Centre for Geo-Information

Thesis Report GIRS-2005-03

COMPETITION AND HABITAT SELECTION AT MULTIPLE SCALES IN LARGE ARBOREAL MARSUPIALS USING GIS

(A case study at Newholme property in Armidale, Australia)

Anneloes de Raad

February 2005

WAGENINGEN UNIVERSITY
WAGENINGEN UR

Competition and habitat selection at multiple scales in large arboreal marsupials using GIS

A research conducted in collaboration with the
University of New England, Armidale (Australia)

Name course : Thesis Geographical Information Systems
Number : K075-704
Study load : 27 credits
Date : 15 February 2005

Student : A.L. de Raad
Registration no. : 801020-677-080
Study programme : O10-B (Tropical Land use)

Supervisors : Ir. J. Crompvoets (WUR)
Dr. L. Kumar (UNE)
Dr. ir. F. van Langevelde (WUR)
Dr. K. Vernes (UNE)
Examiner : Ir. J. Crompvoets (WUR)
Group : Geo-Information Science and Remote Sensing
Droevendaalsesteeg 3
6708 PB Wageningen
Tel : +31 (317) 47 46 40
Fax : +31 (317) 41 90 00

WAGENINGEN UNIVERSITY
ENVIRONMENTAL SCIENCES

PREFACE

The journey started at Wageningen University with my application for the LEAFSE exchange program. This exchange program led me to Armidale, a small town on the New England Tablelands in Australia. I was able to live in a fantastic place at the Newholme property of the University of New England: drafty, but fantastic! Here I conducted my fieldwork, which forms the basis of the following research. My stay in Australia was terrific, even under sometimes harsh condition (nobody told me it could freeze in that part of the world!). It wouldn't have been the same without the following people: From UNE I would like to thank my two supervisors Karl Vernes and Lalit Kumar. Peter Jarman and Stuart Green deserve my credits and thanks for participating in the world biggest contest: Louise's Pooh Quiz! For logistics and fun, the ever so helpful Cate and Bec; thank you so much. My LEAFSE coordinators and good friends Paul Kristiansen, Acrac Taji and to Heiko Daniels and his beautiful family! My fellow LEAFSE students Hanne and Kasper, thanks for the great times!

Back in the Netherlands the journey continued at the GIS faculty at Wageningen University where the analyses and write up of this report took place. For my supervisor Joep Crompvoets: You have given me intense supervision, stimulated me with your enthusiasm and motivated me when I needed it most. It was a real experience to realize you don't have to go all the way to Australia for culture difference; you can simply walk into a GIS faculty! I wanted to become a 'real' GIS-girl and I think I have come a long way! I could not have done it without you.

For my supervisor Frank van Langevelde: You amaze me with your enthusiasm for ecology (especially your patterns and patches), your ideas and your intensity. Thank you for being my supervisor and friend and for learning me what nuthatches are really all about!

SUMMARY

1. This study aims to contribute to research on habitat selection of large arboreal marsupials at tree and landscape scale and to investigate whether competition affects the habitat selection of large arboreal marsupials. Competition is expected to result in spatial segregation at landscape scale (hypothesis 1) or in niche differentiation at tree scale (hypothesis 2), when animal densities are low both hypothesis be confirmed.

2. A faecal pellet survey was conducted to gain presence-absence data for koala, common brushtail possum, common ringtail possum and greater glider. Animal species distribution at landscape level was analyzed to test hypothesis 1 using GIS. Two sets of distribution maps were created, the second including environmental variables as well as the proximity of other animal species. Secondly, tree characteristics analyses were performed in order to show whether a preference for certain tree characteristics exists within and / or between the study species to test hypothesis 2.

3. Tree density and rockiness are the most important environmental factors in predicting the probability of occurrence in arboreal marsupials. Other environmental factors influencing the distribution of arboreal marsupials are rainfall, elevation and ground cover. Koala and brushtail possum are negatively associated, greater glider is positively associated with koala and brushtail possum. *E. laevopinea* ranks as the most important tree species for all arboreal marsupials, while *E. viminalis* and *E. youmanii* rank as least important. Koala, brushtail possum and greater glider show a significant preference for larger tree diameter and larger tree canopy diameter. Niche differentiation occurs between brushtail possum and the other arboreal marsupials species.

4. Competition between koala and brushtail possum affects their habitat selection at landscape scale and tree scale (hypothesis 1 & 2 confirmed). Competition between brushtail possum and greater glider as ringtail possum affects their habitat selection at tree scale (hypothesis 1 rejected, hypothesis 2 confirmed). Koala, ringtail possum and greater glider do not seem to be affected by competition in their habitat selection and seem indifferent to each other (hypothesis 1 & 2 rejected).

5. Possibly niche differentiation between koala, ringtail possum and greater glider does occur at smaller spatial scales or at temporal scales. Tree density and rockiness are suggested to both be surrogate measures for the nutrient status in leaves of eucalypt trees and that habitat selection takes place at leaf scale. Therefore, nutritional factors at leaf scale are recommended to be included in future studies on competition and habitat selection. The complexity in habitat selection and the lack of information of how the species interact means that predicting the ultimate distribution of the species is difficult. Interspecific competition is shown to be an active force in habitat selection in some arboreal marsupials. Further research needs to be conducted to study to what *extend* interspecific competition is an active force in habitat selection. The mechanisms of exploitation need to be studied in future research to provide understanding of the competitive process.

TABLE OF CONTENTS

INTRODUCTION

Understanding the underlying mechanisms of habitat selection of species is a central theme in ecology that requires consideration of a wide variety of environmental variables and their relationships. Different species respond to environmental variables at different spatial scales, which can influence the distribution and habitat selection of the species (Lindenmayer 1999). Habitat selection has been studied at different spatial scales for birds: e.g. nuthatches (S*itta europaea*) (Burkhardt et al. 1998), red-winged blackbird (*Agelaius phoeniceus*) (Pribil & Pickman 1997) and mallard (*Anas platyrhynchos*) (Pösyä 1998), for herbivores: e.g. muskoxen (*Ovibos moschatus*) (Danks 2002), cattle (WallisdeVries et al. 1998; Voeten 1999) and for insects: e.g. butterflies (Fleishman et al. 2001).

Many detailed field and modeling studies on habitat selection have been completed for arboreal marsupials at two different spatial scales: tree scale and landscape scale. Studies at tree scale have focused mostly on tree species preference and tree characteristics (e.g. diameter and height) most likely to be used as food trees (Hindell & Lee 1987; Philips et al. 2000; Roberts 1998 unpublished), whereas landscape scale studies have focused on the relationship between habitat selection and environmental variables (e.g. elevation, soil nutrients, slope, temperature) (Bennet et al. 1991). In addition, many studies have tried to model distribution and habitat selection as a function of different environmental variables (at landscape scale) and micro habitat variables (at tree scale, e.g. tree size, canopy height, understory density, no. of hollow bearing trees) (Lindenmayer et al. 1991; Pausas et al. 1996; Wormington et al. 2002; Cork & Catling 1996; Smith & Murray 2003). Cork & Catling (1996) and Lindenmayer et al. (2000) have emphasized the importance of studying and integrating data on distribution and habitat selection of arboreal marsupials at multiple scales, since information on the variables influencing the distribution at one spatial scale are important for informing processes at another. In a study on large scale patterns of habitat selection of koalas, Sullivan et al. (2003b) also highlights the importance of including multiple scales in survey design in order to investigate the organizational complexity of ecological systems.

Studies on distribution and habitat selection of arboreal marsupials have employed a range of statistical modeling tools, including principal components analysis, decision trees, multiple regression and generalized linear modeling (Cork et al. 1996). Recent studies on habitat selection at landscape scale have used Geographical Information Systems (GIS) to model distribution and habitat selection for many animal species: e.g. Mt. Graham red squirrel (Pereira and Itami 1991), butterflies (Fleishman et al. 2001), red and grey squirrel (Rushton et al. 1997), and muskoxen (Danks and Klein 2002). GIS provide a set of powerful tools that allow spatial data (environmental and habitat variables, distribution of a species) to be collected, stored, maintained, transformed and displayed for a specific purpose, thereby allowing an analysis of complex spatial problems (Danks and Klein 2002). It is possible to extrapolate the geographical distribution (abundance, density or presence-absence) of a species from local sample data or field observations to a continuous distribution surface, predicting the species distribution for locations where no samples were taken. By using environmental conditions required for survival by a species (e.g. GIS layers of climate, soil, vegetation, remotely-sensed data etc), the distribution of the species may be mapped through GIS overlay rules (Skidmore et al. 1996). Without the use of a powerful tool as GIS, modeling distribution and habitats when plot data is sparse, for a large area or for many species would require time and labour-intensive fieldwork (Danks and Klein 2002; Skidmore et al. 1996).

Despite the extensive use of GIS in studies on distribution and habitat of many species, few studies have been completed in this field for arboreal mammals. In fact, only studies on distribution and habitat of the koala (*Phascolarctos cinereus*) have used GIS. Lunney et al. (1998) have used a GIS overlay to determine the distribution of koala habitat in Port Stephens (New South Wales, Australia). In a later study, Lunney et al. (1999) have mapped koala habitat on private lands for the Coffs Harbour shire (New South Wales, Australia) using GIS. Bryan (1997) has used a GIS to predict optimal, sub-optimal and unsuitable koala habitat based on the combination of preferred eucalypt species with soil properties (e.g. water logging, rockiness, salinity) in the southern Mt. Lofty Ranges in South Australia.

