). Restricted areas of temperate rainforest occur on the lowland zones along with moist sclerophyll found throughout the study area at higher altitudes and in moist valleys (State Forests 1994).

Extensive logging operations have been in process since European Settlement in 1830 with a well established industry by the 1860's, supplying timber to the Sydney colonies (Lunney & Leary 1988). This has resulted in less than 10% of the lowland zone having scattered tree cover (Brooks 1994). The remaining forested areas are increasingly regrowth due to the continued logging of the Murrah, Mumbulla and Bermagui State Forests. The region also has an extensive history of drought, bushfire and prescribed burns (State Forests 1994; Lunney & Leary 1988).

2.2. The History and Current Status of the South Coast Koala

The koala has long been found in the Bega Valley, the history of which has been well documented in Lunney and Leary (1988). It was reported that an increase in numbers occurred soon after European settlement, assumed to be associated with the reduction of Aboriginal hunting in the area and they were so common that by 1865, the Bega District News reported that it was possible to 'catch a Koala or Native Bear in the main street of Bega' (BDN 10/11/1865 cited Lunney & Leary 1988).

The population continued to remain at a high level for the remainder of the nineteenth century, able to support an extensive fur trade beginning in the 1890's (Melzer *et al.* 2000; Lunney & Leary 1988). Several million skins were exported from NSW over a 20 year period (Phillips 1990). The fur trade soon collapsed and it was estimated that koala numbers in the late 1930's were "only hundreds" throughout NSW (Phillips 1990). Though the koala population across NSW may have recovered somewhat in the past 80 years, the distribution of koalas has been severely limited due to their vulnerability and inability to adapt to changing habitat conditions.

Figure 2.2: One of the most recent sightings of a koala within the study area. 'Allen' was sighted near Bermagui in 2009. Photo: Rob Summers

By using a range of methods including radio tagging, audio playback, community survey and scat survey analysis, a number of studies have been conducted to investigate the current size and distribution of the remaining koala population across the Far South Coast (Braithwaite 1983; Cork 1990; Reed *et al.* 1990; Reed & Lunney 1990; Jurskis & Potter 1997; Lunney *et al.* 1997). These studies have shown that the numbers and density of koalas has remained low throughout the region with the current population confined to less fertile and rugged terrain, located across NSW State Forests, National Park and also small sections of private land (Jurskis *et al.* 2001; Allen 2010). It is estimated that in the forests to the north-east of Bega, no more than 42 individual koalas remain (Allen 2010).

The continuing decline of habitat quality throughout the study area is apparent "because of multiple factors including extensive canopy dieback, clearing due to rural-residential development and commercial forest harvesting" (NSW Scientific Committee (2007), cited in Allen 2010 p.18). This in turn has resulted in limited connectivity between the two known koala populations located in Kooraban National Park and those in the Bermagui-Mumbulla region, with anecdotal evidence suggesting that the link may have been severed in the past 10-15 years (Allen 2010). This study is focussed on these populations between Dignams Creek and Tathra, with the analysis of habitat quality being the primary outcome.

2.3. Faecal-pellet Surveys

Faecal pellet surveys to collect data for this study were conducted throughout the study area from 2007-2010 by NSW National Parks and Wildlife Service (Division of Office of Environment and Heritage) along with Forests NSW and extensive volunteer involvement. These surveys aimed to assess the distribution and abundance of the koala population. Approximately 21,000 hectares was surveyed from north of Tanja through to Gulaga National Park, north-east of Bermagui across multiple tenures including National Park, Nature Reserve, State Forest and private land.

Figure 2.3: Chris Allen (OEH) demonstrating the survey methods used to collect information on the distribution and location of the koala population. Photo: Lynne Strong

The Regularised Grid-Based Spot Assessment Technique (RBG-SAT) survey method was developed Dr Stephen Phillips and has been used extensively for medium-density koala populations, though it has also been proved a viable method for low-density populations (Phillips & Callaghan 2011). Sampling sites were selected at 1km grid based intervals to ensure geographic coverage while ensuring that the sampling interval was sufficient to detect koala activity. In certain regions, adaptive sampling strategies were undertaken where koala evidence was found, with sites assessed at 350m intervals surrounding the active sites in order to delineate the margins of the utilised area.

At each of the survey sites, a centre tree was defined and the surrounding 30 live trees with a diameter greater than 150 mm at breast height (dbh) were examine for koala faecal pellets at a 1m radius from the trunk (Figures 2.3 & 2.4). The dbh, tree species and the presence or absence of faecal pellets of each of the 30 trees was recorded. In accordance with Phillips et al (2000) and Phillips and Callaghan (2000), survey sites were initially classed as ‘active’ or ‘inactive’ based on the presence or absence of koala faecal pellets.

Figure 2.4: Examples of koala faecal pellets found in the South Coast study area. Photo: Rhonda Ayliffe

Evidence of koalas was found at 72 of the 657 survey sites (Figures 2.5 & 2.6). The activity level of each site was calculated (DECCW 2010) using methods adapted from Phillips and Callaghan (2000). A percentage was attained from the proportion of trees with evidence of koalas divided by the total number of live trees assessed at each plot (*n* = 30). Activity cells were then developed which resulted an activity level ranging from 3.33-36.67% at active sites across the study area, cluster analysis explored the possible home range of these koalas (calculations by DECCW 2010). This revealed in an average occupancy rate of 10% being calculated across the survey area suggesting that if home ranges of individual koalas are 50-100 ha then a population of 21-42 koalas has been estimated (Allen 2010).

This small and dispersed population reveals the need for further investigation into determinants of koala habitat preferences in order to create informed management strategies for this population. While a number of studies have examined the role of nutrients and toxins in food choices made by koalas; the presence of a relatively small number of eucalypt species remains to be the key determinant in koala habitat quality. Consequently, tree species preferences from active sites will be statistically assessed and applied to each survey point in order to interpolate a ranked habitat model to be used for fragmentation analysis.

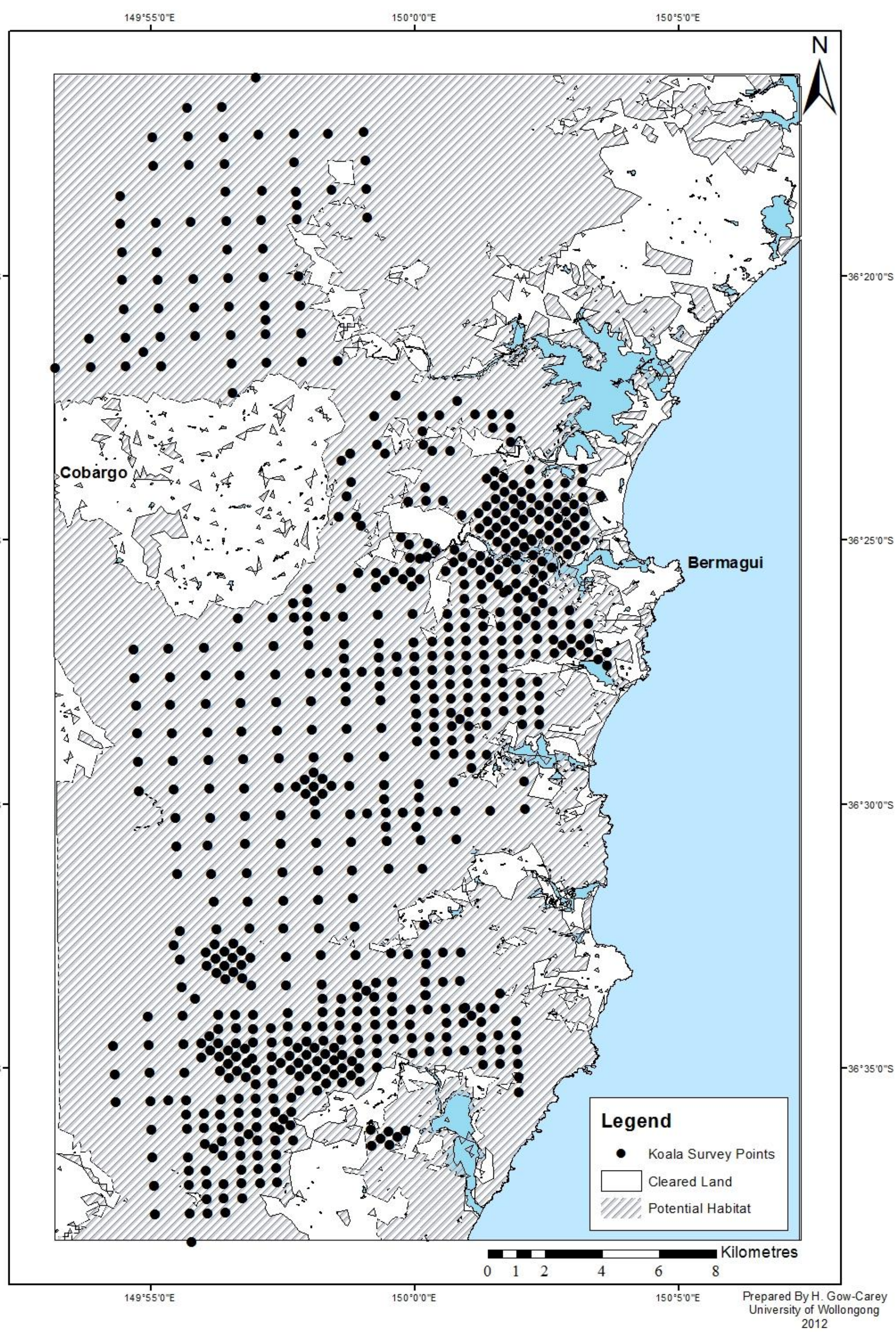

Figure 2.5: Extent of survey sites across the study area, located throughout National Parks, State Forest and Private Land.

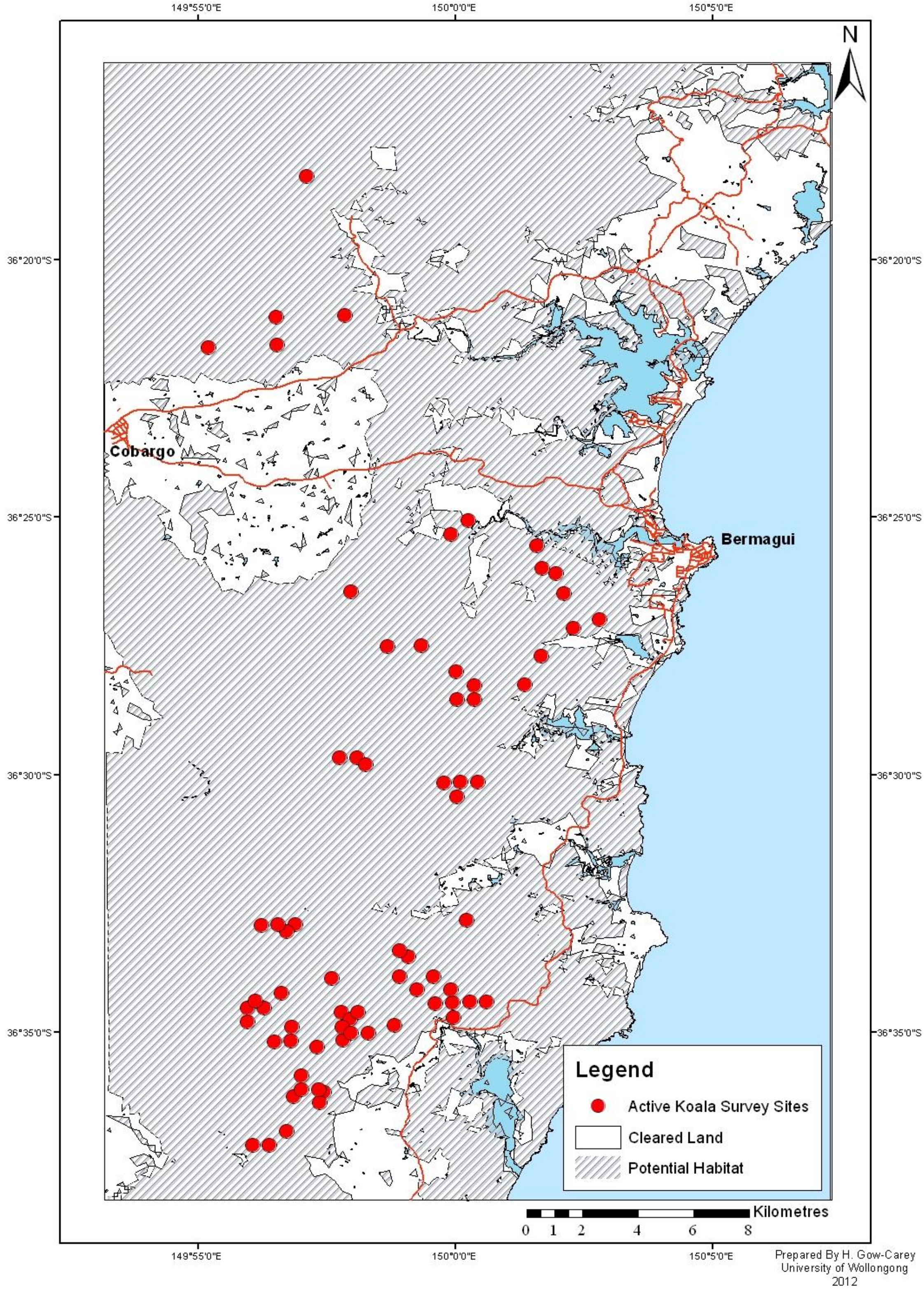

Figure 2.6: All active sites across the study area where evidence of koalas was found and recorded.

Chapter 3 Tree Species Preferences

The primary aim of this chapter was to determine preferred local tree usage species at a landscape scale and create a ranking (primary, secondary and supplementary) based on both the strike rate and proportional usage when compared to overall availability. All tree species that were statistically analysed met inclusion criteria to satisfy sampling size requirements.

3.1. Methods

3.1.1. Inclusion Criteria

In order to rank tree species usage and to further identify potential habitat, the focus of all analysis was on 'active' sites in accordance with Callaghan *et al.* (2011). This is due to a number of factors such as disturbance history, site-isolation effect, threats or population spatial dynamics, which could influence the absence of koalas rather than indicating low habitat quality or suitability.

Data sets for a given utilised tree species 'i', from all 72 active sites were pooled to give a proportional index (P_i) – which is furthermore referred to as the *strike rate* – derived by dividing the total number of surveyed trees (i) from all active sites (p_i) by the number of trees of species (i) with faecal pellets (n_i).

$$P_i = \frac{p_i}{n_i}$$

Derived this way, the strike rate is also a conditional probability estimator (± s.e) related to the use of a given tree species by koalas (Phillips & Callaghan, 2000).

Pooled data sets were considered to be suitable for analysis when they satisfied the following criteria:

i) the number of trees sampled was at least 30 (Callaghan *et al.* 2011)

ii) the active data set had been obtained from at least 3 independent active sites (Phillips & Callaghan 2000)

iii) the number of trees sampled of species '*i*' multiplied by the proportion of trees of species *i* with (n_iP_i) and without pellets ($n_i(1 - P_i)$) were both ≥ 5, for approximation of a normal distribution (Phillips *et al.* 2000; Callaghan *et al.* 2011)

Data that satisfied these criteria were considered part of a primary data set containing those tree species that were being frequently utilised by koalas and thus most likely to be of importance in terms of sustaining the population. All species that did not meet the criteria formed an auxiliary data set and were deemed to be of some importance to koalas but the size of the data set would not allow for accurate analysis.

3.1.2. G-Test of Independence of Strike Rates

In order to establish whether there was any significant heterogeneity among strike rates, the main dataset was assessed using a log-likelihood ratio G-test of Independence with William's correction (Sokal & Rohlf 1995). The G-test of independence is seen as an alternative to the chi-squared test and is used to compare proportions of one nominal variable to proportions of a second nominal variable. The null hypothesis states that all proportions are equal, or in other words, all strike rates are heterogeneous. If the expected numbers in some cases are small (< 5), the G-test will give inaccurate results, consequently William's correction (Williams 1976), was applied to reduce the value of G for smaller sample sizes and have progressively less effect as the sample size increases. All calculations were conducted using R statistical software (R Development Core Team 2012. Version 2.15.1).

The G-test of independence was applied to the data set as a whole, and where heterogeneity was discovered, step-wise G-tests were applied for rows and columns in the (R x C) contingency table. Using simultaneous test procedures to identify non-significant subsets, it was noted where strike rates do not differ significantly among any species within the group, but do differ significantly from all other species (Callaghan *et al.* 2011). Following this, the species were initially grouped into primary, secondary and supplementary classes based on significant differences between strike rates of individual species.

3.1.3. Use versus Availability Analysis

The literature states that, for koalas, the delineation of suitable habitat includes tree presence, abundance and use as indicators of habitat quality. To validate and furthermore refine the strike rate classification, two further factors were compared: tree usage and the overall availability of the utilised species. The combination of use versus availability analysis, along with the G-test for Independence gives further important insights into the tree species preferences. Previous to this study, the combined approach was not used extensively in deriving tree species lists for koalas, though Callaghan *et al.* (2011) concluded that use and availability analysis is an important factor to assess whether species are being actively targeted (preferred) or are underutilised compared to their abundance (avoided).

Each of the parameters were calculated as follows:

Use (u_i)

$$u_i = \frac{p_i}{\sum p_i}$$

Where, (p_i) is the used trees of each species and ($\sum p_i$) is all used trees across all active sites.

Availability (a_i)

$$a_i = \frac{n_i}{30 \times n_a}$$

Where, (n_i) is all trees of one species and (n_a) is all trees across active sites

The use versus availability coefficient is calculated by:

$$= u_i - a_i$$

Where, (u_i) is the relative utilisation of a tree species and (a_i) is the abundance of that species.

The sign and magnitude of the resulting coefficient implies only that the frequency habitat use is greater or lower than that expected by chance based on the availability of the defined sample (Beyer *et al.* 2010). It can only be inferred that if an individual tree species has a low mean availability yet high mean usage, that koalas are actively selecting, or prefer this species. Conversely, suggestions that the species is less preferred or avoided can only be made by the species having high mean availability but low mean usage by koalas. This can result in negative coefficients being associated with species of high mean usage if that species is relatively common.

3.1.4. Overall Species Classification

Each individual species was grouped based on the results of both the G-test for Independence and the use versus availability analysis, resulting in three distinct classifications of primary, secondary and supplementary koala use species (Table 3.1).

Table 3.1: Primary, secondary and supplementary species classifications as adapted from Callaghan *et al.* (2011) and Phillips (2000a).