Habitat selection by an animal can be influenced by a number of factors: animals have requirements for food and shelter and are adversely affected by competition and predation. Thus, whether an habitat is suitable for an individual depends on the available resources and conditions (e.g. food resources, climate), but also on proximity of other individuals of the same species (e.g. intra-specific competition for resources, reproduction) and of other species (e.g. interspecific competition for resources, predation). Few studies have been conducted on intra- or inter-specific competition in small arboreal marsupials. Righetti et al. (2000) have shown intraspecific as well as interspecific competition occurs in small arboreal marsupials (*Antechinus stuartii, Antechinus swainsonii, Sminthopsis murina*) by interference. Smith and Lindenmayer (1988), also suggested interspecific competition for hollows between Leadbeater's possum (*Gymnobelideus leadbeateri*) and other species that use hollows as a refuge. Banks et al. (2000) showed that interspecific interference competition exists between small mammals (*Antichinus stuartii, Rattus fuscipes and Rattus lutreolus*), resulting in the absence of one species at sites due to the presence of other species. Dickman (1983) also showed evidence of a negative spatial association among competing small marsupials, which preferred the same types of macro habitat, but spatially segregated into different micro habitats when their abundance was relatively high.

In contrast to the situation for small marsupials, no studies have been conducted on competition in large arboreal marsupials (to the best of my knowledge). However, competition in large arboreal mammals has been suggested to occur: Runcie (1999) suggests competition for food (due to overlapping diet) and den resources between rock-haunting possum (*Petropseudes dahli*) and scaly-tailed possum (*Wyulda squamicaudata*) as both species use dens for refuge. Shepherd et al. (1997) do suggest possible inter-specific competition for plant resources between five large marsupials (western grey kangaroo, tammar wallaby, common brushtail possum, western ringtail possum) due to their diet overlap. However, they assume that competitive limitations of particular food resource species are unlikely due to the polyphagous (feeding on many species of food) nature of these particular herbivores and an ability to shift resource preferences. In contrast, Dickman (1986) concluded that competition appears to affect several aspects of habitat selection of the marsupials *Antichinus stuartii* and *Antichinus swainsonii,* and suggests that competition also influences habitat selection and population parameters in a much wider range of marsupial species.

Most large arboreal marsupials are herbivores: e.g. koala (*Phascolarctos cinereus*) and greater glider *(Petauroides volans*) feed almost entirely on eucalyptus leaves, whereas the common ringtail possum (*Pseudocheirus peregrinus*) and common brushtail possum *(Trichosurus vulpecula*) also feed on flowers, buds, nectar, and fruit, in addition to their diet of mainly foliage. The common brushtail possum may also feed on insects, bird eggs and nestlings, and other small mammals. Koala, brushtail possum and ringtail possum are solitary territorial species and they use scented secretions to mark their territory. Greater gliders are also solitary animals, but only the males maintain separate territories (Incoll et al. 2001). Competition between these species can be expected since their diet overlap to a great extend (all feed primarily on eucalyptus leaves), they all they show territorial behaviour and all species use hollow trees for den refuges (except for koala who spend the majority of their time resting and sleeping in a fork between the trunk and a upper branch of *Eucalyptus* trees).

Competing species may either exclude one another from particular habitats so that they do not co-exist, or they may co-exist, for example by utilizing the habitat in slightly different ways (so-called niche differentiation) (Begon et al. 1986). The aim of this study is to contribute to research on habitat selection of large arboreal marsupials at tree scale and landscape scale and to investigate whether competition affects the habitat selection of large arboreal marsupials. The following two hypotheses were tested:

1) When competition affects habitat selection, this results in spatial segregation between competing species at landscape-scale level (negative spatial association): species do not co-exist.
At landscape scale, distribution of koala, brushtail possum, ringtail possum and greater glider is identified, using a Geographical Information System (GIS). Habitat selection models are created which attempt to predict the probability of the species presence and which is used to create distribution maps for each species using cell based Boolean overlays using GIS. Environmental variables and the influence of the proximity to and the presence of one species on another are included in the model.

2) When competition affects habitat selection, but no spatial segregation occurs (hypothesis 1 can be rejected), then segregation between competing species at tree-scale level (niche differentiation) occurs: species co-exist.
At tree scale, food tree use is studied for koala, brushtail possum, ringtail possum and greater glider by looking at preference for tree species and tree characteristics. Food tree use is compared between the animal species to show potential niche differentiation.

3) When competition affects habitat selection and species densities are low, this results in both spatial segregation as niche differentiation (hypothesis 1 and hypothesis 2 are both accepted).
When the competing species would occur in high densities they are forced into the same space and spatial segregation will no longer take place; hypothesis 1 has to be rejected (hypothesis 2 is still valid).

METHODS

Overview

This study can roughly be divided into four parts: preparation period, fieldwork period, analyses and write-up. The preparation period was used to conduct extensive literature research in order to write a research proposal in which the objectives and research questions for this study were determined. Moreover, methods that were to be used for the fieldwork were determined.

All data collection was performed in the fieldwork period. Faecal pellet survey (Putman 1983) let to presence-absence data for all four study species: koala (*Phascolarctos cinereus*), greater glider (*Petauroides volans*), common brushtail possum *(Trichosurus vulpecula*) and common ringtail possum (*Pseudocheirus peregrinus*). To gain insight in the accuracy of the faecal sampling, validation of species scat identification was carried out by an expert. During the faecal pellet survey, landscape data of sampled sites and tree characteristics of sampled trees were collected. Coordinates of all sampled sites were recorded in the WGS 84 – UTM zone 56S coordinate system, by means of an handheld Garmin geographical positioning system (GPS). In addition, existing environmental data of the study area were collected from the University of New England database.

Two main analyses were carried out. Firstly, animal species distribution at landscape level was analysed to test hypothesis 1. A first set of distribution maps were created for each species taking only the sampled presence-absence values into account. Additionally, a second set of distribution maps were created for each species based on a multiple logistic regression model, including environmental variables (collected during faecal sampling and existing data) as well as the proximity to other animal species. Thus, for each study species two distribution maps were created. Secondly, tree characteristics analyses were performed in order to show whether a preference for certain tree characteristics exists within and / or between the study species to test hypothesis 2.

Study Area

Newholme field laboratory is property owned by the University of New England and consists of 1946-ha of farmland, woodland and natural forest. It is situated approximately 10 km north of Armidale, New South Wales, on the New England Tablelands. The property surrounds and includes Mt. Duval, a prominent peak (1393 m) which is capped by a productive moist tall-open eucalypt forest, more typical of the sub-coastal mountain forest found further to the east (Smith et al. 1987). Since 1982, a 496-ha wildlife reserve has been fenced off and destocked to allow natural regrowth upon Mt. Duval for conservation and research purposes. Part of Mt. Duval was State Forest which was turned into a Nature Reserve, named Duval Nature Reserve, in 1999.

Geological parent material is dominated by Duval adamellite, a component of a granatic geological formation known as New England batholith (Smith et al. 1987). This results in generally poor soils occurring across the property. Soil types on Mt. Duval are mostly red podsolics and brown earths. With the exception of a small area on the south-eastern lowland fringe of the property the landscape is characterized by rocky outcrops which seem to increase with steeper slopes. Due to the presence of Mt. Duval the topography generally varies from rolling (2-5˚) slopes on the lowlands to steep slopes (18-28˚) close to the crest of the mountain. Annual rainfall in the lowland is about 750 mm and 1000 mm on top of Mt. Duval, with a peak in summer. All trees sampled in this study were of the genus *Eucalyptus*. Nine subspecies could be identified: smooth bark species *E. dalrympleana, E. viminalis* and *E. nobilis,* stringy bark species *E. caliginosa, E. laevopinea* and *E. oblique* and box bark species *E. melliodora, E. bridgesiana* and *E. youmanii*.

Study Species

Distribution of four arboreal marsupials was studied: koala (*Phascolarctos cinereus*), greater glider *(Petauroides volans*), common brushtail possum *(Trichosurus vulpecula*) and common ringtail possum (*Pseudocheirus peregrinus*) (see appendix I and table 1). The study species differ in social organization from solitary life to family groups. Brushtail possums lead a largely solitary life. However in areas where numbers are high and shelter is in short supply several may share sleeping places. Ringtail possums may live solitary or in small family groups and greater glider lives are solitary animals, home ranges of females may overlap but males maintain separate territories. However, males and females usually share a den from the onset of breeding until the young emerge from the pouch. Koala populations are characterized by complex social interactions. Koalas are social animals, but they are also very territorial. In the wild, koalas exist in stable breeding groups, but each member of the group maintains its own home range and lives mainly solitary. Where socially stable koala populations occur, the home ranges of individual koalas overlap with those of their neighbors. The trees found in these overlapping areas are very important within koala populations because most of the social interaction takes place in these trees.

Table 1. Ecology of the study species

species	**Habitat**	**diet**	**social organisation**
koala	eucalypt forest and woodlands of eastern Australia	herbivore	solitary strong family groups
brushtail	woodland and forest, also urban and some grassland	omnivore	mostly solitary
ringtail	woodland and forest, with well developed under storey	herbivore	solitary to small family groups
greater glider	wet and dry sclerophyll forest and some tall woodland	herbivore	solitary

FIELDWORK

Faecal pellet survey

A faecal pellet survey was carried out to determine species distribution, food tree selection and habitat selection. Faecal surveys showed to indicate patterns of habitat selection by vertebrates (Leopold et al. 1984) and to provide an inexpensive and convenient method for investigating aspects of animal ecology (Putman 1983). Faecal sampling was proven to be a successful method to determine distribution of many animals such as macropods (Johnson & Jarman 1987; Hill 1982), rufous-hare wallaby (Lundie-Jenkins 1993), common brushtail possum (Munks et al. 1996) and koala (Sullivan et al. 2002; Achurch 1989; Moon 1990; Lunney et al. 1998). Few studies on the distribution and abundance of arboreal marsupials have been conducted in the Newholme region. However, it is believed that several of the study species occur at low densities (Clark 1980 unpublished). Despite the study of Davey (1990) in which spotlighting was found to be the most efficient method for surveying arboreal marsupials, several other studies have put question marks with the efficiency of spotlighting as a survey method (Lindenmayer et *al*. 2001) especially when species densities were low (Foley 1981). Davey (1990) did not include faecal sampling in his review of sampling methods but Lindenmayer (2001) and Foley (1981) did. Moreover, Putman (1983) supports the use of an indirect sampling technique such as faecal pellet surveys, to establish patterns of habitat use, where it is thought the animal species in question occurs in low densities. Therefore was decided to use faecal pellet survey instead of another census method for determining distribution of the arboreal marsupials.