Category	G-test for Independence of Strike Rates	Use versus availability analysis
Primary	A statistically significant proportion of surveyed trees having one or more koala faecal pellets than the proportion for other tree species	High ranking for use compared with availability, indicating active selection
Secondary	A significantly higher proportion of trees with pellets than for the remaining species (excluding the primary category)	Medium to high ranking for use versus availability
Supplementary	A significantly lower proportion of trees with pellets than for secondary species, but greater than for other species that generally lacked evidence of use by koalas	Low ranking for use versus availability

3.2. Results

In total, 19260 trees were assessed from 657 sites across the study area. Of these sites, 72 (11.21%) were active with 176 trees indicating evidence of koalas. In total, 9 out of 18 eucalypts and 6 out of 36 non-eucalypts showed evidence of koalas.

Those species that satisfied the defined criteria for statistical analysis were included in the main data set (Figure 3.1 & Table...) and those that failed to do so are outlined in Table ... These auxiliary species have little or unknown usage value to koalas across the study area. No further auxiliary was undertaken on this ancillary data set.

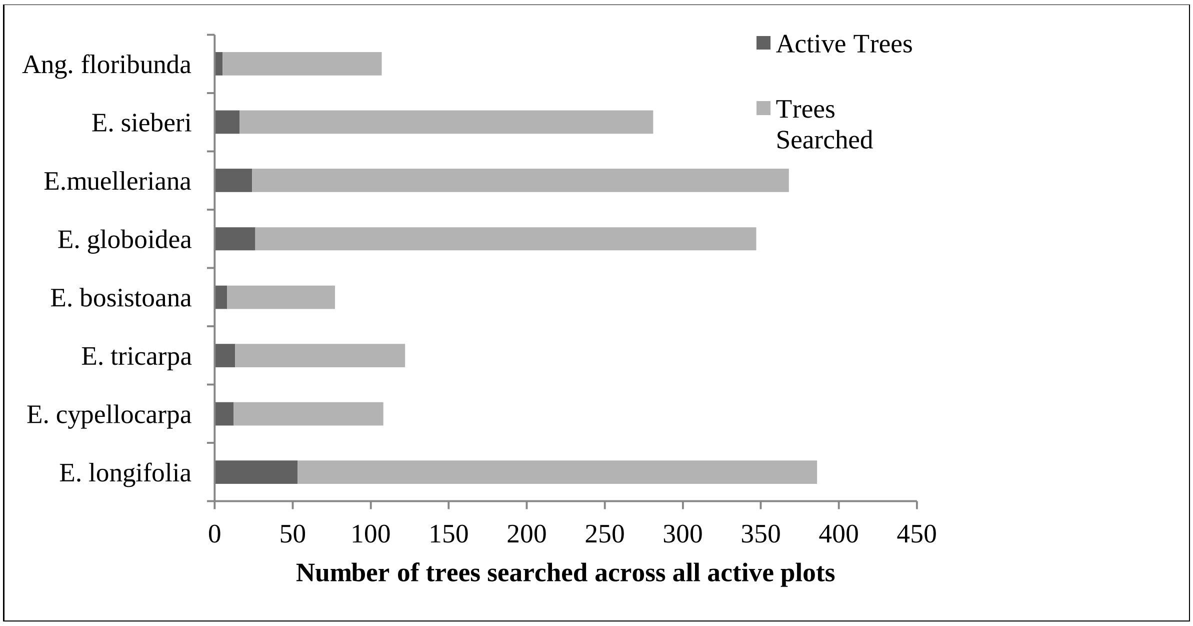

Figure 3.1: Proportion of trees in the main data set that were searched during the RGB-SAT surveys that had evidence of koalas compared to trees of the same species where no evidence was found.

Main Data Set

Table 3.2: Main dataset showing recorded use of species throughout the south coast study site. The number of survey sites (n_s), pooled sample size (n_i), and strike rate (P_i) ± se are indicated for each tree species.

Main Data	n_s	p_i	n_i	P_i ± se
Eucalyptus longifolia	34	53	333	0.1592 ± 0.0200
Eucalyptus cypellocarpa	9	12	96	0.1250 ± 0.0338
Eucalyptus tricarpa	10	13	109	0.1193 ± 0.0310
Eucalyptus bosistoana	6	8	69	0.1159 ± 0.0385
Eucalyptus globoidea	22	26	321	0.0810 ± 0.0152
Eucalyptus muelleriana	18	24	344	0.0698 ± 0.0137
Eucalyptus sieberi	13	16	265	0.0604 ± 0.0146
Angophora floribunda	4	5	102	0.0490 ± 0.0214

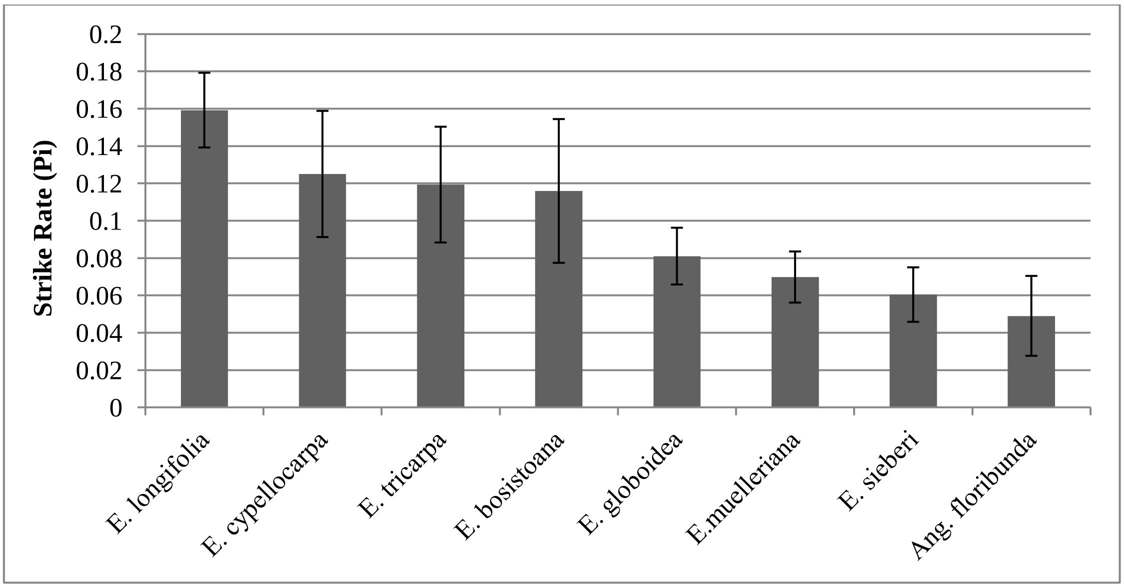

Figure 3.2: Graph of main dataset showing recorded use of species throughout the south coast study site, including standard error bars.

Auxiliary Data Set

Table 3.3: Auxiliary dataset showing recorded use of species throughout the south coast study site. The number of survey sites (n_s), pooled sample size (n_i), and strike rate (P_i) ± se are indicated for each tree species.

Auxiliary Data	n_s	p_i	n_i	$P_i \pm se$
Eucalyptus consideniana	1	1	5	0.2000 ± 0.1789
Acacia falciformis	2	2	20	0.1000 ± 0.0671
Exocarpus cupressiformis	1	1	10	0.1000 ± 0.0949
Eucalyptus botryoides	2	3	32	0.0938 ± 0.0515
Corymbia gumnifera	1	1	24	0.0417 ± 0.0408
Eucalyptus agglomerata	3	3	75	0.0400 ± 0.0226
Allocasurina littoralis	2	7	196	0.0357 ± 0.0133
Acacia spp.	2	1	34	0.0294 ± 0.0290

3.2.1. Analysis of Strike Rates

Eight species satisfied the validation criteria to be included in the main dataset for statistical analysis. The strike rates for these species ranged from 0.1592 for *Eucalyptus longifolia* to 0.0490 for *Angophora floribunda*. Significant heterogeneity was detected among the strike rates of the eight utilised species ($G= 25.834 > x^2_{0.05\ [7]} = 14.067$, $P = 0.0005393$) hence a paired log-likelihood ratio G-test with Williams correction was conducted to reveal where the specific heterogeneity lay.

Table 3.4: Log likelihood G-test results for paired comparisons of koala faecal pellet strike rates (Pi) for all species in the Primary dataset. Comparisons that resulted in significant differences at $P \leq 0.05$ are in bold. Critical value $x^2_{0.05\ [1]} = 3.8415$. Statistics calculated using R with William's correction applied to all calculations.

E longifolia (E lon)	*E lon*						
E cypellocarpa (E cyp)	0.6933	*E cyp*					
E tricarpa (E tri)	1.0604	0.0153	*E tri*				
E bosistoana (E bos)	0.8636	0.0302	0.0044	*E bos*			
E globoidea (E glo)	**9.5263**	1.5838	1.3443	0.7906	*E glo*		
E muelleriana (E mue)	**13.5965**	2.7143	2.4507	1.5004	0.2979	*E mue*	
E sieberi (E sie)	**14.8785**	3.6706	3.4061	2.1913	0.9274	0.2137	*E sie*
Angophora floribunda	**9.7008**	3.6152	3.3616	2.4647	1.2357	0.5763	0.1759

Eucalyptus longifolia was the most preferred species, with the stepwise paired log-likelihood G-tests indicating a distinct separation of strike rates from the four lowest ranked species ($G > x^2_{0.05[1]} = 3.8415$). Furthermore, *E. cypellocarpa* and *E. tricarpa* all gave a G statistic nearing the critical value when tested against *E. sieberi* (E cyp: 3.7606. E tri: 3.4061) and *Angophora floribunda* (E cyp: 3.6152. E tri: 3.3616), hence indicating that these two species were ranked substantially lower compared to the rest of the group. Comparisons using this procedure grouped *E. longifolia, E. cypellocarpa, E. tricarpa* and *E. bosistoana* as the highest ranked group, *E. globoidea* and *E. muelleriana* as a secondary group and *E. sieberi* and *Angophora floribunda* as the lowest ranked species.

3.2.2. Use versus Availability Analysis

This analysis revealed the selective tree usage by koalas across all active sites. While a positive coefficient indicated that the tree is being selectively utilised, negative results indicated that the species is either underutilised based on availability or actively avoided by koalas. Of the eight species in the main dataset, five resulted in positive coefficients indicating that these species are actively selected (Table...). The highest usage ranking resulted from *Eucalyptus longifolia* (+0.3011), *E. globoidea* (+0.1477) and *E. muelleriana* (+0.1364), though the availability of both *E. globoidea* (+0.1446) and *E. muelleriana* (+0.1550) resulted in both of these species having a relatively low ranking. The highest overall ranking for use versus. availability analysis was *E. longifolia* (+0.1511) while active selection was also indicated for *E. cypellocarpa, E. tricarpa, E. bosistoana* and *E. globoidea. Angophora floribunda* and *E. muelleriana* were used marginally lower than expected with *E. sieberi* being used the lowest for its overall availability.

Table 3.5: Final ranking of active tree species that met inclusion criteria from 'most preferred' to 'least preferred' based on the difference between the mean proportion use and the mean proportion availability throughout active sites in the study area.

Species	**Use (U_i)**	**Availability (A_i)**	**U_i-A_i**	**Rank**
Eucalyptus longifolia	0.3011	0.1500	0.1511	1
Eucalyptus cypellocarpa	0.0682	0.0432	0.0249	2
Eucalyptus tricarpa	0.0739	0.0491	0.0248	3
Eucalyptus bosistoana	0.0455	0.0311	0.0144	4
Eucalyptus globoidea	0.1477	0.1446	0.0031	5
Angophora floribunda	0.0284	0.0459	-0.0175	6
Eucalyptus muelleriana	0.1364	0.1550	-0.0186	7
Eucalyptus sieberi	0.0909	0.1194	-0.0285	8

3.2.3. Overall Tree Species Classification

The overall rankings for both the analysis of strike rates and the use versus availability analysis are outlined in Table 3.6. For both methods of analysis, the rankings of the first five species are identical, with the use versus availability analysis refining only the ranks of the lowest three species (*Eucalyptus muelleriana*, *Angophora floribunda* and *E. sieberi*). The final ranking was used to delineate species based on the criteria in Table 3.1.

Primary species included *E. longifolia*, *E. cypellocarpa* and *E. tricarpa.* Secondary species were revealed as *E. bosistoana* and *E. globoidea* and *E. muelleriana*, while *E. sieberi* and *Angophora floribunda* are classed as supplementary species.

Table 3.6: Overall ranking and classification for important tree species usage by koalas across the study area based on separate results from the log-likelihood ratio G-test of Independence and the use versus. availability analysis.

Species	**Strike Rate Rank**	**U_i-A_i Rank**	**Final Rank**	**Overall Classification**
Eucalyptus longifolia	1	1	1	Primary
Eucalyptus cypellocarpa	2	2	2	Primary
Eucalyptus tricarpa	3	3	3	Primary
Eucalyptus bosistoana	4	4	4	Secondary
Eucalyptus globoidea	5	5	5	Secondary
Eucalyptus muelleriana	6	7	6	Secondary
Angophora floribunda	8	6	7	Supplementary
Eucalyptus sieberi	7	8	8	Supplementary

The important factor to note is that this final ranking does not give an indication of the diet of koalas throughout the study area as only extensive cuticle analysis from faecal pellets would reveal this, but rather this ranking defines the overall individual species use whether it be for feeding or shelter purposes.

Chapter 4 Predictive Habitat Modelling

The primary aim of this chapter was to create a ranked predictive habitat map based on areas of vegetation that includes a high proportion of preferred koala usage species. Based on the preferences outlined in Chapter 3, the tree species were examined at each individual survey point to create an overall vegetation suitability rank. This was then interpolated to generate a continuous surface across the study area.

4.1. Methods

4.1.1. Vegetation Ranking

The points that were surveyed (*n* = 657) across the study area involved listing the searched trees (*n* = 30) with a diameter at breast height greater than 150mm for each individual site. As the dataset compiled from the faecal pellet surveys represented an accurate sample of overstorey vegetation, each site was assigned a habitat quality rank based on the proportion of identified preferred koala usage tree species.

For the purposes of this project, the classes were divided into four habitat suitability classes: highly suitable, suitable, marginal and unsuitable (Table 4.1). These classifications were originally designed for the Koala Habitat Atlas of Ballarat (Jaunchowski *et al.* 2008) and were assigned to each survey site based on the proportional abundance of preferred (primary and secondary) tree species determined from the statistical analysis of the faecal pellet surveys.

The regularised grid-based (RGB) survey database allowed the creation of an almost evenly spaced point surface across the study area at 1km to 350m intervals. Using ArcMap 10, a vector point layer was created based on the survey sites recorded latitude and longitude.

Table 4.1: Koala habitat classes derived from Jaunchowski *et al.* 2008, detailing the criteria used for the delineation of ranked habitat classes based on the presence of primary and secondary usage species.

Habitat Quality Class	**Food tree rank percentage of overstorey**		
	Primary Species	**Primary and Secondary Species**	**Secondary Species**
Highly Suitable	≥ 30%	≥ 50%	or ≥ 50%
Suitable	< 30%	< 50%	< 50%
Marginal	< 15%	< 30%	< 15%
Unsuitable	Scattered Trees	Scattered Trees	Scattered Trees

4.1.2. Substrate Investigation

As the literature indicated that often tree species suitability or preference is altered by the substrate, a preliminary investigation was conducted as to whether the use of substrate would improve the prediction of habitat. Based on the soils layer “Landscapes (Mitchell) of NSW - Version 2” (Mitchell 2002), all survey points were overlaid on the layer and the underlying substrate recorded.

4.1.3. Cluster Analysis

In order to move from a point layer to a continuous raster surface, analysis of the clustering of the assigned vegetation rank was undertaken. This investigation was necessary to determine whether it was suitable to utilise an interpolation tool to create an accurately ranked vegetation map based on the four defined classes. As the survey data is spread across two different projections (GDA 94 Zone 55 and GDA 94 Zone 56), all calculations that included Euclidean distance required that the data be analysed in the separate zones.

Initially the High/Low Clustering (Getis-Ord General G) tool was utilised, followed by the Spatial Autocorrelation (Global Moran’s I) tool to examine the extent of spatial clustering. The null hypothesis for the cluster analysis for both tools was complete spatial randomness. Meaning that vegetation rank values are reflecting random spatial processes, and they are randomly distributed among the features of the dataset.

The tools were run on both zones of data, with the output generating measures of statistical significance (z-scores and p-values). These values allowed the rejection or acceptance of the null hypothesis, showing an indication of apparent similarity or dissimilarity of the vegetation distribution.

4.1.4. Interpolation of Ranked Vegetation

Interpolation was determined to be a suitable tool due to the positive results of cluster analysis, as interpolation relies on the assumption that spatially distributed objects are spatially correlated (Appendix 2). Each of the survey points contained the vegetation rank attribute, and consequently it was determined that the Inverse Distance Weighted (IDW) tool would be the most suitable interpolation method based on the influence of spatial autocorrelation on vegetation classes (Roberts *et al.* 2004).

IDW uses linear combinations of weights at known points to estimate unknown location values. The tool estimates cell values by averaging the values of sample data points in the neighbourhood of each processing cell. The closer a point is to the centre of the cell being estimated, the more influence, or weight; it has in the averaging process (ESRI, 2010).

In interpolation models Z (s_o) is the value at unknown locations and is calculated by the weighting value (λ_i) and the known values at surrounding locations Z (s_i).

$$Z(s_o) = \sum_{i=1}^{n} \lambda_i Z(s_i)$$

In the IDW equation, $d(s_i,s_o)$ is the Euclidean distance between s_i and s_o. P is a power that controls the rate of influence by surrounding points. For this study, the power was kept at the default value of 2 as this is the most commonly used for interpolation applications (Gotway *et al.* 1996).

$$\lambda_i = [d(s_i,s_o)]^p \,/ \sum_{i=1}^{n} [d(s_i,s_o)]^p$$

Using the ArcMap10 IDW tool, *n* can be set as a number of points or a variable radius. For this study a variable radius of 12 points was specified at this has been determined as the most effective by a number of studies (Zimmermann *et al.* 1999). The IDW tool was run to create a continuous raster surface was across the study region with values ranging from 1 (Highly Suitable) to 4 (Not Suitable).

Manual classification of this grid was based on cross referencing with a ranked polygon layer based on the measured plot radius using the values outline in Table 4.2. Where no plot radius was recorded, an average of all plots was used.

Table 4.2 : Manually classified values for the delineation of habitat classes.

Value	**Assigned Rank**	**Class**
1 – 1.5	1	Highly Suitable
1.5 – 2.25	2	Suitable
2.25 – 3.25	3	Marginal
3.25 – 3.9995	4	Not Suitable

As the IDW tool interpolated values for the entire point surface, the further away from a measured value, the less accurate the estimation becomes. Due to this, the IDW ranked vegetation layer was limited to a 2km radius from each measured point within the study area. Further masking was undertaken to exclude the interpolated layer from areas that were known to be cleared land. Using the South Coast-Illawarra Vegetation Integration Project (SCIVI) vegetation layer (Tozer *et al.* 2010), regions of cleared land were masked from the layer. The final process was to mask the coastline and water bodies restricting the vegetation to terrestrial areas.