To use a faecal pellet survey to determine habitat selection or food tree selection, two assumptions were made: i) arboreal marsupials defecate while present in trees and not while moving from one tree to another ii) the presence of scats underneath a tree indicate that that particular tree has been used as forage. Findings from previous studies on behaviour and feeding preferences show that the application of these assumptions is valid for koala (Robbins and Russell 1978; Hindell et al. 1985; Smith 1979; Sullivan et al. 2003; Lunney et al. 1998).

The validity of the faecal survey depends on scat detect ability, which may be influenced by factors such as i) environmental variation and search ability, ii) scat durability and decomposition (Smith 1964; Putman 1983; Roberts 1998), iii) identification of the scats. Scat detect ability largely depends on environmental variation throughout the study area, particularly ground cover. In the study area the ground cover density ranges from 0 to 100%, higher cover density making it harder to detect scats. Cover density partly depends on tree species, since bark shedding trees make it more difficult to detect scats, especially in the area around the base of the tree. Type of cover is also of influence on detect ability of scats (e.g. scats are more easily detected in grass than in ferns). Therefore, more time was spent searching underneath trees with higher ground cover.

In time, scats are more difficult to detect due to decomposition by weather influences. Also, scats decompose and sometimes totally disappear because of invertebrate activity (ants, beetles and larvae) (Johnson and Jarman 1987; Cochran and Stains 1961; Common and Horak 1994). In this study temporal scales (e.g. seasonal change in habitat selection) were not included and therefore all scats, fresh and old (as long as they were still identifiable), were taken into account.

For identification of scats the book “Tracks, scats and other traces” (Triggs 1996) was used. This book gives suggestions how to identify scats best (e.g. break the scat open), gives a detailed description of scats and includes coloured photos. Scats of the study species were easily distinguished from scats of other animals occurring in the study area (see appendix II). Most scats of different animal species were distinguished with confidence due to different size, shape and odour (see appendix II). In some cases, scats of different species can be difficult to distinguish, depending on age of the animal, age of the scat or the individual animal. Brushtail possum scats and koala scats can look alike as well as ringtail possum and greater glider scats. To validate the accuracy of identification, 55 samples were taken and sent to Mrs. B. Triggs for re-identification, which resulted in a 90% accuracy of the original identification. For this study, scat detect ability is considered sufficient for a valid faecal pellet survey. Therefore faecal pellet survey is considered a good method to determine species distribution, habitat selection and food tree selection in this study.

Sampling technique – data collection

According to Australian Map Grid (AMG) coordinates, grid reference markers (an 1.5m steel marker post with red tape around the top) were set out at a 200 meter interval throughout the study area (see appendix III) by Smith in 1987, which provided the basis for the faecal pellet survey. All study species are arboreal marsupials; therefore only area covered with trees (forest) was sampled. At each marker the nearest five trees with a tree diameter measured at breast height (dbh) larger than 30 cm (Roberts 1998) were sampled. In total 230 sites, thus 1150 trees were sampled. Scats for each study species were considered to be either present or absent underneath each sampled tree.

Even though koalas deposit a disproportional high amount of their scats within 1 m of the base of trees (Ellis et. al 1998), it was still necessary to search further away from the base to detect scats of other study species, since they spend the night in a hollow tree and therefore do not rest nor defecate at a place between the trunk and a major branch. With larger trees (larger tree diameter, larger canopy diameter) more time was spent searching underneath the tree, so search time per area would be equal amongst sampled trees. More time was also spent with higher ground cover and special attention was given to areas underneath major branches and the base of the tree. A maximum of five minutes per tree was spent. Besides tree species, the following individual tree characteristics were recorded: canopy density (%) (Florence 1996), canopy diameter (m), tree diameter measured at breast height (dbh) (cm). The individual tree characteristics recorded and collected from existing data are surrogate measures for tree size: high canopy density, large canopy diameter and large tree diameter indicate a large tree size. The number of hollows, which are required for shelter and protection for brushtail possum, ringtail possum and greater glider (Kehl and Borboom 1984), increase with diameter (Lindenmayer 2000). Lindenmayer et al. (1990; 1991) found hollows to be an explanatory variable in predicting probability of occurrence of arboreal marsupials. For koalas it has been suggested that they select for particular trees with dense foliage such as clumps of mistletoe, which are most frequent in large trees, to assist in thermoregulation (Hindell and Lee 1987; Hasegawa 1995) by maximizing shade from direct solar radiation. In addition, it has been suggested that larger trees also provide higher quality food resources (Incoll 2001). Alternatively, large trees may provide more shelter and greater security from predators for koalas. Therefore, koala, brushtail possum, ringtail possum and greater glider are expected to select for larger (hollow-bearing) trees with high canopy density.

Additionally, at each marker, environmental variables were recorded: ground cover (%), understory density (%), understory height (m), density of trees (scale of 1-5), rockiness (%).Some authors (Lindenmayer et al. 1990c; Lindenmayer et al. 1991a; Smith and Lindenmayer 1992) showed that understory density, particularly *Acacia* density, is an important factor in predicting the occurrence of marsupial species. High understory density and high tree density allow easier movement within the forest, easier access to nests for non-gliding species (Pausas et al. 1995) and may decrease predation risks. Some species of understory may also serve as a food resource for arboreal marsupials. Therefore arboreal marsupials are expected to be positively associated with understory density, understory height, ground cover and tree density. Rocky outcrops have not yet been considered as an explaining variable in the distribution of arboreal marsupials. However, the study area is characterized by rocky outcrops which seem to occur mostly on steep slopes. To show whether rockiness has any influence on the distribution of large marsupials it was included in the logistic regression models. Steepness of slope has been found to have a positive relationship with arboreal marsupials (Lindenmayer et al. 1991; Cork & Catling 1996). Therefore, rockiness is expected to be positively associated with arboreal marsupials.

Existing environmental variables collected from the UNE GIS database (table 5) included: hollows (1-hollows, 2-no hollows), dbh (cm), canopy height (m), elevation in the form of a digital elevation model (DEM) (m), slope (°), dead trees (number of dead trees/ha), soils (1-red podzolics, 2-brown soils, 3-brown earths, 4-yellow earths), tree association (table 2), rainfall (mm), drainage (1-streams, 2-no streams). Bennet et al. (1991) found elevation to be an explaining factor in the distribution of arboreal marsupials: brushtail possum was found at lower elevation, koala at middle elevation and greater glider occurred mostly at higher elevation. In addition, Kavanaugh et al. (1995) found that koalas were associated with lower elevation forests in north-eastern New South Wales. In this study an overall high elevation occurs (1100 – 1400m range) and therefore elevation is expected to predict the absence of the brushtail possum and koala (negative association) and to predict the presence of the greater glider (positive association). Since ringtail possum has been found to occur over an entire elevation range (Bennet et al. 1991), elevation is not expected to be an explaining factor in predicting the occurrence nor the absence for the ringtail possum. Pausas et al. (1995) found the amount of decorticating bark and therewith the availability of arthropods, soil nutrients and the quality of leaves to be the main factors predicting the occurrence of arboreal marsupials. These factors were surrogate measures for the availability and quality of food. Since the number of dead trees, soils and tree association can also be treated as indirect measures for the availability and quality of food, these factors are expected to influence occurrence of arboreal marsupials. A positive association is expected with the number of dead trees, fertile soils and the tree associations growing on these soils.

Literature suggests that koalas in relatively dry environments are dependent, to some degree, on the availability of water (Gordon et al. 1988; Melzer & Lamb 1994). Ellis et al. (1995) suggest that koalas may respond to a temperature/moisture gradient within available habitats that minimizes heat stress and maximizes water intake. This is supported by the study of Sullivan et al. (2003) which found rainfall to be one of the most important factors affecting habitat selection of koalas. The final drainage raster used for the regression model contains values that indicate the distance to water (gullies and creeks). Water availability is expected to predict the presence of koalas and therefore a positive association with rainfall and a negative association with drainage are expected.

Table 2. Vegetation associations occurring in the Newholme region at Mt. Duval

Species Code	**Vegetation Association**
1	*E. obliqua / E. viminalis / E. nobilis*
2	*E. laevopinea / E. melliodora / E. bridgesiana*
3	*E. laevopinia / E. caliginosa / E. melliodora / E. bridgesiana*
4	*E. youmanii / E. bridgesiana*
5	*E. dalrympleana*
6	*A. floribunda / E. laevopinea / E. dalrympleana*
7	*E. melliodora / E. balakelyii*
8	*E. nova-anglica / E. viminalis*
9	*E. viminalis*
10	*E. laevopinea / E. dalyrmpleana / E. bridgesiana*
11	pasture

DATA ANALYSES

Landscape scale analyses

Given the explicit importance of spatial habitat variables in the species ecology, it was decided to use Geographical Information Systems (GIS) as a tool to data management and analysis. Spatial analyses of the databases were performed using ESRI's Arc/Info GIS (ESRI 2004). The process of the landscape scale analysis is shown in figure 1. Different steps taken in the analyses are explained in table 3 and a description of the variables involved is shown in table 5. Tables of collected environmental data and spatial data collected with a GPS were joined (figure 1: step 1) and transformed into a vector file (figure 1: step 4). After transformation from vector to raster (figure 1: step 5), the first set of distribution maps were created based on the species presence-absence using the inverse distance weighted spatial interpolation (figure 1: step 14). Spatial interpolation creates a continuous surface, e.g. it predicts values for all cells in a raster from a limited number of sample points. The inverse distance weighted technique (IDW) is based on the geographical principle that elements close to one another are more alike (ESRI 2004). So, to predict a missing value, it will look at the value of the neighborhood. As the distance increases the values are weighted inversely, hence the name IDW. This interpolation technique was used, since it is accurate with systematic sample points. The outcome of the IDW technique are rasters with cell values between 0 and 1, which represent the probability that the species is present (first set of distribution maps).
Existing data was reclassified (figure 1: step 2.1 – 2.4), so they could be considered ratio scale variables and in addition, they were re-sampled to a cell size of 30 meters. The drainage file was transformed from vector to raster (figure 1: step 3), after which the distance to available water was calculated (figure 1: step 7). The distance to available water is calculated by measuring the straight (euclidian) distance from each cell in the raster to the closest drainage point (e.g. streams and gullies).

Regression analysis is a statistical method that can be used to explore relations between species and environment, on the basis of observations on species and environmental variables at a series of sites. Animal species may be recorded in the form of abundances or merely as being present. In contrast with ordination and cluster analysis, it is not possible to analyze data on all species simultaneously. Each regression focuses on a particular species and on how this particular species is related to environmental variables. In terminology of regression analysis, the species presence is the response variable and the environmental variables are explanatory variables. Logistic regression is a binomial generalized linear model suited for presence/absence data, as predictions are restricted between 0 and 1 they are directly interpretable as the estimated probability of the modeled event (Hosmer and Lemeshow 1989), which in this study is the presence of pellets and therewith animal species. In this study, the environmental variables collected during faecal sampling and the existing environmental variables (table 5) were used as explanatory variables. In addition, the influence of the proximity and presence of other animal species to the species in question has been used as an explanatory variable, to show whether competition affects habitat selection (figure 1: step 12). The influence of the proximity of one species to another was assessed by firstly calculating the inverse distance from each cell to all sampled active sites and secondly by summing these values. By calculating the inverse distance, a higher weight is given to sampled active sites nearby. So, when a species occurs at a sampled site closeby a given location, then the influence of this species at this locoation is higher than when it would occur at a samped site further away. For each species a grid was created in which cell values represent the sum of the inverse distance from that particular location to known active sampled sites. All cell values range between 0 and 1, where higher values represent a higher influence of the species in question on that location.

The process of step 12 is further shown in figure 2. Different steps taken in the analyses are explained in table 4. Animal species rasters [koala, brushtail, ringtail and greater glider] contain value 1 (absence) and 2 (presence) and were reclassified to 1 (presence) and "no-data" (absence) values (figure 2: step 1.1 – 1.4). Then these values were reclassified to 1 (presence) and 0 (absence) (figure 2: step 2.1 – 2.4). N.B. The animal species rasters contain value 1 for all active sites, value 0 for all non-active sites and "no-data" for all other cells, whereas presence rasters [p_k, p_b, p_r and p_g] contain value 1 for all active sites and value 0 for all other cells. The presence rasters were transformed to vector data (figure 2: step 4.1 – 4.4). Then all active sites (cells with values greater than 0) were selected and the sum of the inverse distance from all cells to all active sites was calculated (see figure 2: step 6.1 – 6.4), herewith transforming the vector data into a .dat file (figure 2: step 5.1 – 5.4). Step 3 to step 6 were written in Arc Macro Language (AML) (appendix III).

Input for the regression analyses in the form of an ASCII file was produced using the SAMPLE function in ARCGRID (figure 1: step 8 – 9). The SAMPLE function is performed for each animal species and creates a file listing the x and y coordinates of cells selected in a 'mask raster' and the respective cell values of other specified rasters (ESRI 2004). Thus, the mask raster defines which cells were sampled and the other specified rasters are those rasters whose values were sampled based upon the mask raster. In this study, the mask raster were the animal species raster, containing presence-absence data for the sampled sites and the other specified rasters were the explanatory variable rasters. Since the cell values are extracted at the exact locations of the cells in the mask (sampled sites), an IDW was performed on all environmental variables (figures 1: step 6) to create a continuous surface. Otherwise, the ASCII file would list missing values.

Multiple logistic regression analysis was carried out for each animal species (figure 1: step 10) to: i) predict the probability of a species' presence at each location based on environmental variables ii) assess which environmental variables contribute most to the species' response and which environmental variables appear to be unimportant. Based on the logistic regression model, a second set of distribution maps for each study species was created. The values shown in these distribution maps represent the probability ($0 < P < 1$) of animal presence at a given cell, which is represented by the equation:

$$P = \frac{e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots \beta_n X_n}}{1 + e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots \beta_n X_n}}$$

where 'β' is the value derived from the regression model and X is the explanatory variable (table 14).

Finally, these maps were compared with the first set of distribution maps created based solely on presence-absence of the species (figure 1: step 14), by subtracting the first set of distribution maps of the second set.

Table 3. Steps taken (1 – 12) in landscape scale analyses (figure 1)

Activity	*Objective*
1 join tables	to join two tables into one
2 reclassify	to reclassify so variables become ratio scale and have equal cell sizes
3 transformation	to transform from a vector file to a raster
4 transformation	to transform from a database excel file into a vector shape file
5 euclidian distance	to calculate the euclidian distance from drainage
6 inverse distance calculation	to create a continuous surface for each landscape variable
7 sample function	to get the values of each grid using the animal species raster as a mask grid
8 transformation	the output of the sample function is an ascii file
9 multiple logistic regression	to determine which variables influence the distribution of the animal species
10 create raster	to create a distribution map on basis of the regression model and herewith taking environmental variables and presence / absence of other species into account
11 analysis 12	to calculate the sum of the inverse distance for all cells to all active sites
12 inverse distance calculation	to create a distribution map for each animal species taking only the presence / absence into account

Table 4. Steps taken (1 - 6) to create a competition raster for each species (figure 2)

Activity	Objective
1 reclassification	to reclassify active sites which receive value 1; others cells are given “no-data”
2 reclassification	to reclassify “no-data” values into value 0
3 combine	to combine three grids to one grid; cells receiving the maximum value of the combined grid – this allows for competition analysis
4 transformation	to transform grid file to point file
5 transformation	to transform point file to .dat file as part of distance calculation
6 inverse distance calculation	to calculate the sum of the inverse distance for all cells to all active sites

Table 5. Environmental variables measured at each site and used in the analyses as independent variables

Variable	*Scale*	*Domain [unit]*
existing environmental variables		
hollows	nominal	hollows / no hollows
rainfall	ratio	725 – 975 [mm]
digital elevation model (dem)	ratio	1100 – 1400 [m]
drainage	nominal	water drainage point / no data
forest	nominal	forest / pasture / not classified
diameter at breast height	ratio	30 – 100 [cm]
soils	nominal	red podzolics/brown soils/brown earths/yellow earths
canopy height	ratio	0 – 50 [m]
dead trees	ratio	0 – 226 [no/ha]
tree association	nominal	see table 2
collected environmental variables		
cover	ratio	0 – 100 [%]
rockiness	ratio	0 – 100 [%]
tree density	ratio	1 – 5
shrub height	ratio	0 – 600 [cm]
shrub density	ratio	0 – 100 [%]

Figure 1. Creation of two different sets of distribution maps using IDW and a logistic regression model for each species at landscape level