4.2. Results

4.2.1. Vegetation Ranking

From literature, the tree has been seen as the individual unit of koala habitat quality. Examining the proportion of highest ranked koala usage species at each individual survey point revealed that highly suitable habitat dominated the landscape (300 sites) followed by suitable (141), marginal (113) and not suitable (38) (Figure 4.1).

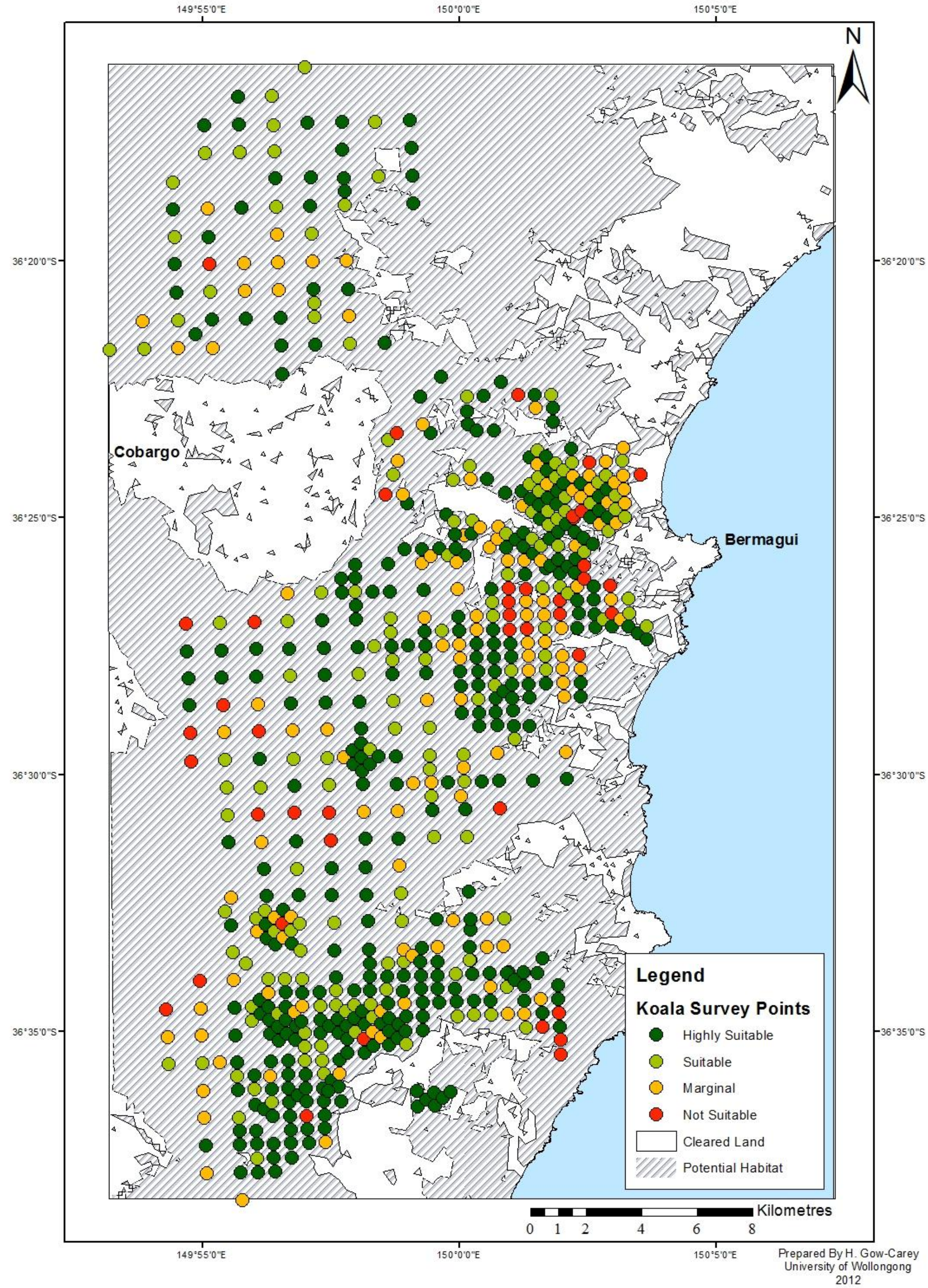

Figure 4.1: Study area showing points corresponding with the determined vegetation suitability rank

4.2.2. Substrate Analysis

An investigation of the underlying substrate across the study area revealed that 98.6% of active survey points were on 'Bega Coastal Foothills' (Figure 4.2). From this finding, it was concluded that soils would not provide additional value as an explanatory variable for the overall quality of habitat and the habitat usage choices that koalas were making. No further analysis using this soils layer was undertaken.

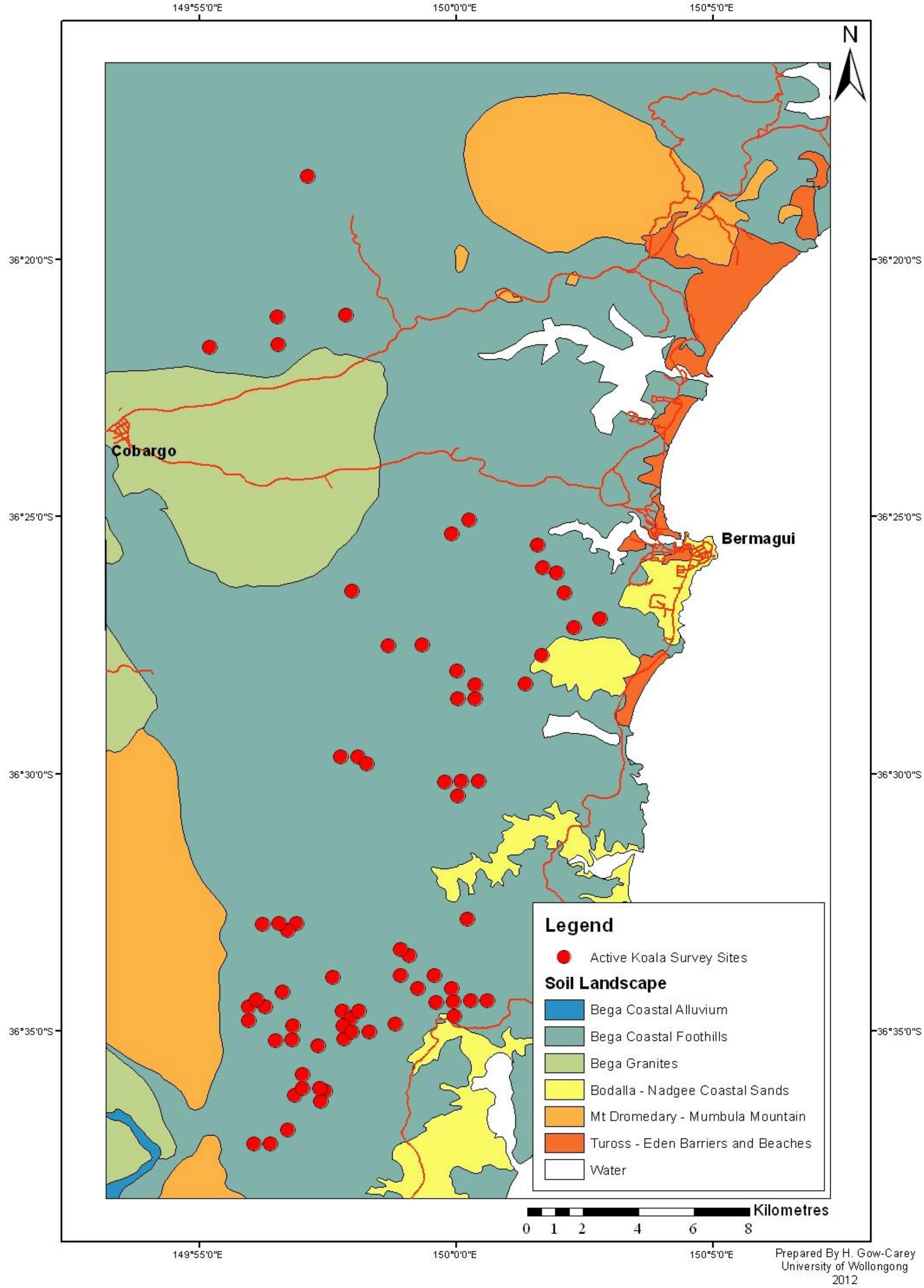

Figure 4.2: All koala survey points overlaid on the mapped substrate classes, revealing that majority of points are on consistent substrate – 'Bega Coastal Foothills'.

4.2.3. Cluster Analysis

An initial cluster analysis using high-low clustering revealed that while points in GDA 94 Zone 55 were seen to be clustered (99% Confidence, $Z = 5.49 > z_{0.01} = 2.58$), those in GDA 94 Zone 56 resulted in a random scattering result (99% Confidence, $Z = 1.39 < z_{0.01} = 2.58$). Further investigation using this tool revealed that in areas where there were clusters of high values alongside clusters of low values, it could create a null clustering result.

Hence the use of the spatial autocorrelation tool was employed on both zones to determine whether the ranked points were in fact experiencing spatial autocorrelation between all habitat rank values.

Results were as follows:

Zone 55: $Z = 6.23 > z_{0.01} = 2.58$ (99% Confidence)

Zone 56: $Z = 5.48 > z_{0.01} = 2.58$ (99% Confidence)

These z-scores failed to accept the null hypothesis and indicated that there is less than 1% likelihood that this clustered pattern could be the result of random chance.

From cluster analysis of the point surface it was found that an interpolation of ranked vegetation would be suitable across the landscape to provide a continuous ranked habitat model (Appendix 2).

4.2.4. Interpolation of Ranked Vegetation

A continuous raster surface was successfully generated by using the IDW tool within ArcGIS 10 (Figure 4.3). The layer was restricted to a 2km buffer surrounding known points along with being excluded from areas of cleared land. The final map gave an indication of the extent of adequate habitat across the region, to be used in fragmentation analysis.

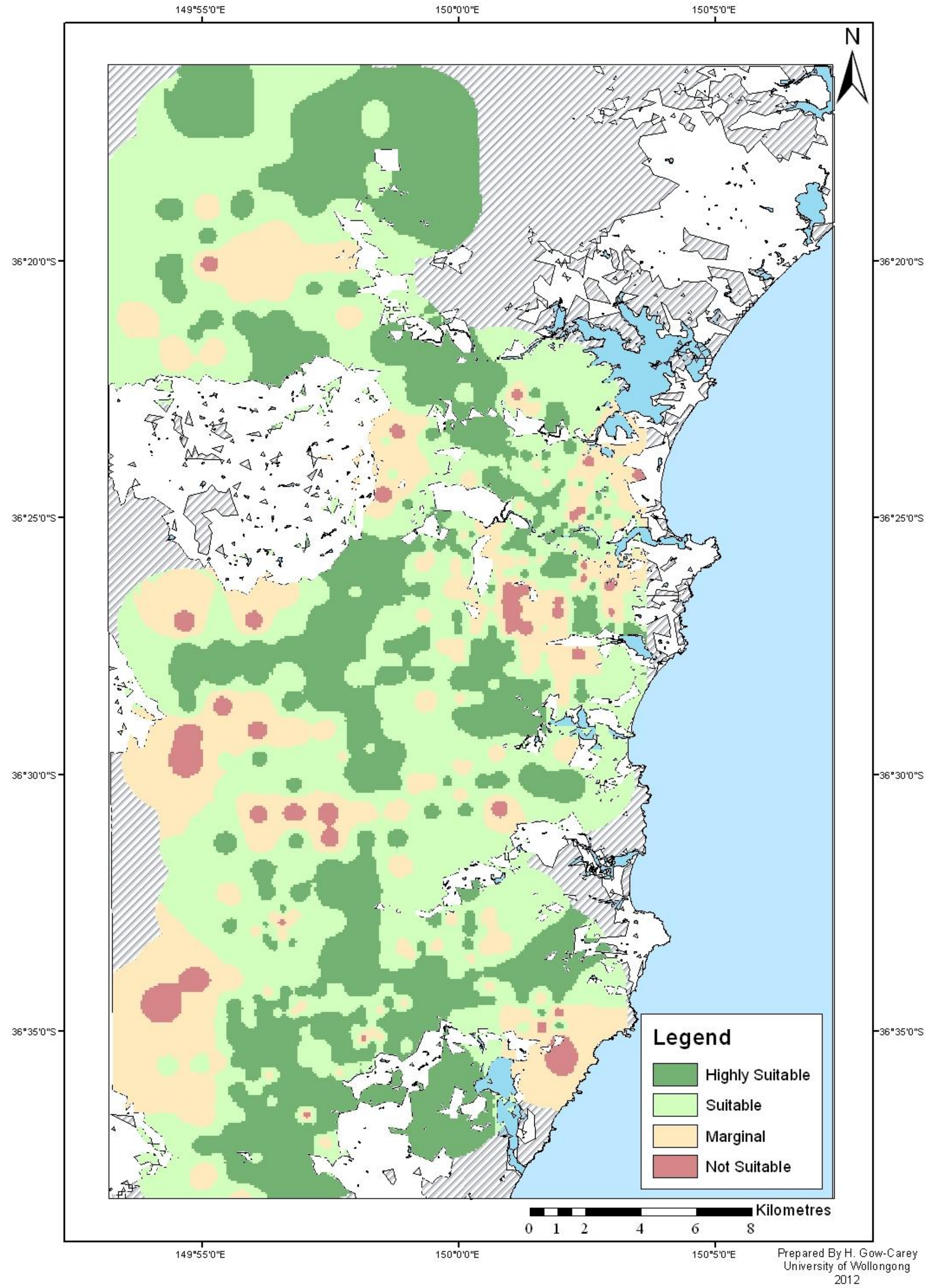

Figure 4.3: Koala habitat suitability model with 2km buffer surrounding known survey points and restricted to known areas of cleared land.

Chapter 5 Habitat Fragmentation

The primary aim of this chapter was to utilise the ranked habitat model to examine the extent and configuration of habitat patches in relation to known koala populations at a landscape and patch scale. This investigation was used to draw conclusions about the overall habitat quality based on the extent of fragmentation and other landscape metric interactions across the region.

5.1. Methods

Initially the use of FRAGSTATS (McGarigal *et al.* 2003) software was investigated for use in achieving this aim as number of other studies into koala habitat extent and configuration utilise this method (eg. Jaunchowski, 2008; McAlpine *et al.* 2006a; Rhodes *et al.* 2008). Though, due to time and data constraints, it was concluded that manual analysis using ArcMap10 would provide sufficient results to calculate many similar metrics in order to reveal habitat quality based on the guidelines by McAlpine *et al.* (2007b).

Assessing the habitat of koalas in a fragmented landscape is possible by adapting methods outlined in the ‘Planning Guidelines for Koala Conservation and Recovery’ (McAlpine *et al.* 2007b). In order to conduct conservation planning for koalas and the forest ecosystems that they inhabit, the extent of habitat patches must be examined. The effects of fragmentation due to roads, the size and shape of adequate habitat patches and the relationships between active sites and the extent of habitat within close proximity to these areas were explored to achieve the third aim of this study.

5.1.1. Road Fragmentation

The fragmentation of habitat due to the effects of roads is largely negative and the cumulative effects cover a large area. Due to the vulnerability of koalas that repeatedly come into contact with roads (Dique *et al.* 2003a), the influence of the road system in fragmenting the ranked vegetation map was included in analysis.

Forman (2000) defined buffer zones around roads where the width of the buffer varied dependent on the type of road (Table 5.1). These distances were adapted and applied to the road layer within the DTDB Topographic Layer. This was then masked from the ranked vegetation layer to further fragment the landscape. A sensitivity analysis was conducted by increasing the buffer distance by 10 % to determine whether the amount of habitat affected was influenced extensively by the road network. Furthermore, both a class and patch analysis were conducted to quantify the impact that roads have on koala habitat throughout the region.

Table 5.1: Buffer distances adapted from Forman (2000) using the stored ‘road type’ attributes from the topographic layer

Road Type	**Classification**	**Effect Distance Buffer**
Primary Road (Sealed)	Primary	335 m
Arterial Road (Sealed)	Secondary	200 m
Arterial Road (Unsealed/Two or More Lanes)	Secondary	200 m
Sub-Arterial (Sealed)	Tertiary	100 m
Sub-Arterial (Unsealed/Two or More Lanes)	Tertiary	100 m
Local Road (Sealed)	Tertiary	100 m
Local Road (Unsealed/Two or More Lanes	Tertiary	100 m

5.1.2. Landscape Analysis

The preliminary step to fragmentation analysis involved defining the landscape and the landscape boundaries that are utilised by koalas. As the ranked vegetation layer was restricted to boundaries of cleared land and also within a 2km boundary to known values, the spatial extent of the area had been defined (Section 2.3). The interactions that koalas have with the urban and natural matrix assist in the definition of the landscape, with McAlpine *et al.* (2007b) describing the conceptual models related to koala ecology (Figure 2).

In order to examine the extent of suitable habitat across the landscape to determine whether there is sufficient habitat to sustain a viable koala population, an analysis of the proportion of the ranked vegetation classes, including areas of cleared land and potential habitat was undertaken. To determine the extent of habitat across the study area, the proportion of each habitat class was calculated. The form of landscape represented by the study area was examined and determined based on Table 5.2.

Table 5.2: Landscape classifications as adapted from McAlpine *et al.* (2007b).

Landscape Type	**Proportion of Native Forest**	**Description of landscape components**
Intact landscape	>90%	Low proportion (<10%) of urban and rural land use, but provide almost continuous native forest habitat for koalas. Threats from road traffic and dog attacks are generally low.
Variegated landscape	60-90%	May have an expanding human land use and road network perforating and subdividing the original forests. Koalas face increasing pressures from habitat loss, fragmentation, vehicle collisions and dog attacks.
Fragmented landscape	10-60%	In urban and semi-urban landscapes, road densities and traffic volumes are high as the human population increases. The remaining koalas are forced to live in small remnants surrounded by urban and rural land use and roads. Movement of individuals is more hazardous, especially in urban areas, although koalas may move more easily through rural areas if scattered trees are present.
Relictual landscape	<10%	They have a high density of roads and high traffic volumes. The likelihood of koalas surviving in these landscapes is low, especially if urban land use dominates.

5.1.3. Patch Metric Analysis

As identified from literature, the size and shape of habitat patches are a key determinant of habitat quality and are indicative of the future viability of a koala population. Within this thesis, a number of patch metrics have been calculated based on those outlined by McGarigal *et al.* (2002) using ArcMap 10 and Microsoft Excel analysis tools.