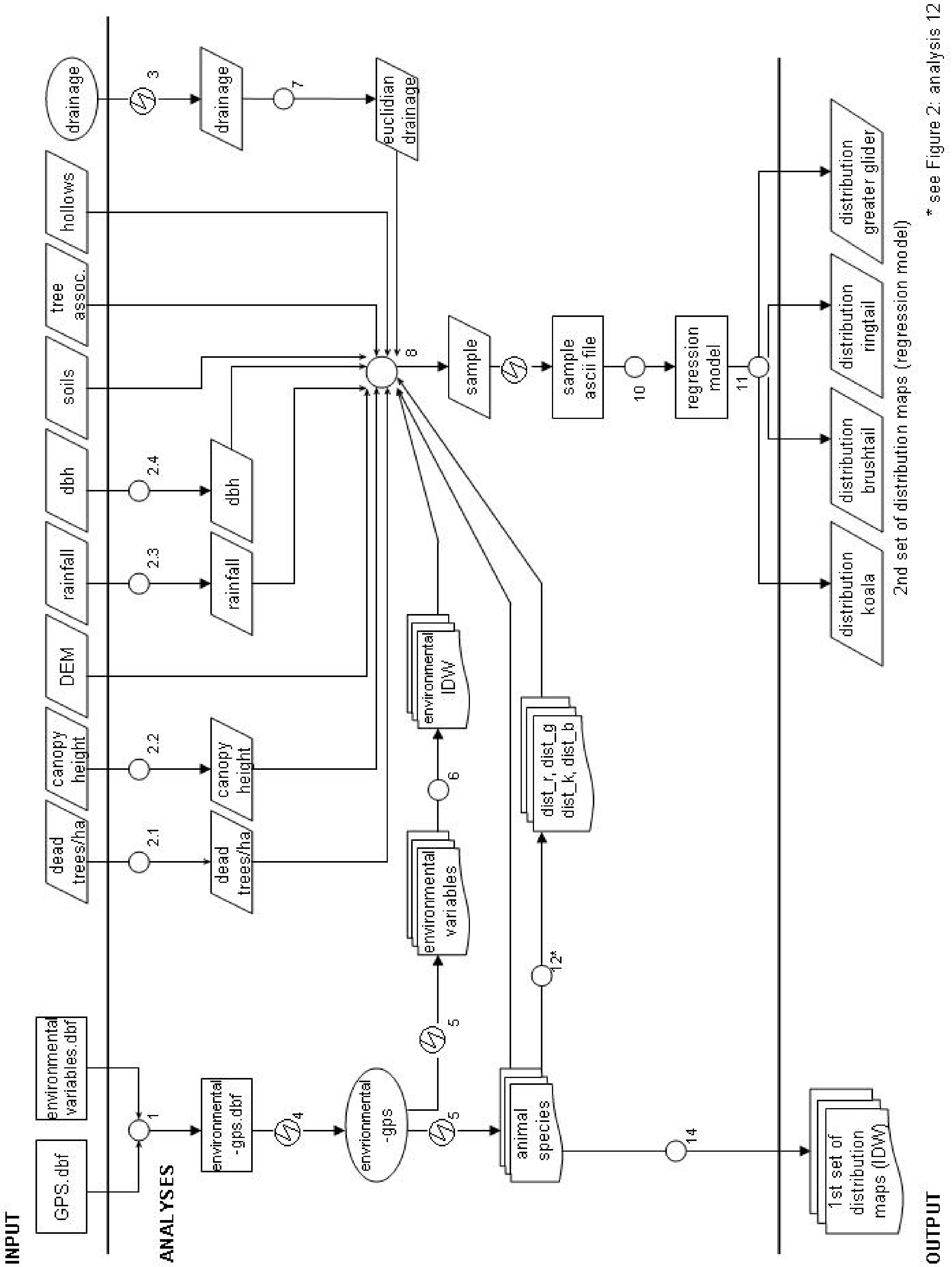
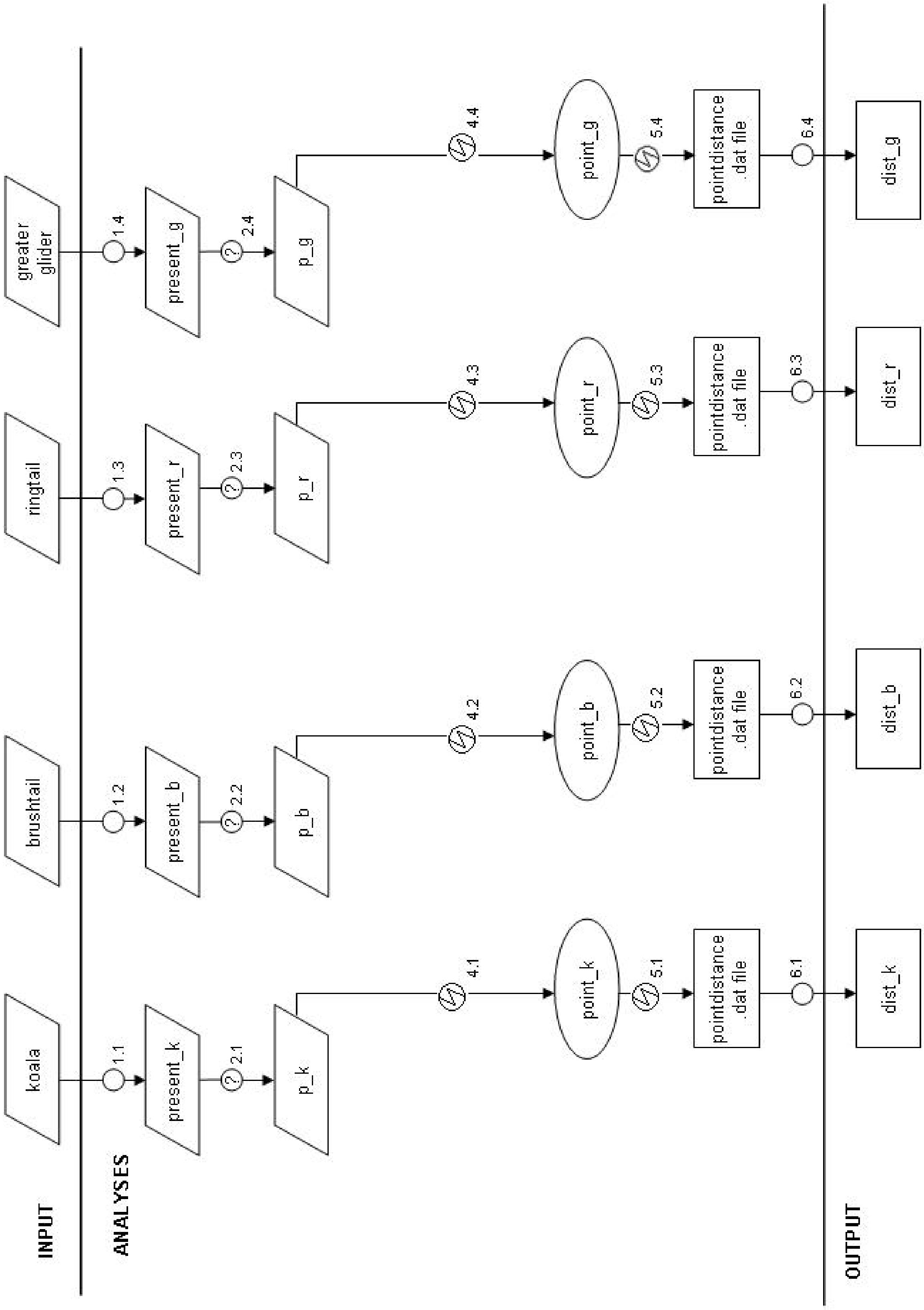


Figure 2. Assessing the influence of the proximity of one species to another by calculating the sum of the inverse distance from each cell to all sampled active sites (figure 1: analysis 12)



Tree scale analyses

The process of the tree scale analyses is shown in figure 3. Different steps taken in the analyses are explained in table 6 and a description of the variables involved is given in table 7.

Active sites

To avoid potential for biasing results whereby the recorded absence of faecal pellets at a given sampled site was possibly a consequence of factors other than poor habitat quality *per se*, sampled sites were categorized as 'active' on the basis of whether scats were present or absent underneath one or more of the 5 trees sampled respectively (figure 3: step 2) (Lunney et al. 2000; Philips et al. 2000). Only these 'active' sites were considered for analyses at tree scale.

Preference for tree species

Recent studies have concluded that the use of counts of accumulated faecal pellets for determining tree species preferences is problematic (Melzer et al. 1994; Hasegawa 1995; Pahl 1996). Therefore the example of Philips et al. (2000) was followed and faecal pellets were considered to be either present or absent, thus transforming the association between tree species and their use by the different study species into that being measured by a binary variable. Use of trees can be compared with the proportion of the same tree species present in the area. If the study species are not selective in their utilisation of trees, then the frequency of use will be proportional to the relative frequency of occurrence of that species of tree, i.e. the Relative Exploitation Index (RE) equals '1' (White & Kunst 1990).

Equation 1: Relative Exploitation Index (RE) = Ui / Ai

Where 'Ui' is the relative utilization of species 'i' (percentage of trees of species i with scats found underneath of the total number of trees with scats found underneath) and Ai is relative tree availability of species 'i' (percentage of trees sampled of species 'i' of the total number of trees sampled)

If the expected use of a tree species is significantly different from the observed use, then the preference or avoidance can be expressed as either "over" or "under" exploitation; RE>1 or RE<1 respectively. The RE is a simple method of assigning preference ranks to trees, based on relative proportions of use to availability (White & Kunst 1990; Jurskis et al. 1994; Jurskis & Potter 1997). The Preference Index (Martin 1985a; Hindell et al. 1985) is a different way of expressing the same disproportionate use of trees and was also used by Jurskis et al. (1994) and Hasegawa (1995).

Equation 2: Preference Index (Pi) = (Ui / Ai) / T

Where 'Ui' is the relative utilization of species 'i', 'Ai' is the relative tree availability of species 'i' and

$T = \sum_{i=1}^{n} \left(U_i / A_i \right)$, 'n' is total number of tree species.

The Preference Index does not necessarily convey importance, and some tree species that may be highly preferred may not contribute significantly to the overall population survival. For example, a particular tree species that is considered highly preferred by a marsupial, but has a low relative abundance may be less important than a tree species that is preferred slightly less, but which is reasonably abundant. The Importance Index provides a more realistic appraisal of how marsupials are using the trees available (White

& Kunst 1990). The Importance Index was derived by adjusting the Preference Index to reflect the preference for a species of tree, as well as the abundance of trees of that species (Equation 3).

Equation 3: **Importance Index (Ii) = (Pi * Ui) / S**

Where ‘Pi’ is the preference index of species ‘i’ (equation 2), ‘Ui’ is the relative utilization of species ‘i’,

and $S = \sum_{i=1}^{n} \left(P_i * U_i \right)$, ‘n’ is total number of tree species.

The use of Importance Index overcomes problems associated with floristic heterogeneity because the index gives weight to common species that are relatively more uniformly distributed than uncommon species (Roberts 1998). The Relative Exploitation Index, Preference Index and Importance Index were calculated for each animal species (figure 3: step 4).

Preference for tree characteristics and niche differentiation analyses

Tree data were divided in used trees (trees with one or more scats found underneath) and non-used trees (trees without scats found underneath) for each animal species (figure 3: step 3.1 – 3.2). To show whether marsupials have a preference for certain tree characteristics, data for used trees and non-used trees were tested for differences (within species analyses). These analyses were performed for each tree characteristic, using the Mann-Whitney test (figure 3: step 5). The Mann-Whitney test is used when testing for differences between two groups (used vs. non-used) with non-normal data (Field 2000). Used tree data of all study species were pooled and between species analyses were performed for each tree characteristic to study niche differentiation using the Kruskal-Wallis test (figure 3: step 6). This test is used when testing for differences between more than 2 groups (koala, brushtail, ringtail and greater glider) with non-normal data (Field 2000). Scheffe’s posthoc test was performed to show between which species possible niche differentiation occurred.