Patch metrics investigated:

- Mean Patch Size
- Patch Size Variability
- Patch Density
- Patch Size Standard Deviation

5.1.4 Detailed Habitat Guideline Analysis

From this point onwards, 'adequate' habitat refers to a combination of both suitable and highly suitable habitat vegetation that has been reclassified into a single layer. The guidelines hereby outlined are adapted from McAlpine *et al.* (2007b) in order to assess the current extent and configuration of adequate habitat.

Guideline 1.1: Maintain at least 40-50% of the landscape as adequate habitat across landscape extents 1 km radius around where koalas occur.

To determine this proportion, 1km buffers were constructed surrounding active sites and the 'clip' tool to select the vegetation classes that intersect with the buffered area. The quantity of adequate vegetation was then calculated.

Guideline 2.1: Adequate habitat patches should be larger than 50-100 ha in size.

As the size of a patch has been seen to be a limiting factor as to the presence of koalas, all patches of adequate habitat > 50ha were identified and mapped, removing all patches that did not meet this criteria. The location of active sites were also analysed in relation to these larger patches to determine the viability of the population, assessing the extent of adequate habitat patches greater than 50ha that intersect with a 1km buffer surrounding active sites.

Guideline 3.1: Koala habitat patches should be more circular than liner in shape so as to minimise edge effects.

To maintain a landscape of koala habitat that minimises the influence of edge effects, the shape of adequate habitat patches must be considered. Patches that are more circular in shape minimise these effects and can be determined from the perimeter-area ratio. This was calculated within ArcMap 10 by assessing amount of edge in relation to the relative area of each patch.

5.2. Results

5.2.1. Road Fragmentation

Using the variable buffer distances outline by Forman (2000), the area affected by roads buffered and masked from the ranked vegetation layer creating a further fragmented landscape.

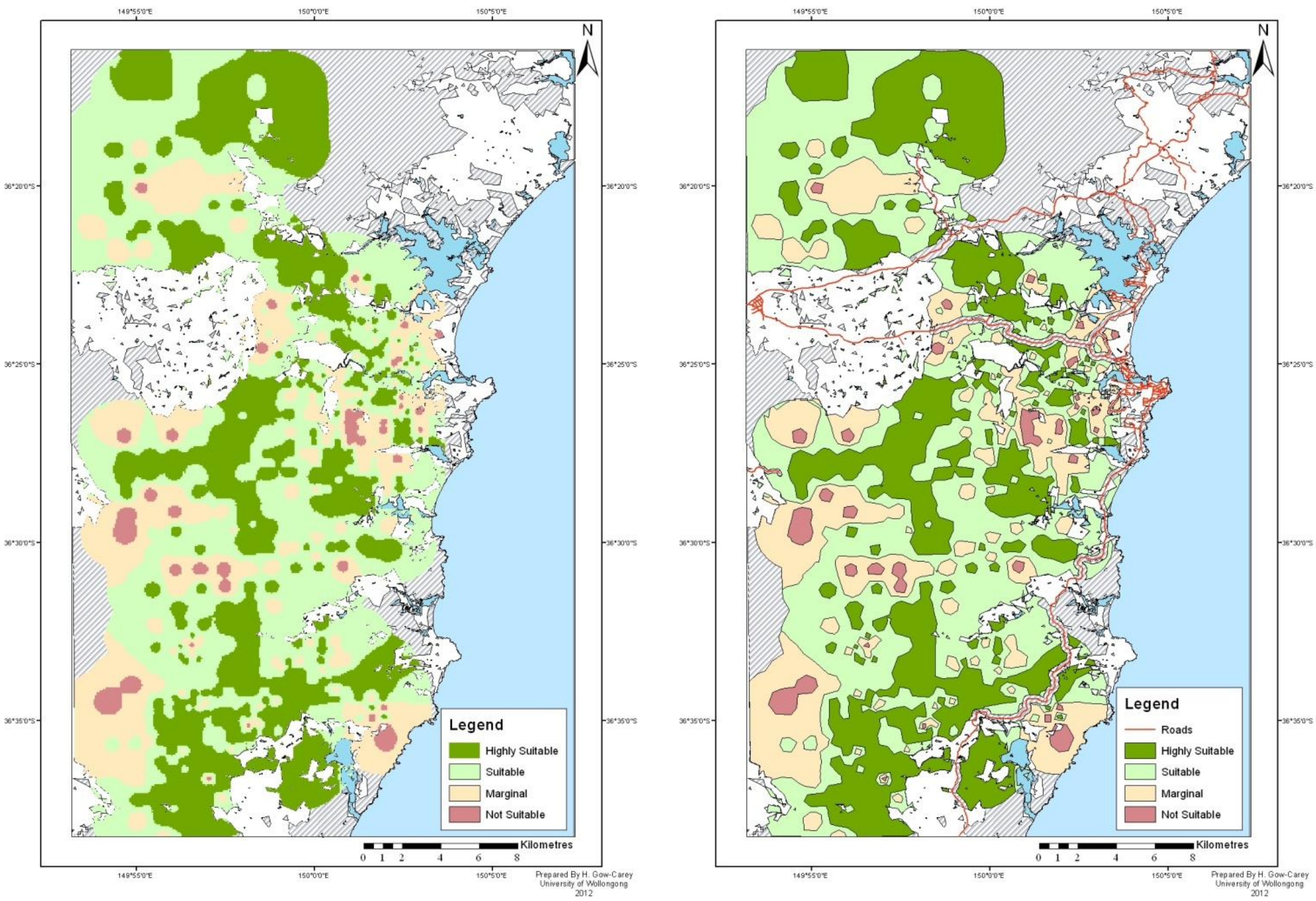

Figure 5.1: The two habitat layers that were utilised to investigate the affect that roads have on koala habitat throughout the study area.

Sensitivity Analysis

A sensitivity analysis (Table 5.3) revealed that although a 10% increase in buffer size resulted in an obvious increase in habitat that was affected, the value was not significant for any of the individual classes (<10%). Across the entire study area, a 10% buffer increase resulted in a 9.96% increase in the extent of koala habitat (highly suitable, suitable and marginal) being affected. From this value, it can be concluded that roads are a cause of fragmentation throughout the study area but koala habitat is not particularly sensitive to increases in disturbance from existing roads.

Table 5.3: Sensitivity analysis with a 10% increase in the buffer values used to determine area affected by roads.

	Standard buffer values		**10% buffer increase**		
Class	**Area affected by roads (m^2)**	**No. of Patches**	**Area affected by roads (m^2)**	**No. of Patches**	**Increase in habitat affected (%)**
Highly Suitable	3484432	23	3847297	24	9.43
Suitable	6035835	26	6661878	28	9.40
Marginal	2487837	11	2695277	12	7.70
Not Suitable	-	-	-	-	-

Area affected by roads – Class Analysis

Across the study area it was found that there was 9536534 m^2 (953ha) of adequate (suitable and highly suitable) koala habitat affected by roads, and consequently removed from further habitat analysis. Of this amount, 2.43% was highly suitable, 3.26% was suitable and 2.77% was determined to be marginal (Table 5.4). The 'not suitable' vegetation layer was not located in close proximity to roads and was consequently not affected.

Table 5.4: Area before and after the removal of habitat due to being within buffer zones surrounding roads, including the percentage lost.

Class	**Area before (m^2)**	**Area lost due to roads (m^2)**	**Area lost due to roads (%)**
Highly Suitable	143500528	3490517	2.43
Suitable	185426677	6046017	3.26
Marginal	90054482	2494009	2.77
Not Suitable	10246845	0	0.00

Area affected by roads – Patch Analysis

The effect of road fragmentation was also analysed in terms of the number of patches and the mean patch size of each suitability class (Table 5.5). It was found that while the total area of habitat decreased for highly suitable (-3490517 m^2), suitable (-6046017 m^2) and marginal habitat (-2494009 m^2), the mean patch size for both highly suitable and suitable habitat actually increased. This was due to the number of patches decreasing by 6 and 8 patches respectively.

Table 5.5: The effect of fragmentation of koala habitat due to roads including the total area lost and the effect that roads have on the number of patches, and consequently the mean patch size.

	Before fragmentation due to roads			**After fragmentation due to roads**		
Class	**Area (m^2)**	**No. of Patches**	**Mean Patch Size (m^2)**	**Total Area (m^2)**	**No. of Patches**	**Mean Patch Size (m^2)**
Highly Suitable	143500528	107	1341126	140010011	101	1386238
Suitable	185426677	159	1166205	179380660	151	1187951
Marginal	90054482	92	978853	87560473	91	962203
Not Suitable	10246845	31	330543	10246845	31	330543

5.2.2. Landscape Analysis

Proportion of habitat across landscape

For this landscape type analysis, only terrestrial landscapes (Figure 5.2) were included with the area of each classified patch calculated in square metres. At the landscape level, it was found that suitable habitat made up the largest proportion of the terrestrial environment, covering 17938 ha (26.89%). Cleared land made up 21.23% (14161 ha), while there was 16.23% of the landscape classed as potential habitat (10824 ha) as it consists of native vegetation that is simply outside the extent of current koala surveys.

Table 5.6: Landscape analysis detailing the proportion of habitat classes and other land-use activities of the terrestrial landscape. The study area represents a variegated landscape.

Class	**Total Area (m^2)**	**Total Area (ha)**	**Proportion of Terrestrial Landscape (%)**
Highly Suitable	140010011	14001	20.99
Suitable	179380660	17938	26.89
Marginal	87560473	8756	13.13
Not Suitable	10246845	1024	1.54
Potential Habitat	108245222	10824	16.23
Cleared Land	141614162	14161	21.23

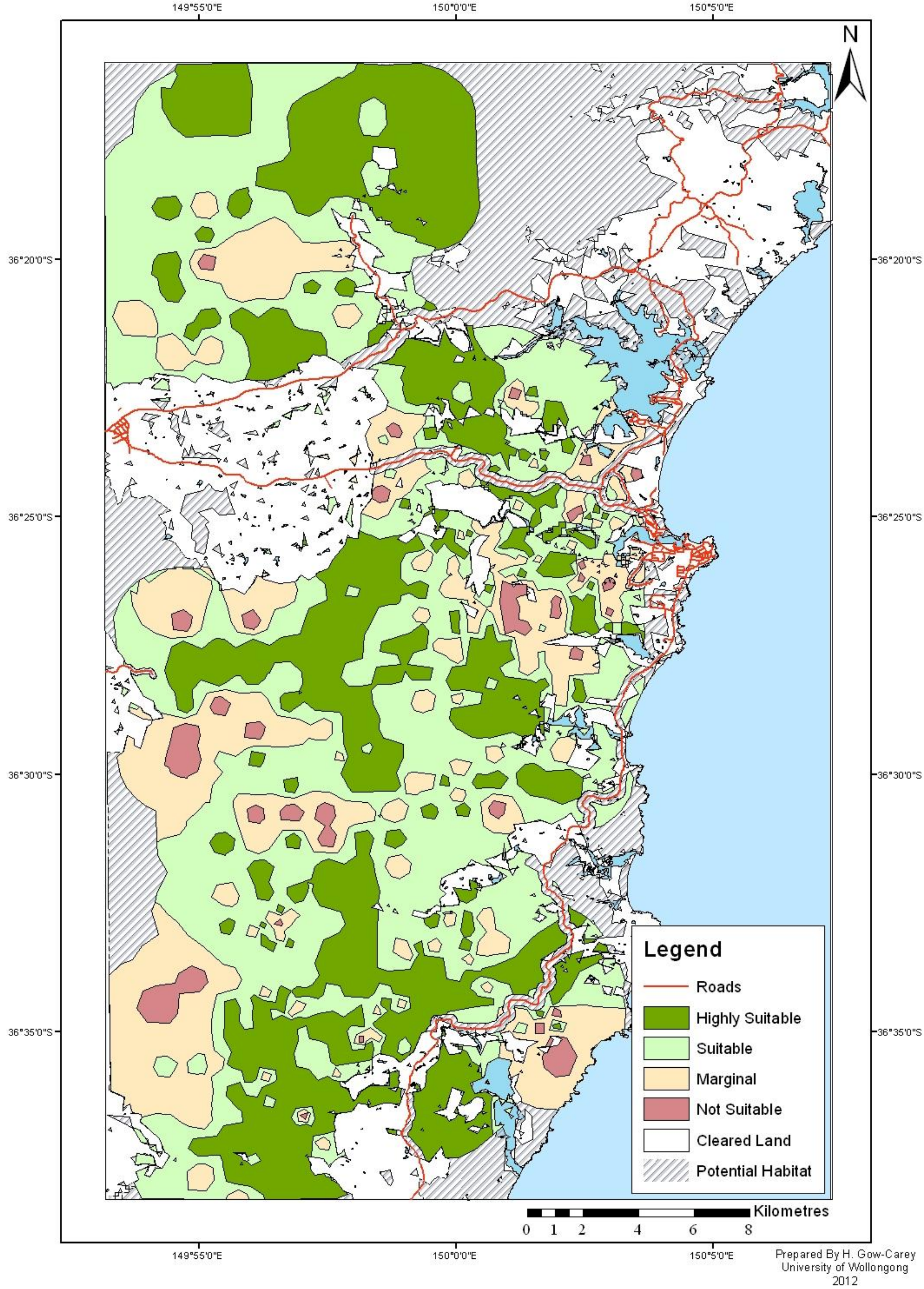

Figure 5.2: Final fragmented habitat suitability model used to conduct fragmentation analysis.

Proportion of each habitat class

At a landscape level it was found that ‘suitable’ habitat covered the largest area (17938 ha) which represented 43.0% of the mapped habitat classes. Highly suitable habitat was the next largest (14001 ha) making up 33.6% of all mapped suitability classes. Together these two classes of most adequate habitat cover a region of 31939 ha (76.6%).

Table 5.7: Class analysis revealing proportions of each mapped habitat class across the landscape.

Class	**Percentage of Habitat**	**Total Area (m^2)**	**Total Area (ha)**
Highly Suitable	33.6 %	140010011	14001
Suitable	43.0 %	179380660	17938
Marginal	21.0 %	87560473	8756
Not Suitable	2.4%	10246845	1024

5.2.3. Patch Metric Analysis

Mean Patch Size

Mean patch size was calculated as the total area of each class divided by the total number of patches that the class is comprised. Highly suitable habitat had the largest mean patch size of 138.6 ha which was followed by suitable habitat with 118.7 ha. The mean patch sizes of marginal (96.2 ha) and not suitable habitat (33.0 ha) were much lower.

Table 5.8: Mean patch size of vegetation classes within the landscape mosaic.

Class	**Total Area (ha)**	**No. of Patches**	**Mean Patch Size (ha)**
Highly Suitable	14001	101	138.6
Suitable	17938	151	118.8
Marginal	8756	91	96.2
Not Suitable	1024	31	33.0

Patch Size Variability and Standard Deviation

The greatest extent of patch size variability was the suitable habitat class, as indicated by the standard deviation of 8609656 m^2. Suitable habitat also had the largest individual patch size of 94447774 m^2 while the smallest patch size was that of highly suitable (76 m^2). The largest overall variability was within both highly suitable and suitable habitat.

Table 5.9: Patch size variability, outlining the smallest and largest patches for each suitability category.

Class	**Smallest Patch Area (m^2)**	**Largest Patch Area (m^2)**	**Mean (m^2)**	**Std Deviation (m^2)**
Highly Suitable	76	27340933	1386238	4617546
Suitable	547	94447774	1187951	8609656
Marginal	434	16897609	962203	2574403
Not Suitable	27271	2069864	330543	473368

Patch Density

Habitat patch density calculated as being the number of patches for each class divided by the total mapped landscape area (417 km^2). Suitable habitat resulted in the highest patch density (0.36) indicating that although there are a large number of patches across the landscape, they are most likely smaller than those of the highly suitable classification. Highly suitable (0.24) and marginal (0.23) were very similar with the lowest patch density being not suitable (0.07), this can give an indication that the range of patch variation is likely lower while having a generally smaller total area across the study landscape.

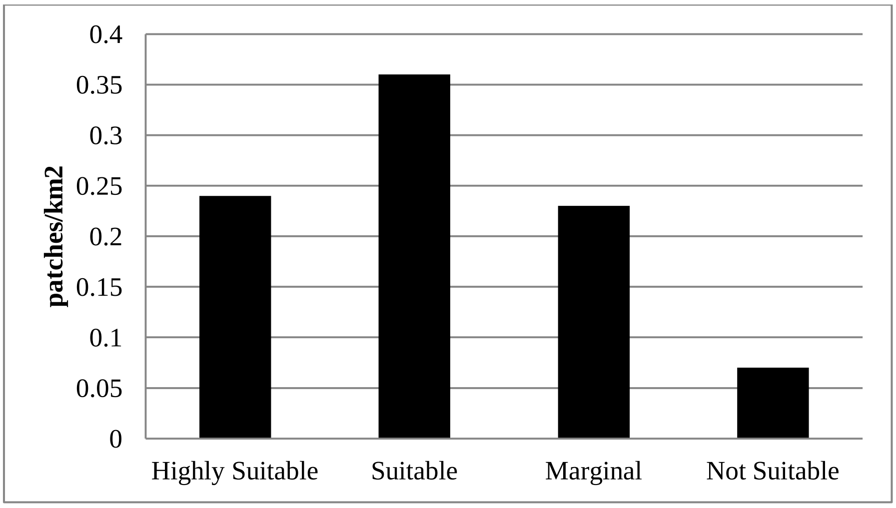

Figure 5.3: Patch density for all modelled vegetation suitability classes.

5.2.4. Guideline Habitat Analysis

Guideline 1.1: Proportion of habitat within 1km of active sites

An analysis of the vegetation within a 1km radius surrounding active sites was conducted in order to reveal whether the landscape contains a sufficient amount of landscape to sustain a viable koala population (Figure 5.4).

In order to determine the extent of adequate habitat, a 1km buffer was constructed surrounding all active sites (*n* = 72) and the area of ranked vegetation contained within these regions was analysed (Table 5.10). Within the 1km buffers across all sites, there was 80.45% adequate habitat, made up of 43.69% highly suitable and 36.76% suitable vegetation.

Table 5.10: Analysis of the extent and configuration of adequate habitat within 1km of active sites.