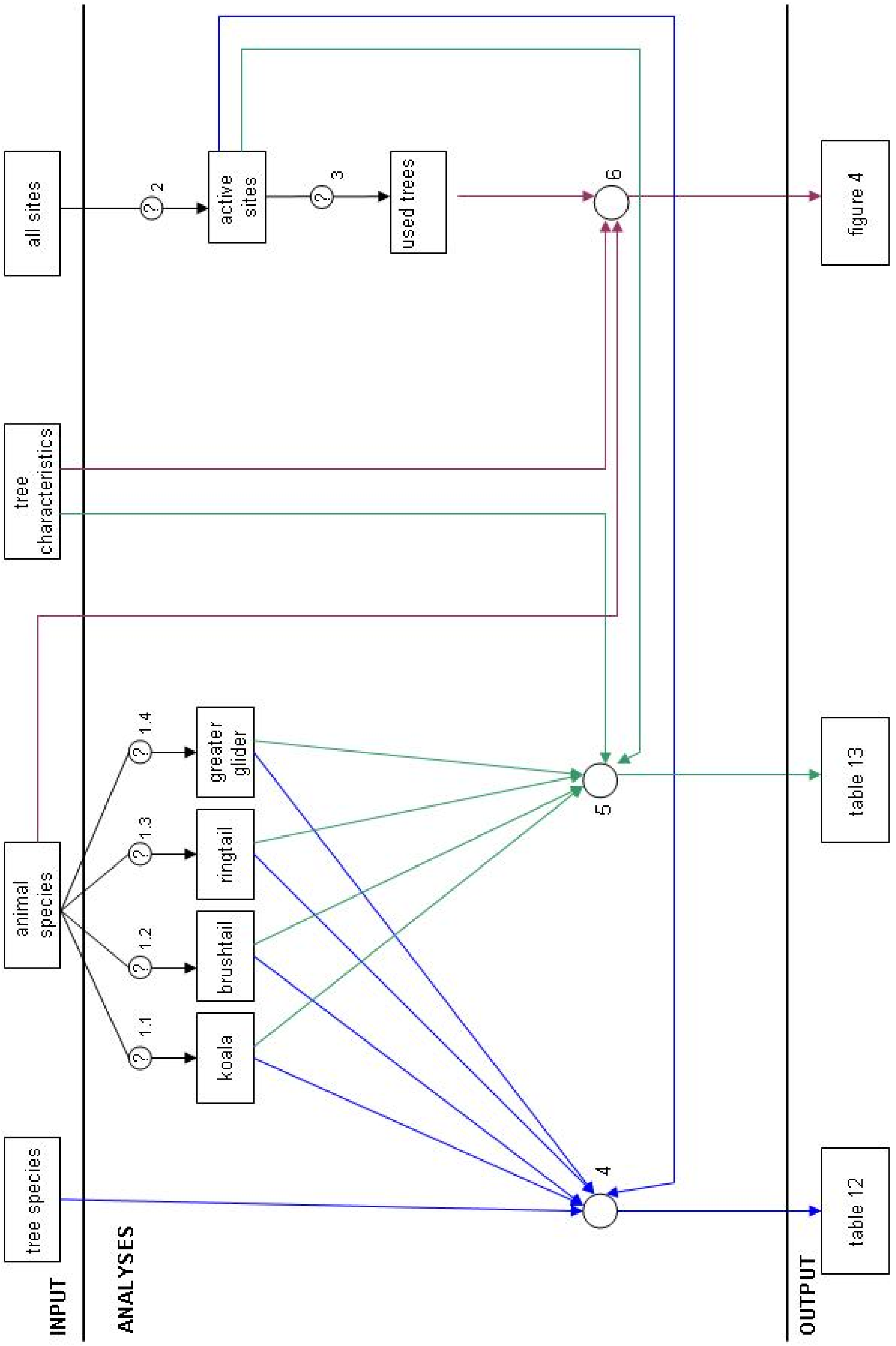
Table 6. Description of the steps taken in the tree scale analyses shown in figure 3

Activity	Objective
1 selection	to select one animal species
2 selection	to select active sites
3 selection	to select trees that have scats underneath
4 tree preference analysis	to calculate tree preference taking only active sites into account
5 Mann-Whitney test	to show whether a preference for certain tree characteristics exists within species taking only active sites into account (1 analysis per species → 4 analyses)
6 Kruskall-Wallis test	to show whether niche differentiation between species exists taking only active sites into account (all species analysed together → 1 analysis)

Table 7. Tree scale analyses variables

Variable	*Scale*	*Domain [unit]*
diameter at breast height	ratio	5 – 125 [cm]
canopy density	ratio	10 – 80 [%]
canopy diameter	ratio	1 – 25 [m]
tree species	nominal	see table 10
animal species	nominal	koala, brushtail, ringtail, greater glider
all sampled sites	nominal	active sites, inactive sites

Figure 3. Within and between species analyses at tree scale to respectively test for tree characteristic preferences for each species and niche differentiation between species



RESULTS

A total of 230 sites were sampled with a total number of trees of 1150. A site showed evidence of species activity if scats of the species in question were found underneath one or more of the five sampled trees at that site. Of the 230 sites sampled, 115 (50%) showed evidence of koala activity, 41 (18%) of brushtail possum activity, 39 (17%) of ringtail possum activity and 159 (69%) of greater glider activity (table 8). Only these active sites were used in the tree scale analyses, thus of the 1150 trees sampled, 575 were used for analyses for koala, 205 for brushtail possum, 195 for ringtail possum and 795 for greater glider.

Table 8. Percentage of active sites for each species

species	no. sites sampled	no. active sites	% active sites
koala	230	115	50.0
brushtail	230	41	17.8
ringtail	230	39	17.0
greater glider	230	159	69.1

Landscape analyses

A summary of the logistic regression model for the presence-absence of the koala, brushtail possum, ringtail possum and greater glider can be found in table 9. Variables not taken into the regression model did not significantly contribute to the model. Rockiness was highly correlated with slope (p.c. = 0.402 p<0.000) as expected and with tree density (p.c. = 0.377, p < 0.000) using Pearson's correlation coefficient.

The logistic regression model of ringtail possum and greater glider showed that they are negatively associated with tree diameter. This is in contrast to many other studies which found tree diameter to have a positive association with the presence of arboreal marsupials (Pausas et al. 1996; Lindenmayer et al. 1990a, 1991a; Incoll 2001; Smith and Murray 2003). The regression models are also in contrast with the results found at tree scale that show that koala, brushtail possum and greater glider select trees with larger tree diameter. The tree diameter raster (collected from the existing UNE GIS database) originally contained cells with a size of 100x100m before it was re-sampled to cell sizes of 30x30m for this study. Apparently, during original sampling when part of the original 100x100m area was an open site a very low value of tree diameter was being assigned to the cell. When the location of a site sampled during this study 'falls into' a cell of which the original 100x100m is mostly open area, the result of the 'sample' function (see methods) is biased: the outcome contains lower values of tree diameter than it should be. During this study, sites were only sampled in forested area; however, for both greater glider as ringtail possum 20% of the tree diameter values are smaller than 20 cm. Therefore it is decided to take tree diameter out of the logistic regression model and to create second models excluding tree diameter for ringtail possum and greater glider. Table 9 shows the summary for the logistic regression model for ringtail possum and greater glider including as well as excluding (c1/d1 and c2/d2 respectively) tree diameter as an explanatory variable. No other variables could contribute to the logistic regression model for ringtail possum instead of tree diameter, so the rest of the model stayed the same as before: rockiness and tree density are the variables explaining ringtail distribution. When taking tree diameter out of the logistic regression model for greater glider, canopy height did not contribute significantly to the model anymore. So, factors for explaining distribution of greater glider are rockiness, tree density, ground cover and proximity to koala.

Koala. The regression model showed that proximity to greater glider and rockiness contributed to the presence (positive β value) of koala. Elevation and proximity to brushtail possum contributed to the absence (negative β value) of koala. The model could predict the presence of the koala with more accuracy than its absence (77.3% versus 65.5%, respectively). The negative association with brushtail possum proximity was expected and supports hypothesis 1. The negative association with elevation and the positive association with rockiness were also expected. However, greater glider proximity was expected to have a negative influence on the presence of koala instead of the positive influence found.

Common Brushtail Possum. For brushtail possum, greater glider proximity and tree density contributed to the presence of brushtail possum, while koala proximity and elevation contributed to the absence of brushtail possum. The model could predict the presence of brushtail possum with more accuracy than its absence (99.5% versus 12.2%, respectively). The negative association with koala proximity was expected and supports hypothesis 1. The negative association with elevation and the positive association with tree density were also expected. However, greater glider proximity was expected to be negatively associated with brushtail possum instead of positive association found.

Common Ringtail Possum. Rockiness and tree density contributed to the presence of the ringtail possum as expected. The model could predict the absence of ringtail possum with more accuracy than its presence (0% versus 100%, respectively).

Greater Glider. Rockiness, tree density, cover and proximity to koala all contributed to the presence of greater glider. The model could predict the presence of the greater glider with more accuracy than its absence (86.0% versus 60.8%, respectively). Koala proximity was expected to have a negative influence on the presence of greater glider instead of the positive influence that was found. The positive association with rockiness, tree density, canopy height and cover was expected.

The first set of distribution maps for each species based only on presence-absence data only using IDW are shown in appendix V and the second set of distribution maps based on the logistic regression model for each species are shown in appendix VI. The comparison between the two sets of distribution maps shows that the IDW method expected a higher probability of occurrence around active sites than the regression model method when, for a particular species, only a few sites sampled were found to be active sites (ringtail possum, brushtail possum). Around inactive sites the regression model method expects a higher probability of occurrence than the IDW method. In general, the regression model method expects higher probabilities than the IDW method when few active sites for the species were found. However, when relatively many sampled sites are active (greater glider 70% active) the opposite is observed. Around inactive sites the IDW method expects a higher probability of occurrence than the regression model. In general, the IDW method expected higher probabilities than the regression model method when many active sites were found.

These results suggest that creating distribution maps based on the logistic regression model results in a smoother transition because it includes environmental variables instead of presence-absence data only. Therefore, the logistic regression models including environmental variables, presence and proximity to other species are assumed to predict the probability of the presence or absence of the arboreal marsupials more accurately than the IDW method using only presence-absence data.

Table 9. Variables included in logistic regression model to predict the presence of koala, brushtail possum, ringtail possum and greater glider (n=261; Sites P.C. = predicted correct)

	Parameter	Value (β)	sig. P
(a) **Koala**	constant	6.987	0.019
R^2 = 0.281	rainfall	-0.012	0.002
Sites P.C.	rocks	0.022	0.000
Present 77.3%	proximity greater glider	0.022	0.001
Absent 65.0%	proximity brushtail	-0.021	0.000
(b) **Brushtail Possum**	constant	17.799	0.000
R^2 = 0.199	elevation	-0.020	0.000
Sites P.C.	tree density	0.328	0.016
Present 99.5%	greater glider	0.048	0.001
Absent 12.2%	proximity koala	-0.028	0.022
(c1) **Ringtail Possum**	constant	-2.617	0.000
R^2 = 0.111	dbh	-0.015	0.050
Sites P.C.	rocks	0.013	0.024
Present 0.0%	tree density	0.323	0.016
Absent 99.5%			
(c2) **Ringtail Possum**	constant	-3.122	0.000
R^2 = 0.086	rocks	0.011	0.036
Sites P.C.	tree density	0.282	0.032
Present 0.0%			
Absent 100%			
(d1) **Greater glider**	constant	-4.288	0.000
R^2 = 0.380	rocks	0.015	0.003
Sites P.C.	tree density	0.239	0.035
Present 87.3%	canopy height	0.063	0.021
Absent 64.7%	dbh	-0.024	0.007
	cover	0.015	0.017
	proximity koala	0.021	0.002
(d2) **Greater glider**	constant	-4.033	0.000
R^2 = 0.348	rocks	0.016	0.001
Sites P.C.	tree density	0.259	0.018
Present 86.0%	cover	0.015	0.015
Absent 60.8%	proximity koala	0.020	0.002

Tree scale analyses

Tree species preference

Tree data were divided in non-used trees (trees without scats found underneath) and used trees (trees with one or more scats found underneath) for each animal species (table 10).

Table 10. Percentage of trees with scats underneath at active sites for each study species

species	no. trees sampled	non-used trees (%)	used trees (%)
koala	575	366 (36.7%)	212 (63.3%)
brushtail	205	140 (68.3%)	65 (31.7%)
ringtail	195	141 (72.8%)	54 (27.2%)
greater glider	795	438 (55.1%)	357 (44.9%)

The Relative exploitation Index, Preference Index and Importance Index for each study species are shown in table 12. The legend of the tree species numbers can be found in table 11. *E. laevopinea* ranks as the most important tree species for all animal species because it is over exploited (RE > 1) for koala, brushtail possum and greater glider and it has a relative high abundance. Even though *E. laevopinea* is slightly under exploited by the ringtail possum (RE = 0.98) it still has the highest rank in importance, because of its relative high abundance. *E. viminalis* and *E. youmanii* rank as the least importance tree species for all arboreal marsupials.

Many studies on tree species preference of koala have been conducted (e.g. Hindell and Lee 1987; Bennet et al. 1991; Philips et al. 2000). Bryan (1997) conducted a survey of published literature on koala habitat selection that revealed that out of the 600 (approx.) known species of Australian eucalypt, 33 species have been found to be preferred and 45 species utilized. So far, no studies have noted *E. lavopinea* as a preferred or utilized food tree species by koalas. Koalas also over exploit *E. dalrympleana* (ranked 2nd in preference), which due to its relative low abundance does not rank high in importance (5th rank). This is consistent with literature that noted *E. dalrympleana* as a utilized tree species. *E. viminalis* was found to rank very low in preference and ranked last in importance to koala, which is in contrast with other studies that found *E. viminalis* to be a preferred tree species (e.g. Hindell et al. 1984; Reed et al. 1990).

Few studies have included tree species utilization or preference by brushtail possum, ringtail possum or greater glider. Wormington (2002) found the density of brushtail possums to be positively correlated with *E. tereticornis* in South-east Queensland, a tree species that does not occur in Newholme region. Bennet et al. (1991) studied habitat use of arboreal mammals in North-eastern Victoria, where amongst others *E. viminalis*, *E. obliqua*, *E. dalrympleana*, *E. bridgesiana*, *E. blakeyi* and *E. melliadora* occurred. Of these tree species only *E. bridgesiana* and *E. melliadora* were (slightly) used by brushtail possum (total of 7% of the observations) (Bennet et al. 1991). In this study, the brushtail possum is also found to use *E. bridgesiana* (ranked 1st in preference), which only ranks 3rd in importance, due to its relative low abundance. *E. lavopinea* is over exploited by brushtail possum and ranked 1st in importance. The ringtail possum over exploit *E. nobilis* (ranked 1st in preference), *E. bridgesiana* (ranked 2nd in preference), and *E. obliqua* (ranked 3rd in preference), which respectively rank 3rd, 5th and 2nd in importance due to their relative abundance. Greater glider over exploit *E. nobilis*, *E. viminalis, E. caliginosa*, *E. laevopinea, E. oblique* (in order of preference rank), which respectively rank 4th, 8th, 3rd, 1st and 2nd in importance due to their relative abundance. *E.*

viminalis was found to preferred (2nd rank) by greater glider, which is consistent with the results of Bennet et al. (1991). However, due to the relative low abundance of *E. viminalis*, it ranks very low in importance to greater glider.

It seems that tree species preference for arboreal marsupials may differ between regions. This has been confirmed for koalas that are known to prefer to feed on one or two locally available species in a region but also prefer individual trees (Hindell and Lee 1987). These regional differences may be due to varying nutrient concentration and/or to qualitative or quantitative variation in the defensive compounds present in some eucalypt species throughout their geographic range (Moore et al. 2001). It is also possible that koalas in different parts of their range may have quite different responses to local environmental conditions and to local eucalypts (Moore et al. 2001). A possible explanation why *E. lavopinea* has so far not been noted as a utilized tree species might be that it does not occur in other regions of Australia or that it occurs in association with other eucalypt species that are more preferred in that region. Moreover, no studies on tree use by arboreal marsupials in the Newholme region have been published.

Table 11. Tree species belonging to each tree species number (table 12)

tree species no.	tree species name
1	*Eucalyptus laevopinea*
2	*Eucalyptus melliadora*
3	*Eucalyptus dalrympleana*
4	*Eucalyptus bridgesiana*
5	*Eucalyptus caliginosa*
6	*Eucalyptus nobilis*
7	*Eucalyptus obliqua*
8	*Eucalyptus viminalis*
9	*Eucalyptus youmanii*

Tree characteristics preference

Within species analysis

The median and interquartile range of each tree characteristic for each species is shown in table 13. The Mann-Whitney test showed there was a significant difference in tree diameter ($p < 0.01$) and tree canopy diameter ($p < 0.01$) between non-used and used trees for koala, brushtail possum and greater glider (table 13). All species selected for larger tree diameter and larger canopy diameter. Ringtail possum shows no significant difference between used and non-used trees for any tree characteristic.

Between species analysis

The Kruskall-Wallis test showed there was a significant difference in tree canopy density ($p < 0.001$, d.f. = 3, $X^2 = 20.20$) and tree canopy diameter ($p < 0.01$, d.f. = 3, $X^2 = 19.05$) between the species. The Scheffe post-hoc test shows that the common brushtail possum uses trees with larger tree diameter and with a lower tree canopy density (figure 4 – 6). Thus, niche differentiation occurs between brushtail possum and the other arboreal marsupials, which is consistent with hypothesis 2. When used trees data of the brushtail possum is taken out of the analysis no significant difference in tree characteristics between koala, ringtail possum and greater glider is found ($p > 0.05$).

Table 12. Relative exploitation (RE), Preference index (PI) and Importance index (II) for each study species (see equations 1-3)

KOALA

tree species no.	trees sampled (no.)	trees sampled (%)	used trees (no.)	used trees (%)	RE	Pi (rank[1])	Ii (rank[1])
1	434	75.5	174	82.1	1.09	0.154 (2)	0.820 (1)
2	47	8.2	15	7.1	0.87	0.123 (5)	0.071 (2)
3	4	0.7	2	0.9	1.29	0.183 (1)	0.009 (5)
4	8	1.4	1	0.5	0.36	0.051 (9)	0.005 (6)
5	25	4.3	4	1.9	0.44	0.063 (8)	0.019 (4)
6	20	3.5	4	1.9	0.54	0.077 (6)	0.019 (4)
7	28	4.9	10	4.7	0.96	0.136 (4)	0.047 (3)
8	3	0.5	1	0.5	1.00	0.142 (3)	0.005 (6)
9	6	1.0	1	0.5	0.50	0.071 (7)	0.005 (6)

BRUSHTAIL POSSUM

tree species no.	trees sampled (no.)	trees sampled (%)	used trees (no.)	used trees (%)	RE	Pi (rank[1])	Ii (rank[1])
1	137	66.8	45	69.2	1.04	0.170 (2)	0.693 (1)
2	30	14.6	8	12.3	0.84	0.138 (3)	0.123 (2)
3	4	2.0	1	1.5	0.75	0.123 (5)	0.015 (5)
4	17	8.3	7	10.8	1.30	0.213 (1)	0.108 (3)
5	8	3.9	2	3.1	0.79	0.130 (4)	0.031 (4)
6	4	2.0	1	1.5	0.75	0.123 (5)	0.015 (5)
7	5	2.4	1	1.5	0.63	0.102 (6)	0.015 (5)
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0