Class	**Area within 1km radius (ha)**	**Area within 1km radius (%)**
Cleared Land or Potential Habitat	886.65	8.07
Highly Suitable	4799.72	43.69
Suitable	4038.57	36.76
Marginal	1194.71	10.88
Not Suitable	65.68	0.60

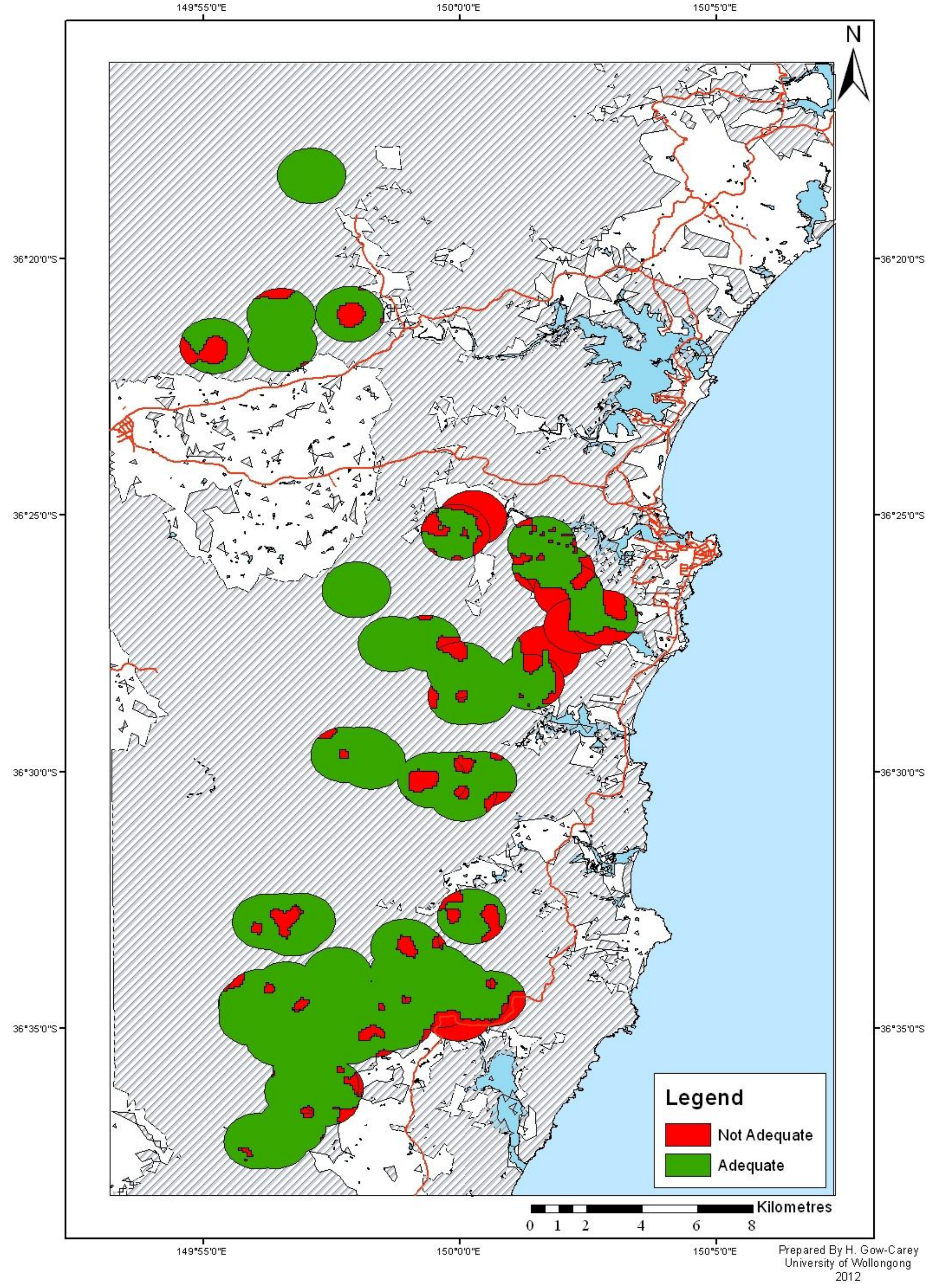

Figure 5.4: Quantifying the extent of adequate habitat within 1km of active sites in order to assess overall habitat quality.

Guideline 2.1: Patches of Habitat > 50 ha

The average patch size for all adequate patches greater than 50ha (combining highly suitable and suitable classes) was 1478251 m^2 (1478 ha) with a standard deviation of 9220485 m^2 (9220 ha). In total there were 128 patches of adequate habitat though only 9 patches satisfied the minimum criteria of 50 ha or greater.

When these patches were analysed in relation to active sites to determine whether there was enough adequate habitat in large patches near koala populations, it was found that all sites that were in suitable or highly suitable areas were also located within patches >50 ha. In total there were 9 out of the 72 active sites (12.5%) that were not located in adequate habitat, but all of these were within 1km of a large adequate patch indicating the overall habitat quality in close proximity to active sites (Figure 5.5).

Furthermore, the patches > 50ha that intersected with the 1km buffers were identified (Figure 5.6) as McAlpine *et al.* (2007b) recognises these as areas for priority of conservation.

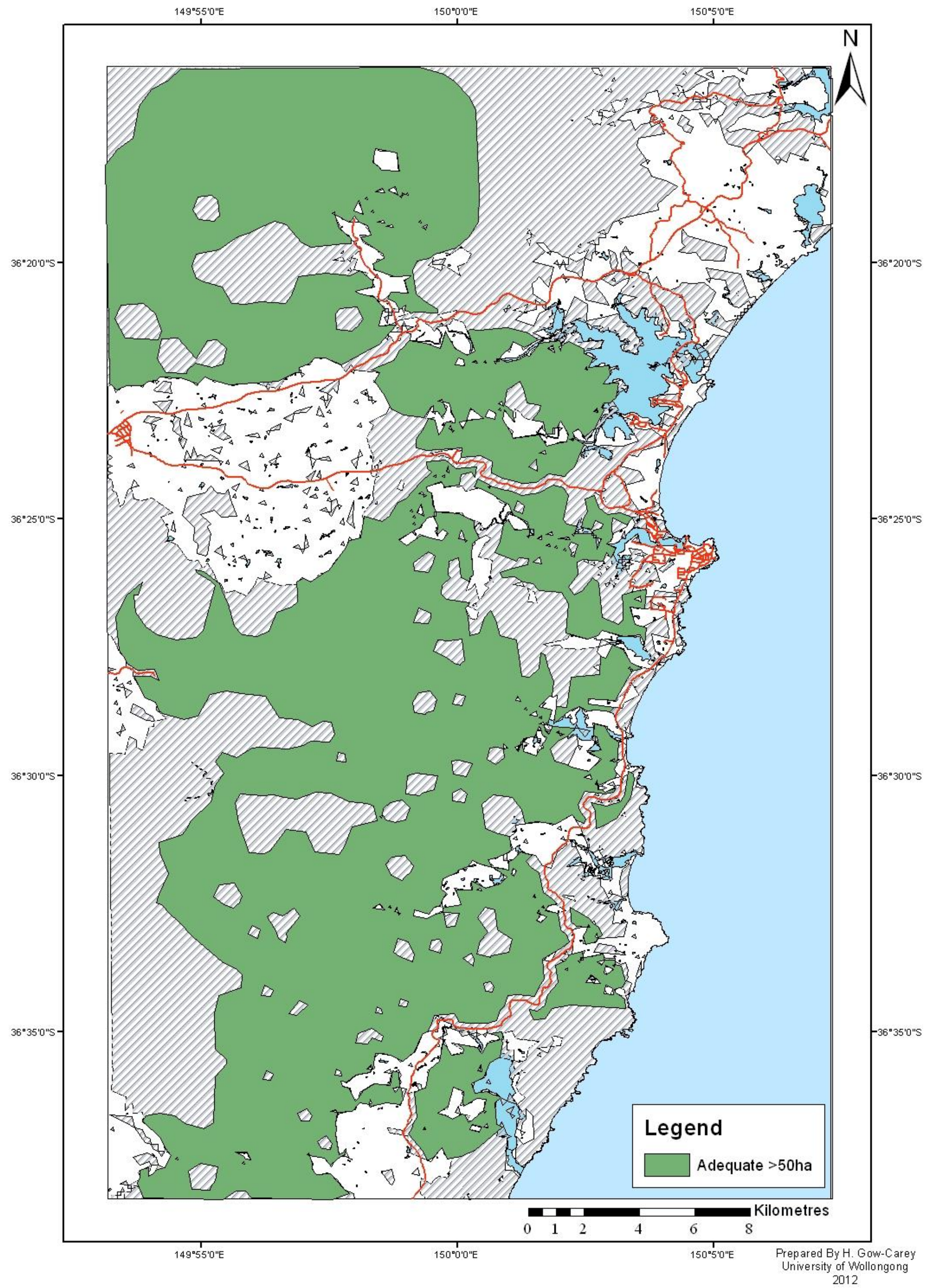

Figure 5.5: Extent of adequate habitat patches greater than 50 ha in area which are above the critical value for koala habitat.

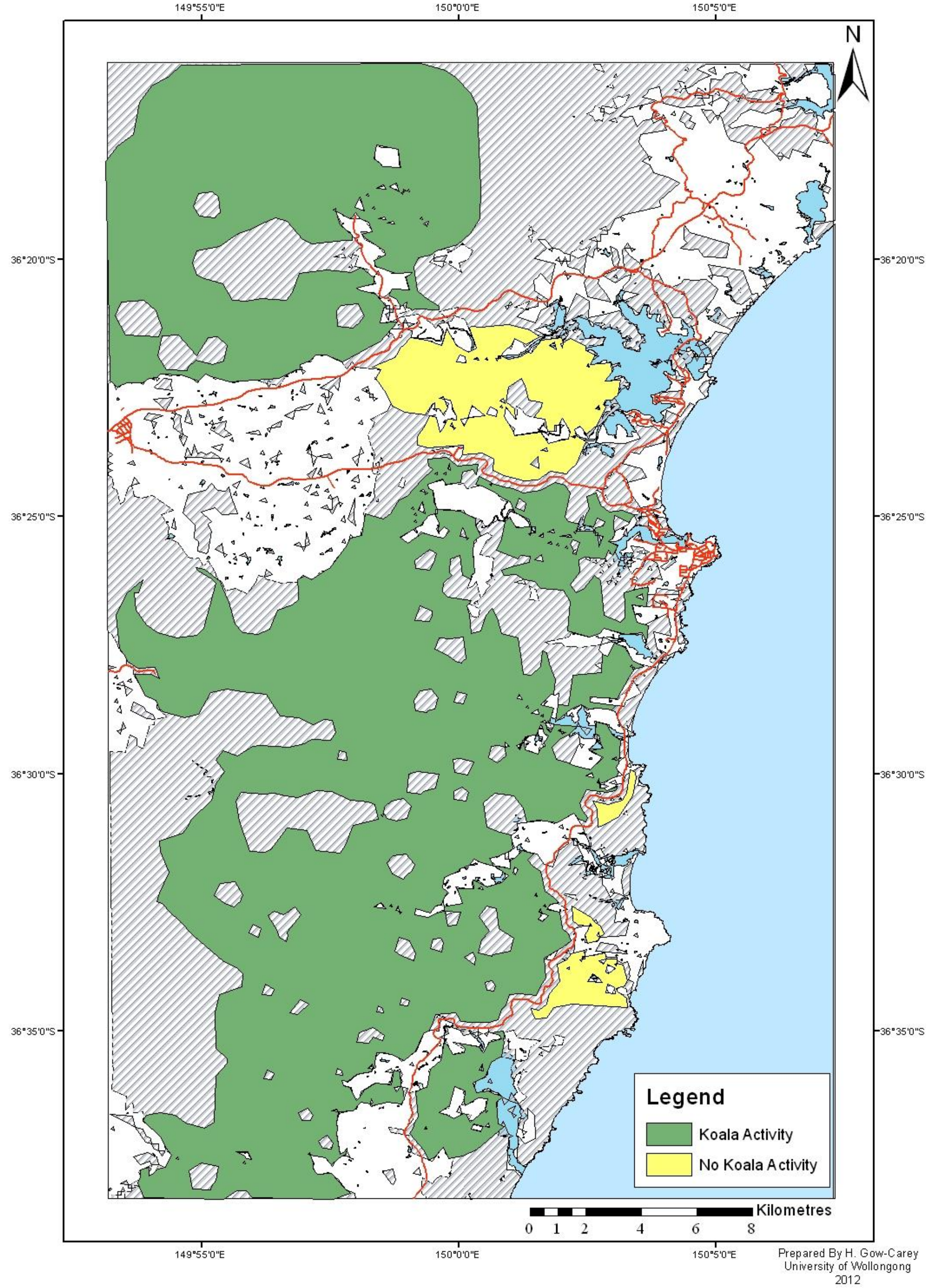

Figure 5.6: Habitat patches greater than 50 ha that intersect with the 1km buffer around active sites, as these should be a priority for conservation.

Guideline 3.1: Patch Shape

When the perimeter:area ratio was calculated for all patches it was found that there was a distinct relationship between patch size and the resulting ratio. Patches with a smaller area were more likely to have a larger ratio (Figure 5.7). This suggests that many of the smallest patches are linear in shape while the larger patches, especially those > 50ha are more circular, hence minimising edge effects.

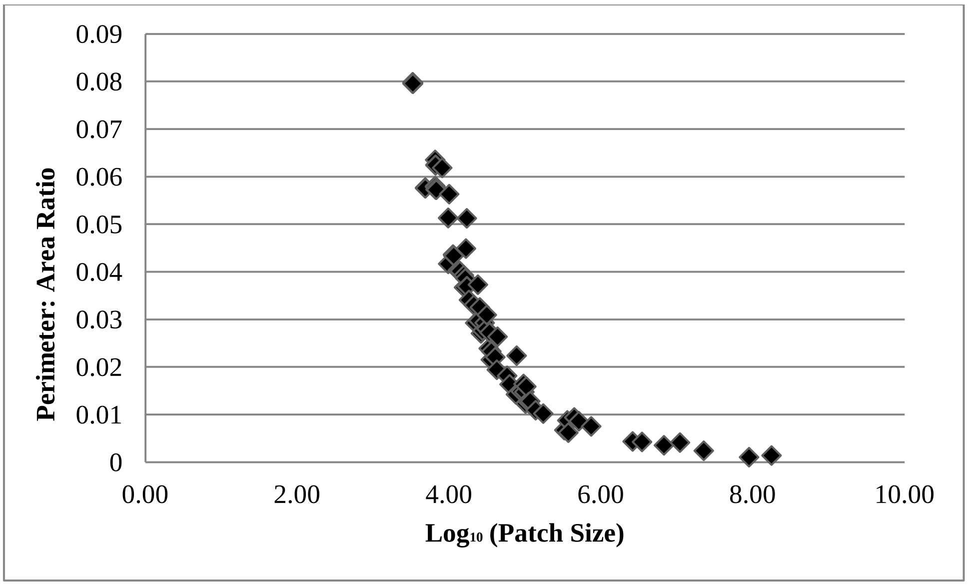

Figure 5.7: Perimeter: Area ratio of all adequate patches across the study area, detailing that larger patches have a smaller ratio and hence are indicative of the overall habitat quality.

Chapter 6 Discussion

The koalas of South East NSW are at critical numbers, with this study investigating and assessing the overall habitat quality to provide information for agencies to make informed decisions regarding the conservation of current habitat. Since koalas have such specialised habitat requirements, it is vital to have an understanding of the overall habitat quality before plans of management can be developed. This study is the first in this region to identify tree species preferences and apply these spatially, while further examining habitat quality through fragmentation analysis.

While the results of this study have a number of practical outcomes at a local scale, the findings also contribute to the wider context of koala conservation and emphasise the need for a localised approach to assessing habitat quality for conservation decision making. Through the course of this project, a number of factors supporting this finding have become apparent, stressing that local investigations are vital for assessing the habitat of all forest dwelling mammals, not only koalas.

6.1. Tree Species Preferences

Through the statistical analysis of strike rates and the proportional usage versus availability for the most utilised tree species, a ranking was created that is representative of the habitat choices that koalas are making throughout the study region. The results of this first aim have a number of implications for the protection and enhancement of areas of prime habitat at a local scale along with habitat utilisation studies in a wider context.

Habitat utilisation and tree species selection for koalas has been an area of extensive study throughout many regions of Australia (eg. Hindell & Lee 1987; Ellis *et al.* 1999; Phillips 2000b; Phillips & Callaghan 2000; Callaghan *et al.* 2011). In the context of conserving forest habitat, these studies play an important role in defining habitat for protection and management (Lunney *et al.* 2000a; Melzer & Houston 2001; Rhodes *et al.* 2006). With the presence or absence of key koala usage species still being the defining unit of habitat quality, these studies have highlighted the importance for localised classification of tree species which has been further supported by the results of this investigation.

Initially, methods for this study involved applying tree usage classifications as outlined in the 'Recovery Plan for the Koala (*Phascolarctos cinereus*)' (DECC 2008), though preliminary investigations into this classification revealed that many of the species outlined were not being utilised by koalas nor occur extensively in the study area (further discussed in Section 6.1.3).

This section addresses the need for delineating local tree species preferences for the South Coast koala population while adapting a methodology for future local plans of management. The results provide an insight into the choices that koalas are making regarding selection of habitat for both feed and shelter along with highlighting the necessity for reassessment of previous tree species classifications referring to this region.

6.1.1. Limitations of Faecal Pellet Survey Techniques

The use of faecal pellets to determine the range, population density and tree species usage have been employed by a number of studies (Hasegawa 1995; Jurskis and Potter 1997; Lunney *et al.* 1998; Phillips *et al.* 2000; Phillips & Callaghan 2000; Callaghan *et al.* 2011) and methods have recently been formally assessed as a method of koala data collection (Phillips & Callaghan 2011).

The RGB-SAT methodology has been proven to provide a sufficient and non-biased data collection technique for low-density koala populations where other methods such as radio collar tagging or direct counts of koalas in trees is logistically difficult. Although this methodology provides an insight into the trees being utilised by koalas, it is important restate that this could be very different to the dietary preferences of the species. Faecal pellet cuticle analysis is necessary to determine exact dietary preferences of koalas within a localised area with a number of studies developing methods to more accurately determine koala feed species (eg. Hasegawa 1995; Ellis *et al.* 1999).

The rate of faecal pellet decay is another factor that limits this methodology with weather conditions, leaf litter type, bushfire, regional variability and bioactivity all influencing the time of which a pellet is detectable (Rhodes *et al.* 2011a). There are also a number of factors such as observer skill, ground vegetation cover, leaf litter, pellet numbers and pellet scatter that limits the ease of detection. Though, as the study is based on presence/absence data rather than actual pellet counts, these are seen as minor limitations.

6.1.2. Tree Species Preferences

Based on the 176 utilised trees across the 72 active survey sites within the study area, a clear representation of the relative usage and preference of tree species was achieved. While the study does not give an understanding of which trees are actually being consumed by koalas, the insight into habitat utilisation across the area from a conservation and management perspective is extremely valuable to future decision-making. The trees indicating evidence of koalas were not only those fulfilling the koalas' dietary requirements, but extend into those used for shelter. This is highlighted by a number of trees of the auxiliary data set comprised by non-eucalypt species (eg. *Acacia falciformis* and *Allocasurina littoralis*).

The link between tree species usage and dietary intake has been highlighted by Hasegawa (1995) which found that the primary species made up >80% of the diet from cuticle analysis over a 12 month period. Consequently, from a management standpoint it can be argued that the highest ranked species are those that make up bulk of the diet, hence there is little need to further differentiate the relative dietary preference of the available tree resources.

While the strike rates revealed which species were used the most in proportion to the number of trees of that same species searched across all active sites; the use versus availability analysis demonstrated a number of interesting relationships between the choices that koalas were making and which species were being actively selected. Many previous studies have investigated the use of either method to determine the importance of an individual tree species (eg. Johnson 1980; Hindell & Lee 1987; Phillips *et al.* 2000; Phillips & Callaghan 2000), though few studies have endeavoured to combine both methods to generate a list of tree species preferred by koalas within a localised region.

The results from the analysis of tree utilisation suggest that throughout the South Coast study site, habitat use is focused on one main Eucalypt species: Woollybutt (*E. longifolia*). It had been utilised across 47.2% of active sites (n = 34) and was shown to be subject of a significantly higher strike rate than a number of the lower ranked usage species. Further support for this species was demonstrated through the substantially higher result in the use versus. availability analysis (+0.1511), suggesting that it is both a highly preferred species and selectively utilised by koalas.

Throughout the study area, two further eucalypt species were identified as having both a high strike rate and use versus overall availability and hence were classified as primary species (*E. cypellocarpa* and *E. tricarpa*). Both of these species were seen to be selectively used by koalas even though they had a lower overall use and availability ranking. This infers that although the distribution density of these species is limited, they are being actively selected by koalas and hence are key species in this region. Three secondary eucalypt species (*E. bosistoana, E. globoidea* and *E. muelleriana*) were also identified as having substantial usage value to koalas.

Although this methodology ranked primary, secondary and supplementary tree species, it is important not to disregard the value of species in the auxiliary dataset. From the results of the koala survey it is obvious that all active trees are important to koalas for either feed or shelter. While a number of species are seen as vital to defining the habitat quality of the area, further research into the interaction of koalas with supplementary species and those in the auxiliary dataset would reveal important relationships to enhance our knowledge regarding tree species preferences.

6.1.3. Regional Tree Species Classifications

There are a number of classifications that refer to the south coast koala populations but the most comprehensive is that developed for the 'Recovery Plan for the Koala (*Phascolarctos cinereus*)' (DECC 2008). This tree species list (Appendix 1) is based on the delineation of primary, secondary and supplementary species outlined by Phillips (2000b). As the methodology for this research is based on the exact same criteria, it creates a very comparable platform.

The list of koala usage trees refers to Koala Management Area 3: South Coast which extends from Nowra to the Victorian border (Appendix 1). As it covers such a large area it can be argued that it has overlooked localised tree species preferences as the classifications are substantially different (Table 6.1).

The three primary species according to DECC (2008) are *E. amplifolia, E. tereticornis* and *E. viminalis,* all three of these species were not found in the OEH koala surveys due to natural distribution and historical land use patterns. It is widely known that both *E. tereticornis* and *E. viminalis* grow on fertile soils, largely along river flats which are also areas of prime agricultural land (Costermans 2010). Since the 1830's, the clearing of the rich granite soils throughout the study area and the logging of *E. tereticornis* for sawlogs resulted in a distinct loss of these species (Lunney & Leary 1988). It can be argued that as these 'primary' species are not present throughout the study area, that this remaining habitat is only marginal for the inhabitation of koalas. Although this may well be the case, there can be two strong arguments made for the composition of tree species across the area.

Table 6.1: Comparison of the classification for trees of this study with those outlined in the Recovery Plan for the Koala (DECC 2008).

Species	**Results**	**Koala Management Area 3 Classification**
E. longifolia	Primary	Secondary
E. cypellocarpa	Primary	Secondary
E. tricarpa	Primary	-
E. bosistoana	Secondary	Secondary
E. globoidea	Secondary	Supplementary
E. muelleriana	Secondary	Supplementary

It can be hypothesised that there may be unique adaptations that koalas in this region have made to exist as a stable low-density population. It has been thought that this endemic population may have a unique ability to forage an existence in this 'marginal' country by having unique genes and an inherited knowledge of country and place (Carey, M. pers. comm. Sept 2012). This can be supported by both *E. longifolia* and *E. cypellocarpa* being ranked as secondary (DECC 2008) but the results of this study ranked them as primary species. This suggests that where 'primary' species are not present, low-density koala populations can still be supported by an abundance of 'secondary' and 'supplementary' species.

Alternatively, based on an analysis of leaf nutrient and toxicity, the preferred tree species on the South Coast study area may be more than suitable to sustain the population. An investigation into the role of nutrients and toxicity on the food choices by koalas on the

South Coast was conducted by Stalenberg (Honours thesis, 2010). Findings of this study showed that koalas were more likely to use trees which contained higher concentrations of available nutrients and lower toxins when compared to neighbouring trees of the same species. Furthermore, that the nutrient levels of those species listed as ‘primary’ according to DECC (2008), were quite similar to those of the most utilised across Stalenberg’s study area (*E. longifolia* and *E. globoidea*). This has particular implications for the delineation of overall ‘habitat quality’ across this region.

The study area has long been thought to be of low to moderate habitat quality due to the poor soils and absence of ‘primary’ feed trees, implying habitat is only suitable for supporting a low-density koala population (Braithwaite 1983; Lunney and Leary 1988; Phillips 2000b). However, considering the results of Stalenberg (2010) in light of the findings of this thesis reveals that habitat quality across the region may well be equal with other areas supporting higher density koala populations. This suggests that there may be other historical land use patterns that have limited the distribution of koalas.

6.1.4. Species Distribution and Previous Studies

Tree species distribution is a key determinant of habitat quality. As the primary focus of tree species preferences across the study area, *Eucalyptus longifolia* is distributed throughout near-coastal open forests from Newcastle to the Victorian border growing on moist, heavier soils in valleys and low country (Costermans 2010). The importance of *E. longifolia* as a koala browse species is recognised by its inclusion on the listing by DECC (2008) and further supported by a limited number of local studies. A pilot study in the southern region of Mumbulla State Forest using similar methodology revealed *E. longifolia* as the most preferred species with *E. cypellocarpa* and *E. sieberi* also meeting inclusion criteria for analysis (Biolink 2008). The strike rates calculated were largely consistent with those of this study and support the importance of *E. longifolia* as the primary usage species.

The importance of *E. longifolia* is furthered by the findings of Jurskis and Potter (1997) who examined tree species preferences using radio tagging in the Eden State Forest. While *E. longifolia* was ranked second in the coastal hills and valleys, the primary ranked species was Yertchuk (*E. consideniana*). It is important to note that this species was the highest ranked of the auxiliary dataset ($P_i = 0.2$), indicating that it may be used selectively by koalas but the true value is unknown as *E. consideniana* is not prolific within the study area as it is common on poorer grey sedimentary soils especially near coastal lowlands (Costermans 2010).

Eucalyptus cypellocarpa, (Monkey Gum or Mountain Grey Gum), is widely distributed across eastern Victoria and South Eastern NSW (Costermans 2010). While it has not traditionally been known as a feed species across NSW (Reed *et al.* 1990), there was evidence of *E. goniocalyx* (now *E. cypellocarpa)* species being used as a primary feed species in Victoria (Warneke 1978). Jurskis and Potter (1997) confirmed suggestions that *E. cypellocarpa* was a primary feed species throughout Far South Coast NSW. The findings of this study support these conclusions as to the overall usage value of *E. cypellocarpa* as a primary usage species.

While confirmation of *E. cypellocarpa* as a primary species was not unexpected given the support of previous studies, the relative importance of *E. tricarpa* as a primary feed species was unexpected. *E. tricarpa* has a very scattered distribution across Mid-Eastern Victoria and South East NSW largely across undulating sedimentary terrain (Costermans 2010). There has been little support for this species being utilised by koalas with only Santamaria (Honours thesis, 2002) mentioning that it had been used to a limited extent in forests surrounding Ballarat, Victoria. Locally, there is no succinct evidence as sampling densities in previous investigations were too low (Jurskis & Potter 1997). Studies into the production of toxins in Eucalypt leaves, found that variation in the production of sideroxylonal in *E. tricarpa* could be caused by genetic variance (Andrew *et al*. 2010). This is of interest to the results of this study as it could be postulated that genetic variability in local *E. tricarpa* could result in higher palatability of foliage across the south coast study area.

Those species that made up the secondary group, *E. globoidea, E. muelleriana* and *E. bosistoana* are still vital to the persistence of koalas throughout the study area. *E. bosistoana* in particular is listed as a secondary species according to DECC (2008) and was the highest ranked of the secondary species within this thesis. The lower ranked stringybarks (*E. globoidea* and *E. muelleriana*), which are seen by Phillips (2000b) as supplementary, but with "significant variation of use of some species across their range," demonstrated a much higher preference than across many other koala habitats. Further investigation into these species could identify whether this is a localised preference or whether the lack of 'primary' species has forced the utilisation of differing *Eucalypt* species throughout the study area.

6.2. Predictive Habitat Modelling

Based on the identified preferred koala usage species, the classifications were applied spatially to model the extent of suitable habitat. This ranked predictive habitat map is the first successful attempt to plot the location and amount of adequate habitat patches for the South Coast koala population. The methodology is simple and easy to adapt to future modelling investigations, having a number of consequences for the broader context of conservation planning for forest habitat.

6.2.1. Use of Key Preference Species for Modelling Suitability

As the Eucalypt is the key unit of habitat quality for koalas, it is maintained that the presence or absence of these species is the primary variable for habitat suitability. The vast numbers of studies that identified tree species as the major limiting resource for overall habitat quality re-assert this position and justify the use of preferred species to model habitat quality. This stance does not disregard the value of supplementary species or those in the auxiliary data set, but recognises that the availability of key eucalypt species essentially determines the probability of the occurrence of koalas.

A number of studies have investigated the use of multiple explanatory variables to predict the extent of koala habitat (eg. Kavanagh *et al.* 1995; Cork *et al.* 1997; Bryan 1997; Cork *et al.* 2000; Lunney *et al.* 2000a; McAlpine *et al.* 2008; Jaunchowski *et al.* 2008; Callaghan *et al.* 2011). While each of these studies have resulted in a method for the prediction of habitat, there is no consensus on the most powerful variables, with only the presence of key tree species and the underlying influence of soils continually being recognised for their influence on koala habitat quality.

Phillips and Callaghan (2000) further argue that habitat quality can be defined solely through the presence and proportion of primary and secondary tree species. As the South Coast study site is largely covering the same substrate (Figure 4.2), modelling habitat quality for the purpose of conservation was based primarily on the key tree species as determined from the statistical analysis of strike rates and the use versus availability methodology. This decision was founded on the overall objective of the study along with the availability and accuracy of data.

Consequently, this method can be seen as a practical way of mapping koala habitat at a landscape scale. The use of key Eucalypt species for advising decision-making regarding conservation and management is further supported by Callaghan *et al.* (2011). This has implications for a wider context with predictive models such as this being able to be used for all forest dwelling mammals, not only koalas. The resulting map of koala habitat suitability provides a basis for an exploration of the distribution and configuration of habitat classes.

Though there are limitations to this approach, as there have been suggestions that this method is seen to be restricted as it fails to account for koala demographics. This aspect should be included associated with measures of population density to develop a comprehensive understanding of overall habitat quality (Wheatley *et al.* 2002). Furthermore, Manly *et al.* (1993) states that in a biological sense, it provides a single measure of ‘quality’ as it does not account for the complex ecological interactions that define whether or not an area has the ability to sustain a koalas. While these are valid arguments and should not simply be dismissed, these limitations require identification and further investigations could aim to address these issues to develop a more robust modelling technique. For the purposes of undertaking a preliminary mapping activity to determine areas of suitable habitat, the use of preferred tree species can be seen as a viable method of habitat quality modelling.

6.2.2. Interpolation of Ranked Vegetation Layer

The extent of data points from the surveys, combined with the detailed attributes that were linked to each point provided a very thorough sample surface with which to work. Initial investigation into alternate methods using existing vegetation layers for the area revealed a mapped surface based on defined vegetation communities which had estimations of the floristic composition (Tozer *et al.* 2010). From assessing this layer and discussions with professionals in the field, it was cautioned that the layer may not be entirely accurate; this led to the development of the IDW methodology.

IDW interpolation modelling uses the values of known samples to estimate the values at unknown points based on a proximity weighting. It has been investigated as a simple, effective and time-efficient mapping technique and studies indicate its value as a method of predicting categorical vegetation (eg. Roberts *et al.* 2004). While other methods of interpolation, such as kriging, have seen to be more robust from a statistical sense, its use compared to IDW is often debated (Zimmerman *et al.* 1999).

Spatial autocorrelation in species-environment relationships of species occurrence or abundance can lead to incorrect conclusions regarding the value of environmental variables (McAlpine *et al.* 2006a). In areas where there is high autocorrelation, a number of studies have revealed that IDW is equal to; or better than kriging for the prediction of vegetation across a surface (eg. Dirks *et al.* 1998).

The results from the cluster analysis outputs for both zones revealed a level of high autocorrelation between ranked vegetation points, inferring that IDW would be a suitable interpolation technique. Manual delineation of classes through the use of the plot radius for each survey point ensured that the IDW was not over- or under-estimating the values across the unknown areas. The resulting classified map output was determined to be an adequate representation of overall habitat suitability.

6.2.3. Limitations of IDW Interpolation

Like all methods of predicting values at unknown points, IDW as an interpolation technique has a number of limitations. When used in environmental GIS based studies, preliminary analysis is often based on the generation of a continuous surface layer on which to conduct further investigations. As the final aim for the South Coast study site was reliant on the construction of the ranked vegetation map, it is important to recognise the limitations of this methodology.

Traditional vegetation mapping has been reliant on the interpretation of aerial photography and the manual delineation of vegetation communities, which often have high time and budget costs associated with the process (Roberts *et al.* 2004). IDW provides a method whereby limited point sampling can be used to create suitable results based on the simplicity of underlying principle, the speed in calculation and the ease of programming for the user (Hu 1995). Though as with all methods of interpolation, IDW is reliant on the input data accuracy and overall representation of the underlying trends.

Sampling methods can have a number of limitations dependent on the sampling methodology used and the extent of the target feature. To collect data for the koala surveys systematic sampling was undertaken at regular points on an x-y grid. This systematic sampling is limited by the sampling interval relative to the features distribution. Studies have demonstrated that plant's distribution and patch sizes skew the overall representation of data if the sampling distribution to too large (Roberts *et al.* 2004).

As the sampling technique used across the South Coast study site was systematic and on a 1km by 1km grid, this can be seen as the most efficient sampling method in regards to time and data quality trade-offs. The methodology for this survey process was developed in conjunction with professionals in the field to achieve the most representative data set possible given the large area over which the survey was conducted.

Hu (1995) further outlines the limitations of the IDW technique in that the interpolation can easily affected by "uneven distribution of observational data points since an equal weight will be assigned to each of the data points even if it is in a cluster and that maxima and minima in the interpolated surface can only occur at data points since inverse distance weighted interpolation is a smoothing technique by definition". Both of these factors were taken into consideration and effects minimised by the manual delineation of classes using categorical data.

For the purposes of this study, the distribution of observational points was on a regularised grid and furthermore, the extent of the IDW surface was limited to a 2km buffer surrounding known points. As IDW does not predict value higher or lower than those represented by the data points, this was seen as beneficial due to the nature of the categorical ranking. In achieving this aim, IDW was concluded to be the most suitable interpolation method to create a continuous surface on which to conduct fragmentation analysis.

6.3. Habitat Fragmentation

Habitat fragmentation caused by expanding development and the demand for resources is a factor that is increasing pressure on forest habitats worldwide. As the koala epitomises the various land-use challenges that face arboreal mammals, an investigation into the extent and configuration of habitat patches in relation to known koala populations at a landscape scale provides many important findings for the delineation of overall habitat quality.

6.3.1. Landscape Analysis

A landscape is a mosaic of habitat patches of differing quality, size and shape, and in the context of koala management it extends across a region of 100s-1000s of hectares (McAlpine *et al.* 2007b). When the proportion of habitat across the mapped landscape was calculated, it was found that a combination of highly suitable and suitable habitat made up 47.88% of the area with marginal being 13.13% and 16.23% potential forest habitat which was outside the range of the study. In total this is almost 80% native forest across the landscape, which according to McIntyre and Hobbs (1999), can be classed as a variegated landscape. This essentially means that although there is a large proportion of native forest present throughout the landscape, koalas in this region may face increasing pressures from habitat loss, fragmentation, vehicle collisions and dog attacks.

Although fragmentation due to roads is often seen as negative from an ecological context (Forman 2000), the affect that roads had on the study area was limited. While as expected, the total area of each vegetation class subsequently decreased with habitat loss occurring due to roads, the mean patch size of highly suitable (+45112 m^2) and suitable habitat (+21746 m^2) actually increased in the road fragmentation model. The mean patch size of marginal habitat decreased (-16650 m^2) due to fragmentation. The changes in mean patch size, before and after roads were buffered away from existing habitat indicated that for both highly suitable and suitable habitat, majority of the largest patches occur away from roads. This is beneficial for the ecological aspects of habitat, though the risks associated with crossing roads are still present for koalas moving between habitat patches (Dique *et al.* 2003a).

6.3.2. Patch Metric Analysis

The patch is the fundamental unit of landscape ecology, and hence the area of a patch within the landscape mosaic is one of the most useful aspects of assessing overall habitat quality. There is significant evidence that the size of a patch is largely related to the overall species richness for a number of species and furthermore, the size of a patch able to sustain a viable population differs between species. Considerable research has revealed that the minimum patch size for koalas is 50ha, with patches considered to be ‘critical’ when between 100-200ha based on evidence from koalas in the Noosa Shire (McAlpine *et al.* 2006a). This value of 50 ha was used due to the similarities between the coastal landscapes.

Mean patch size at a class level is seen to ‘represent the average condition’ (McGarigal *et al.* 2002, p. 76). While it does not give an indication of how many patches are present within the landscape, it does have a number of ecological implications especially when interpreted with the total class area, patch density and patch size variability. Within a largely natural environment, this can give an indication of forest composition heterogeneity while in a fragmented landscape this can be used as a measure of habitat loss (McAlpine *et al.* 2006a).

The mean size of highly suitable habitat was 138.6 ha while that of suitable habitat was 118.8 ha. These values indicate that although the mean size of patches is larger than 50 ha, both values lie between the critical values of 100-200 ha. As the landscape was classified as ‘variegated’, these patch sizes most likely refer to natural changes in the vegetation across the region. Though, future fragmentation of the south coast koala habitat could reduce the mean value of both highly suitable and suitable habitat below that that is able to sustain the population.

Furthermore, an assessment of patch size variability as a second-order statistic ‘measures a key aspect of landscape heterogeneity that is not captured by mean patch size’ (McGarigal *et al.* 2002, p. 76). The fundamental statistic is the use of patch size standard deviation (SD), throughout the study area, the SD varied greatly between classes. Highly suitable indicated a SD of 462 ha with the smallest patch being 76 m^2 and the largest patch of 27 340 933 m^2. Suitable habitat SD was 861 ha with patches being between 547 m^2 and 94 447 774 m^2. Both of these results demonstrate that there is limited uniformity across the study area which may reflect differences in the underlying processes affecting the landscape.

This variability across the study area was further enforced by the density of patches across the landscape. Forest patch density at the 1000m extent has been seen to be a positive indicator of koala habitat quality (Jaunchowski *et al.* 2008). Patches per square kilometre were calculated across the mapped area and was found to be the largest for suitable habitat (0.36) while highly suitable (0.36) and marginal (0.23) were progressively less dense. The use of patch density is indicative of the effects of landscape configuration, with these results revealing that patches of suitable and highly suitable habitat are densely spread across the landscape at a scale that could further predict koala occurrence.

The multitude of landscape metrics available for quantifying environmental patterns, demonstrates the range of ecological processes that are influenced by landscape configuration. The spatially structured nature of habitats at a range of scales define patterns which interact with species perception and behaviour, which in turn, influence population dynamics and community structure (McGarigal 2006). Such strong species-environment relationships are reliant on landscape structure for population viability, along with overall biodiversity and ecological health. Consequently, any disruption to the landscape matrix can compromise the landscape structures functional integrity (McGarigal 2006).

Additionally, Gardner *et al.* (1993) explores the effects of anthropogenic activities which can disrupt both ecological flows of organisms and the overall structural integrity of the environment. In the multi-use landscape of the South Coast study area; there are a number of threatening processes (eg. forestry, agriculture, urban development, bushfire) that have the potential to further disrupt landscape pattern and influence the persistence of the koala population. It is for these reasons, that this study has provided the basis for a study of pattern-process relationships, along with highlighting the need for fragmentation analysis in the decision-making process for conservation and management.

6.3.3. Habitat Guidelines

The investigation into habitat quality based on the habitat conservation guidelines presented by McAlpine *et al.* (2007b) provided a unique insight into the nature of available habitat from the perspective of the koala. Initial research objectives examined the area of habitat needed to determine *enough* habitat. As mentioned in the methods of Chapter 5, all reference to 'adequate habitat' is to the combined classes of highly suitable and suitable habitat.

For this study 40 - 50% adequate habitat surrounding active sites was considered enough habitat (McAlpine *et al.* 2007b). Across the South Coast study area, it was found that within the 1km buffers, there was 80.45% adequate habitat, made up of 43.69% highly suitable and 36.76% suitable vegetation. This gives an indication that there is sufficient adequate habitat within close proximity of known koala populations, though this assumption must be interpreted with caution.

As habitat loss is the most threatening process that affects koalas, a number of studies have attempted to quantify the extent of habitat within a defined study area, though few have sought to identify the minimum amount of habitat which koalas need to survive. This is known as the threshold amount, at which the chance of extinction increases rapidly if that amount is not sustained (Fahrig 2001). Studies across Eastern Australia have revealed a number of interesting relationships between the amount of habitat required to support a viable koala population and the interrelated anthropogenic threats.

Rhodes *et al.* (2006) suggest that for habitat surrounding Port Stephens, NSW, probability of koala occurrence sharply drops when the proportion of adequate habitat falls below 40%. Similarly in Noosa Shire, Queensland, it was found that probability drops when habitat is below 60-70% of the landscape (McAlpine *et al.* 2006a). In contrast, a study at Ballarat, Vic, revealed that the proportion of the landscape needed to support koalas was much lower (20%), which was seen to be the long term affects of historical land-use patterns and a number of reintroductions for the koala population (Jaunchowski *et al.* 2008).

The 80.45% of available habitat across the South Coast study site is substantially higher than these suggested thresholds and consequently it can be suggested that the koalas of this region have *enough* habitat surrounding active areas in which to sustain a viable population. Rhodes *et al.* (2008) cautions against applying uniform threshold levels across the koalas range due to the differences outlined in the above studies as it had been thought that in areas where the density of koalas is low, the proportion of habitat may in fact need to be much higher than where the density of koalas is high. Hence further investigation into the habitat requirements of the South Coast koala population is necessary.

As with the threshold amount for total habitat across an area, similar values are related to the patch size that is suitable for koalas. In a similar fragmented coastal forest landscape, it was determined that due to the average home range of koalas being 50-100ha, a minimum patch size of 50 ha was required for a higher probability of koala persistence (McAlpine *et al.* 2006a). Guideline 2.1 revealed that a large proportion of the adequate habitat across the study region was made up of habitat patches greater than 50 ha. In total, patches > 50 ha made up 98.78% of the area of all adequate habitats. This gives an indication of the overall habitat quality as the mean size of these patches was 1478 ha, substantially larger than the 'critical value' proposed by McAlpine *et al.* (2006a).

Furthermore, when examined in relation to active sites, it was found that 87.5% of active patches were located within adequate habitat patches > 50 ha. Of those points that were not, they were all located within 1km of one of these patches. This is a positive result for the overall habitat quality of the South Coast koalas. This proximity to large patches is also reinforced by known koala dispersal distances which are often between 1–3 km for males and < 2 km for females (Dique *et al.* 2003b). Active koala sites are located within close range to adequate habitat areas which reduces patch isolation and increases the likelihood that koalas are able to breed and support a viable population (McAlpine *et al.* 2007b). These large patches were also seen to have the smallest perimeter:area ratio, and hence reduce the extent of edge effects.

The interaction between the size and shape of habitat patches influences a number of ecological processes. The primary factor is the interaction of edge effects which can influence the persistence of interior-sensitive species and whole ecosystem integrity by a range of threatening factors and environmental variation (McGarigal *et al.* 2002). It is well known that the amount of edge is smallest for patches that are more circular in shape and consequently the results from Guideline 3.1. further enforce this factor. McAlpine *et al.* (2005) found that koalas were tended to be absent from patches less than 100ha with a high perimeter: area value. This is particularly important for the habitat of the South Coast koalas as it was found that there was a definite trend with larger patches having a much lower ratio, and consequently, the patches over 50 ha all had a ratio of <0.01 which aligns with the results of McAlpine *et al.* (2005). As koalas are known to particularly sensitive to edge effects due to their limited ability to move through the land-use matrix, this is an indication that the patches of adequate habitat across the region may be of a suitable size, shape and configuration to support the current koala population.

6.3.4. Limitations of Landscape-Scale Fragmentation Analysis

As with all modelling, the use of fragmentation analysis has a number of limitations. Apart from those criticising the use of the landscape matrix model to investigate overall habitat quality has been seen to be quite successful for the aims of this study. Within this particular investigation, limitations of both habitat boundaries and scale must be acknowledged.

The use of the 2km buffer surrounding known points to define the extent of habitat restricts the mean patch size and adjoining patches could be substantially larger. While this aspect could in fact dramatically alter the results of the fragmentation analysis, all analyses that were undertaken in relation to active sites assists in limiting the effect of this boundary. Additional survey extents would be required to follow the same methodology and further predict the suitability of vegetation.

The problem of scale for conservation planning is one that has been recognised in a number of studies (eg. McAlpine *et al.* 2006a). The successful use of models of habitat by decision-making and management processes is reliant on scale for overall biodiversity of a region across a number of ecological scales. For such a complex species such as the koala, scale of analysis must suit the home-range of the animal while being able to be used in across-landscape planning. For this reason, all analysis was conducted using a 30x30m grid, converted to vector GIS format to assist with further investigation.

6.4. Implications for Koala Conservation

The overall objective for this study was to investigate the extent and quality of koala habitat across the South Coast study area in order to inform conservation planning and management. During the course of this thesis, koala populations throughout NSW, Qld and the ACT have been listed as 'Vulnerable' at a Federal level after rigorous investigation by the Threatened Species Scientific Committee. Consequently, there are a number of plans of management that have been developed to aim the recovery of these populations. At present, there has not been a comprehensive plan of management that refers specifically to the South Coast koala populations. This is largely due to the lack of succinct knowledge regarding the population throughout this region as acknowledged in the 'Far South Coast Koala Management Framework' (Eco Logical 2006).

While there are still a number of gaps in understanding the distribution, structure and feeding requirements of these koalas, this thesis provides a basis for conservation and recovery plans. Vital to the success of all koala management plans is the protection of remnant eucalypt forests, developed in association with spatially adept revegetation strategies using indigenous tree species (McAlpine *et al.* 2006a). Through investigating koala usage trees and applying those preferences spatially, patches of the most suitable habitat were identified. Through restoration programs, these patches can be enhanced to restore overall connectivity throughout the landscape matrix by focused plantings of the identified preferred species.

The primary legislation referring to the conservation of koala habitat in NSW is the State Environmental Planning Policy 44 (SEPP 44) which requires an assessment of forest habitat for the presence of identified koala usage species for guiding decision-making and approvals (Appendix 3). Although SEPP 44 applies to the study area (Schedule 1), the provisions are rarely enforced in this region due to majority of the tree species in Schedule 2 not occurring in large numbers in the study area. Many species on the list are not found at all (eg. *E. microcorys, E. punctata* and *E. populnea*).

This has implications for the conservation of koala habitat as the local councils of the region have not identified any core koala habitat (as defined by SEPP 44) in Local Environment Policy and hence does not provide specific protection for koala habitat. This further enforces the need for the identification of tree usage species and other habitat variables at a local scale in order to enact conservation and management.

It has long been recognised that there is a need for a conservation planning process for remnant forests which develops objectives and priorities based on the role or value of the remnant habitat patch (Saunders *et al.* 1987). The contributions that this investigation have made to the need for specialised assessment of habitat requirements for the purpose of conservation strategies goes beyond applying solely to the koala but for the biodiversity of all species that rely on forest habitats.

In order to assess the vulnerability of a species to extinction, a main priority of conservation science is to understand the ecological traits that make a certain species more vulnerable than others (Davidson *et al.* 2009). One of these ecological aspects is through the selective preference that koalas have for certain tree species. Through this investigation it was proven that the most utilised Eucalypt species was also the most abundant, but that it was not so for the other species in the primary category. This selective use of habitat resources furthers our knowledge of the interaction that koalas have with their environment and can be used to promote the ecological biodiversity for all forest dwelling mammals.

While the results of this study provide a preliminary tree species ranking, further research should be conducted to refine this ranking by increasing the sample size used in analysis along with including other variables. Aspects of leaf toxicity, nutrients and moisture levels can fluctuate depending on seasonal and individual tree variation along with the influence of substrate (Moore *et al.* 2003). This can influence the browsing patterns of koalas and hence would alter the results of the survey depending on what time of the year and in which region data was collected. The species that have been identified in this study are very significant to the remaining koalas in this region so protection and enhancement of the habitat is vital to the ongoing stability of the population.

As the majority of the koala habitat occurs throughout National Parks and State Forests, this can introduce a bias regarding the vegetation communities and substrates that are preserved (Pressey 1995). Koalas' preference for tree species growing on fertile floodplains and valleys is well known, and there is the potential to enhance the extent of the South Coast habitat across the more fertile regions which have been previously cleared for agriculture. A number of studies have examined the role of koala conservation on private land and their potential for incorporation into local government plans of management (eg. Lunney *et al.* 1999). Consequently, it is vital to engage private landholders in enhancing any remnant habitat patches to improve connectivity across regions of cleared land while improving the overall quality of habitat.

The results from the fragmentation analysis revealed that, overall the habitat has maintained adequate patch sizes and a wide distribution of large patches across the landscape. As there is a large extent of habitat where there has been no evidence of koalas recorded, it is apparent that there are other factors influencing the distribution of the population. Further investigations could address these.

From a koala's perspective, there is *enough* habitat for the current animals to be sustained though increases in threats from logging, land clearing, drought and bushfire could jeopardise the stability of the population.

If koalas are to be properly managed across the South Coast study area, it is imperative to:

i. protect and enhance areas of highly suitable and suitable habitat while not excluding areas of marginal habitat from any conservation and management plans as these areas are important for both biodiversity, connectivity and dispersal functions;
ii. investigate the connectivity of habitat patches and examine the potential for wildlife corridors across private land to increase safe movement through the landscape matrix for koalas; and
iii. ensure ongoing population management surveys are undertaken to provide information on changes in the koala community's size and structure.

These issues could be addressed in a plan of management which includes a comprehensive integration of both biodiversity conservation and land use planning.

6.5. Further Research Questions

This study has highlighted that further extensive research is required to answer the following questions.

- How does the connectivity of habitat affect the overall habitat quality of the South Coast koala population?

- Are the primary identified tree species equal in nutrients to other known koala feed species and hence is the area able to support a denser koala population?

- How has the disturbance history shaped the current size of the koala population and where koalas are located in relation to suitable and highly suitable habitat?

- Are there other habitat variables that influence the distribution of koala habitat?

Chapter 7 Conclusion

As the estimated number of koalas across this region is so low, the population can be considered on the brink of localised extinction. Increasing threats from predation, roads disease and habitat loss have put these koalas in a very precarious position. The koalas' ability to adjust to environmental change is so low, that a single catastrophic event, such as drought or bushfire, could all but wipe out the remaining koalas in this region. An acknowledgement of these factors has been made throughout this study, though the most practical outcome for these remaining koalas would be to incorporate the findings of this investigation into a multi-disciplinary plan of management.

This study has provided a unique insight into the choices koalas are making regarding tree species usage through an analysis of the strike rate and the proportional use versus availability on a species level. These findings were applied spatially to create a ranked predictive habitat map for koalas based on areas of vegetation that included a high proportion of identified koala usage species. The extent of fragmentation of this preferred habitat, and the spatial composition and configuration of across the study area was investigated to draw conclusions regarding overall habitat quality.

The research confirms the need for site-specific delineation of preferred usage species and identifies that the species that are the most often chosen by koalas are unique to the study area. When applied spatially, it has revealed that there is in fact a quite extensive adequate habitat network which disproves the assumption that the habitat throughout the region is unable to properly support the current koala population. The configuration of habitat surrounding active sites demonstrates that majority of sites are located in large, high quality patches, which in turn, reduces isolation pressures on the species. From the perspective of the koala, there is *enough* habitat of a suitable standard. Though, for this population is to recover, multi-tenure management strategies must be developed to address any further threats to the habitat area.

Conservation efforts should focus on protecting and enhancing remnant habitat patches while aiming to reduce any further fragmentation through logging, land clearing and bushfire. If these animals are to persist throughout the region, a comprehensive plan of management is required, building on these insights while addressing the knowledge gaps and habitat requirements of this unique population.

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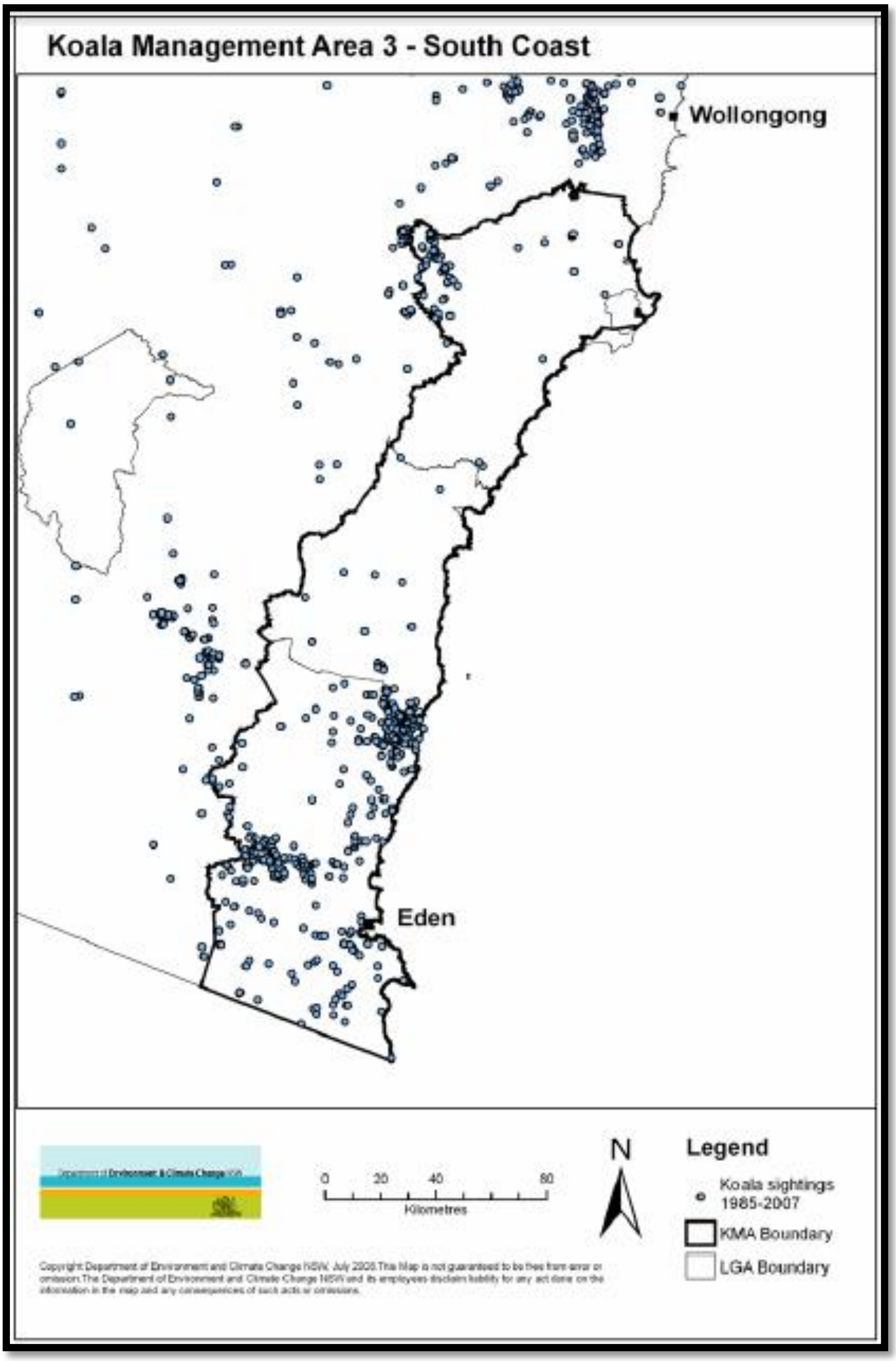
Chapter 9 Appendix

Appendix 1 – Koala Management Area 3

<u>Outline of Region - Recovery Plan for the Koala (DECC 2008)</u>



Koala Feed Species - Recovery Plan for the Koala (DECC 2008)

Koala Management Area 3: South Coast

Primary food tree species:

Cabbage gum *E. amplifolia*	Forest red gum *E. tereticornis*
Ribbon gum *E. viminalis*	

Secondary food tree species:

Yellow box *E. melliodora*	Woollybutt *E. longifolia*
Brittle gum *E. mannifera*	Maiden's gum *E. maidenii*
Yertchuk *E. consideniana*	Snow gum *E. pauciflora*
Swamp gum *E. ovata*	Red box *E. polyanthemos*
Large-fruited red mahogany *E. scias*	Coast grey box *E. bosistoana*
Apple-topped box *E. bridgesiana*	Blue box *E. baueriana*
Monkey gum *E. cypellocarpa*	Bastard eurabbie *E. pseudoglobulus*

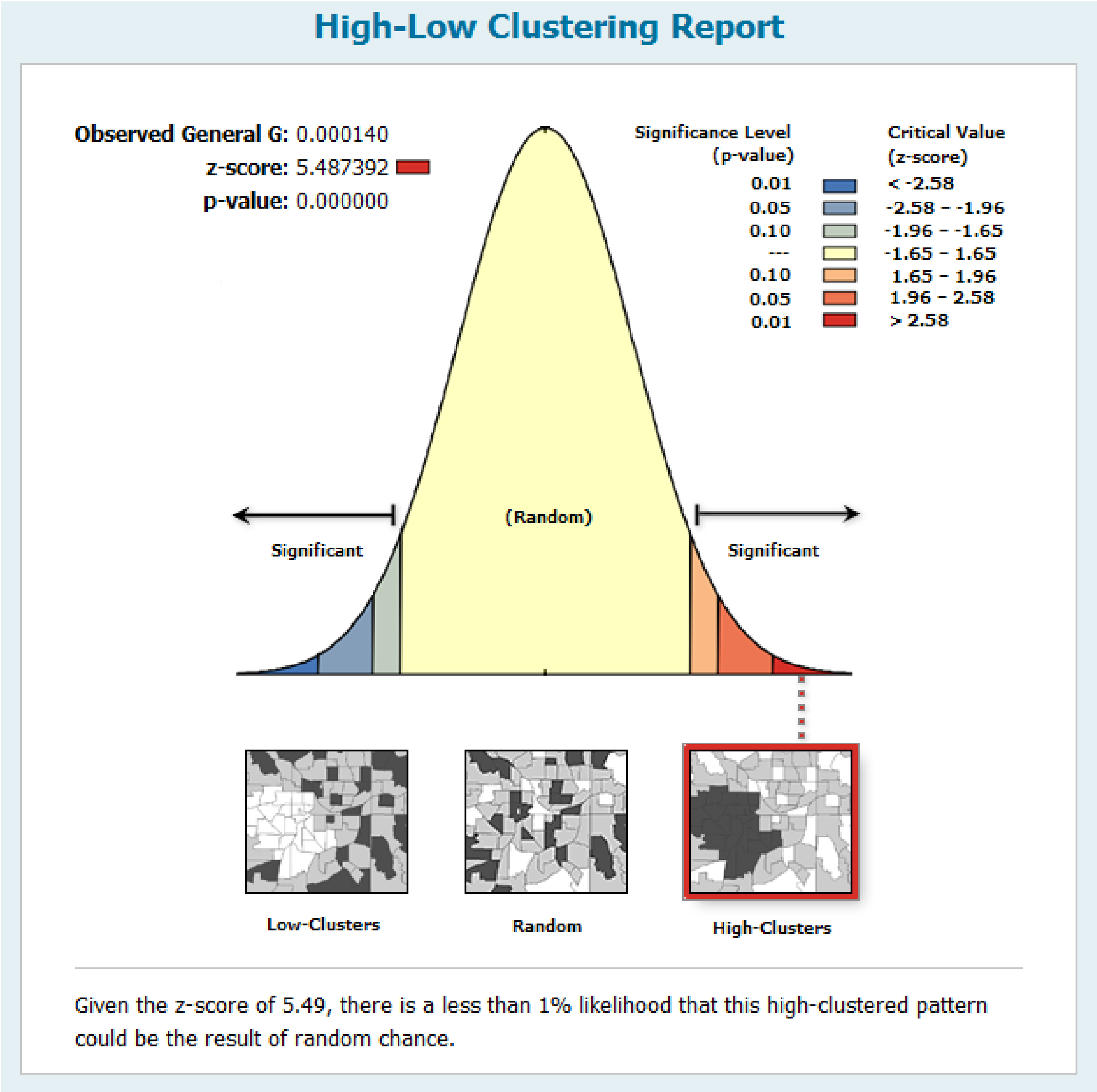
Stringybarks/supplementary species:

White stringybark *E. globoidea*	Brown stringybark *E. capitellata*
Yellow stringybark *E. muelleriana*	Southern white stringybark *E. yangoura*
Blue-leaved stringybark *E. agglomerate*	*E. baxteri*

Appendix 2 – Cluster Analysis Outputs

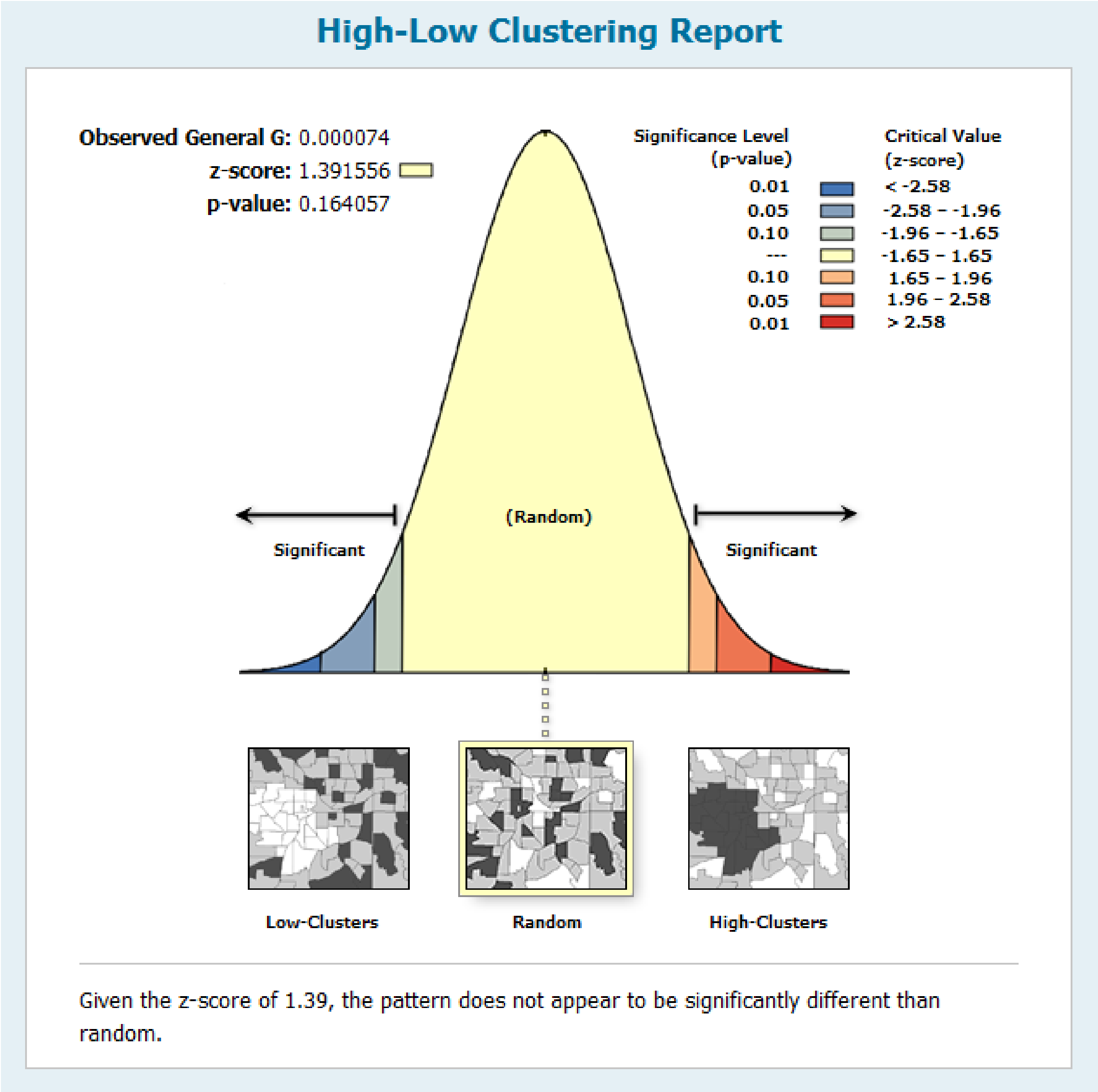
<u>High-Low Clustering Reports</u>

Zone 55



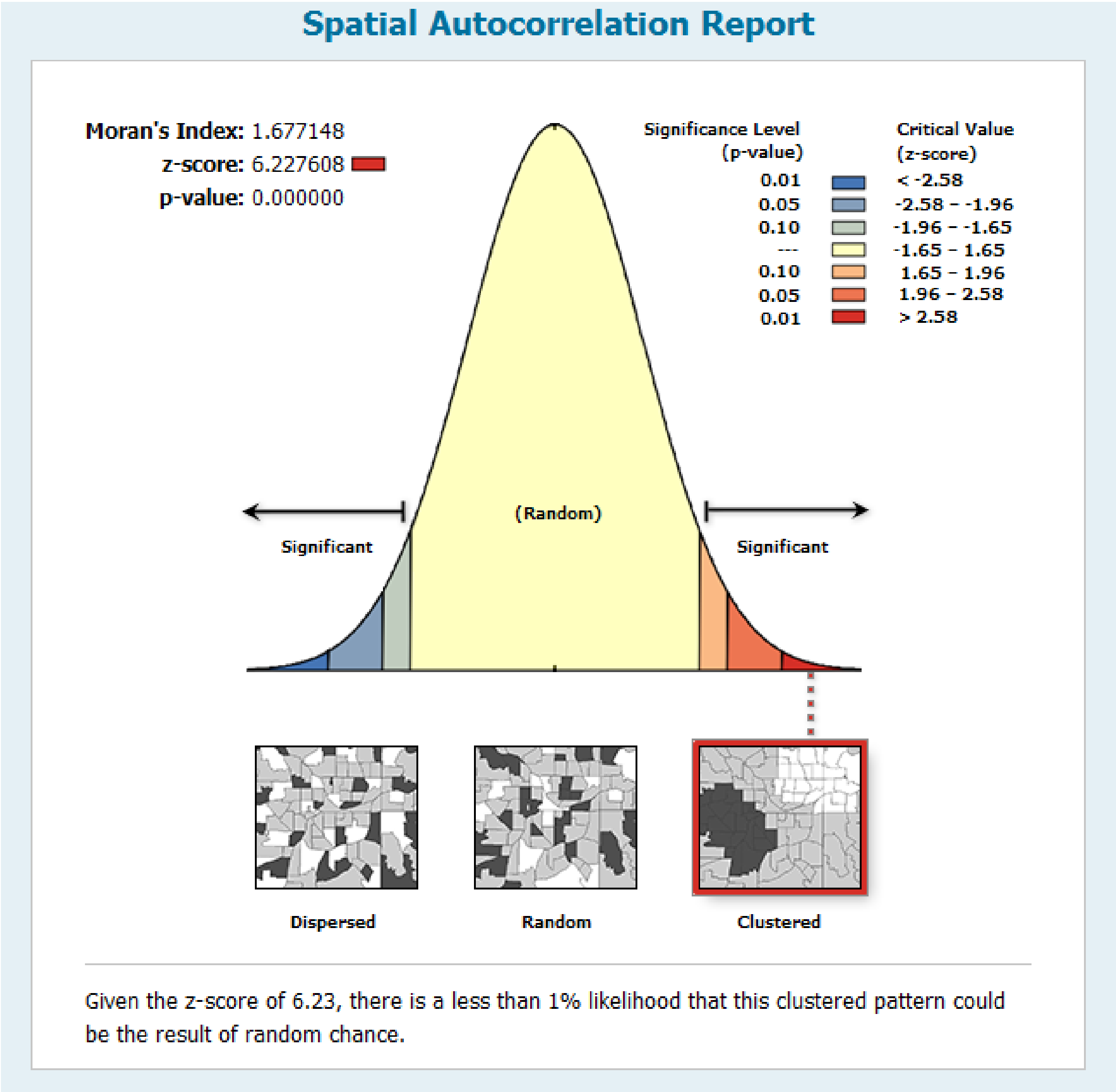
<u>High-Low Clustering Reports</u>

Zone 56



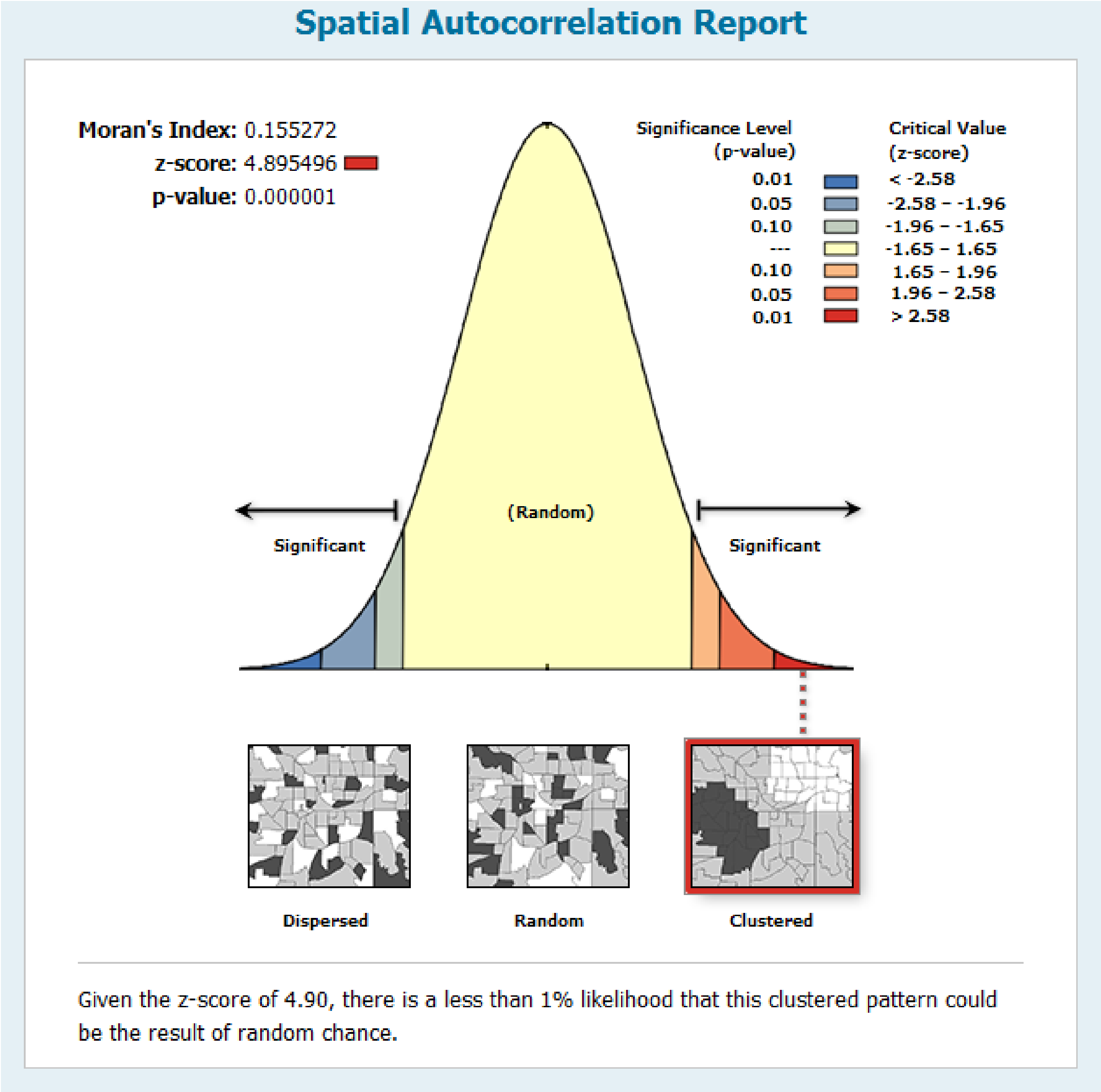
<u>Spatial Autocorrelation Reports</u>

Zone 55



Spatial Autocorrelation Reports

Zone 56



Appendix 3 – SEPP 44

State Environmental Planning Policy No 44--Koala Habitat Protection

As at 26 April 2000

Schedule 1: Local government areas

(Clauses 5 (1), 11 (1), 12, 15)

Armidale	Liverpool
Ballina	Lockhart
Barraba	Maclean
Bathurst	Maitland
Bega Valley	Manilla
Bellingen	Merriwa
Berrigan	Moree Plains
Bingara	Mudgee
Blayney	Mulwaree
Blue Mountains	Murray
Bombala	Muswellbrook
Boorowa	Nambucca
Bourke	Narrabri
Brewarrina	Narrandera
Byron	Narromine
Cabonne	Newcastle
Campbelltown	Nundle
Central Darling	Nymbioda
Cessnock	Oberon
Coolah	Parkes
Cooma-Monaro	Parry
Coonabarabran	Pittwater
Coonamble	Port Stephens
Copmanhurst	Quirindi
Corowa	Richmond River
Crookwell	Rylstone
Dumaresq	Scone
Dungog	Severn
Eurobodalla	Shoalhaven
Evans	Singleton
Forbes	Snowy River
Gilgandra	Tallaganda
Gloucester	Tenterfield
Gosford	Tumbarumba
Grafton	Tumut
Great Lakes	Tweed
Greater Lithgow	Ulmarra
Greater Taree	Uralla
Gunnedah	Wagga Wagga
Gunning	Wakool
Guyra	Walcha
Hastings	Walgett

Hawkesbury	Warren
Hornsby	Warringah
Hume	Weddin
Inverell	Wentworth
Kempsey	Windouran
Ku-ring-gai	Wingecarribee
Kyogle	Wollondilly
Lake Macquarie	Wollongong
Leeton	Wyong
Lismore	Yallaroi
	Yarrowlumla
	Yass

Schedule 2: Feed tree species

(Clause 4)

Scientific Name	Common Name
Eucalyptus tereticornis	Forest red gum
Eucalyptus microcorys	Tallowwood
Eucalyptus punctata	Grey Gum
Eucalyptus viminalis	Ribbon or manna gum
Eucalyptus camaldulensis	River red gum
Eucalyptus haemastoma	Broad leaved scribbly gum
Eucalyptus signata	Scribbly gum
Eucalyptus albens	White box
Eucalyptus populnea	Bimble box or poplar box
Eucalyptus robusta	Swamp mahogany