RINGTAIL POSSUM

tree species no.	trees sampled (no.)	trees sampled (%)	used trees (no.)	used trees (%)	RE	Pi (rank[1])	Ii (rank[1])
1	124	64.9	33	63.5	0.98	0.135 (4)	0.629 (1)
2	13	6.8	3	5.8	0.85	0.118 (5)	0.057 (4)
3	0	0	0	0	0	0	0
4	2	1.1	1	1.9	1.73	0.238 (2)	0.018 (5)
5	13	6.8	3	5.8	0.85	0.118 (5)	0.057 (4)
6	8	4.2	4	7.7	1.83	0.253 (1)	0.076 (3)
7	31	16.2	8	16.4	1.01	0.139 (3)	0.163 (2)
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0

GREATER GLIDER

tree species no.	trees sampled (no.)	trees sampled (%)	used trees (no.)	used trees (%)	RE	Pi (rank[1])	Ii (rank[1])
1	532	67.6	253	71.7	1.06	0.124 (4)	0.695 (1)
2	56	7.1	17	4.8	0.68	0.079 (8)	0.047 (5)
3	8	1	3	0.9	0.90	0.105 (6)	0.009 (7)
4	17	2.2	5	1.4	0.64	0.074 (9)	0.013 (6)
5	50	6.4	25	7.1	1.11	0.130 (3)	0.068 (3)
6	42	5.3	13	6.7	1.26	0.148 (1)	0.065 (4)
7	70	8.9	32	9.1	1.02	0.120 (5)	0.088 (2)
8	6	0.8	3	0.9	1.13	0.132 (2)	0.008 (8)
9	6	0.8	2	0.6	0.75	0.088 (7)	0.006 (9)

[1] Rank is the order of preference (Pi) or importance (Ii): 1 is most preferred or important

Table 13. Within species analyses - differences in tree characteristics between non-used trees and used trees for each species using the Mann Whitney test

KOALA	**trees**	**Median (Interquartile range)**	**N**	**z-value**	**sig.**
DBH	non-used	46.00 (19.25)	366	-3.098	p < 0.01
	used	52.00 (26.00)	212		
CANOPY (%)	non-used	55.00 (10.00)	366		n.s.
	used	56.08 (10.00)	212		
CANOPY (m)	non-used	7.00 (4.00)	366	-2.850	p < 0.01
	used	8.00 (5.00)	212		

RINGTAIL	**trees**	**Median (Interquartile range)**	**N**	**z-value**	**sig.**
DBH	non-used	47.00 (21.00)	141		n.s.
	used	56.50 (27.75)	54		
CANOPY (%)	non-used	55.00 (10.00)	141		n.s.
	used	55.00 (10.00)	54		
CANOPY (m)	non-used	6.00 (3.00)	141		n.s.
	used	8.00 (5.00)	54		

BRUSHTAIL	**trees**	**Median (Interquartile range)**	**N**	**z-value**	**sig.**
DBH	non-used	45.00 (19.00)	140	-3.075	p < 0.01
	used	52.00 (25.00)	65		
CANOPY (%)	non-used	50.00 (15.00)	140		n.s.
	used	50.00 (10.00)	65		
CANOPY (m)	non-used	7.00 (4.75)	140	-4.542	p < 0.01
	used	9.00 (6.00)	65		

GREATER GLIDER	**trees**	**Median (Interquartile range)**	**N**	**z-value**	**sig.**
DBH	non-used	45.00 (22.00)	438	-4.581	p < 0.001
	used	50.00 (23.00)	357		
CANOPY (%)	non-used	55.00 (10.00)	438		n.s.
	used	55.00 (10.00)	357		
CANOPY (m)	non-used	6.00 (3.00)	438	-3.488	p < 0.001
	used	7.00 (4.00)	357		

Figure 4. Between species analysis – significant difference in canopy diameter between koala, ringtail possum and greater glider (group a) and brushtail possum (group b) ($X^2 = 19.05$, $p = < 0.001$)

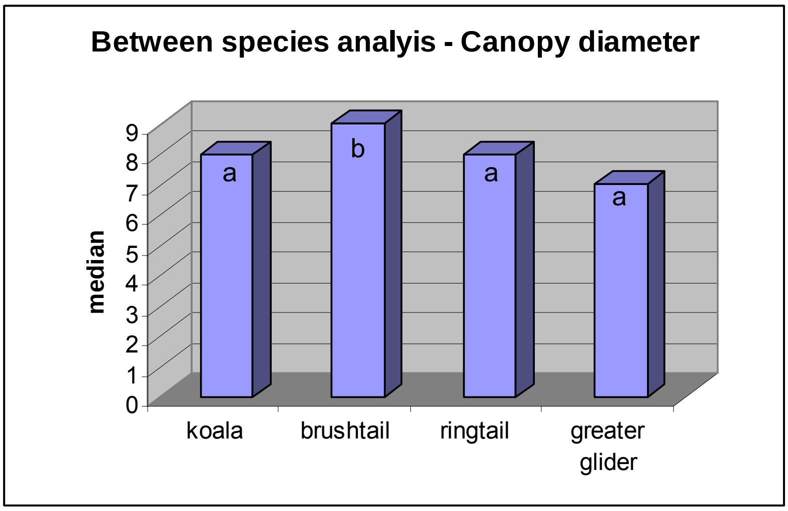


Figure 5. Between species analysis – significant difference in canopy density between koala, ringtail possum and greater glider (group a) and brushtail possum (group b) ($X^2 = 20.20$, $p = < 0.001$)

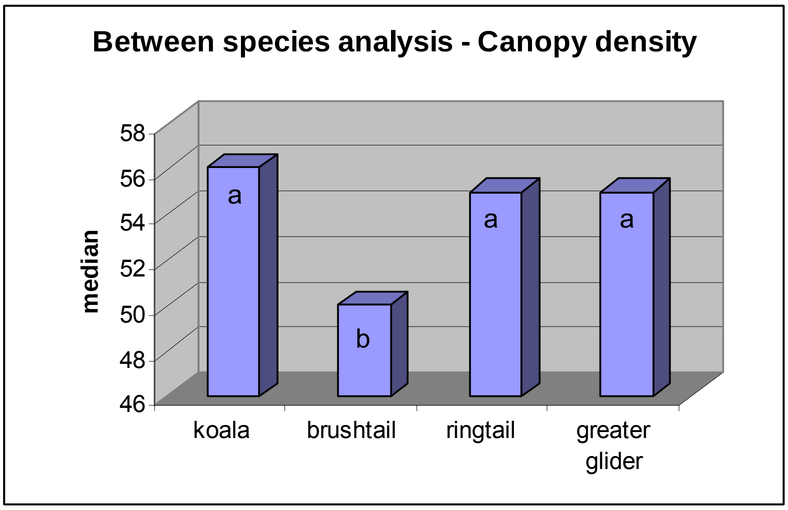
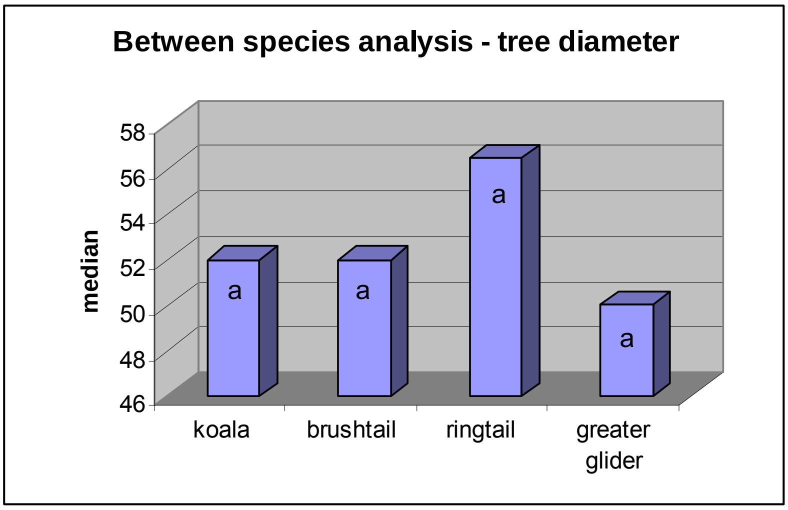


Figure 6. Between species analysis – difference in tree diameter (no significant difference between the species)



DISCUSSION

Competition

The main question of this study was whether competition affects habitat selection of large arboreal marsupials at two different spatial scales. The results of the logistic regression models show that koala and brushtail possum have a negative spatial association, which is consistent with hypothesis 1 that when competition affects habitat selection this results in a spatial segregation between competing species at landscape scale. In addition to the spatial segregation at landscape scale, niche differentiation at tree scale was found between koala and brushtail possum, which is consistent with hypothesis 2. Both hypotheses can be accepted. This indicates that species densities in the study area are low (hypothesis 3) as is being supported by the study of Clark (1980). Thus, competition between koala and brushtail possum affects the habitat selection of these species at both landscape scale and tree scale.

The presence of both koala and brushtail possum can be partly explained by their proximity to greater glider (positive association), which rejects hypothesis 1 for the relation between koala & greater glider and brushtail possum & greater glider. However, niche differentiation between brushtail possum and greater glider occurs, which is consisted with hypothesis 2. These results show that competition between brushtail possum and greater glider affects habitat selection of these two species at tree scale. Koala and greater glider have a preference for different tree species: koala preferred *E. dalrympleana* and *E. laevopinea* and greater glider preferred *E. nobilis* and *E. viminalis*. However, both species rank *E. laevopinea* as most important tree species and the niches of koala and greater glider are not differentiated by tree characteristics, which means hypothesis 2 also has to be rejected for koala & greater glider. Koala and greater glider have similar habitat requirements, which based on the results do not seem to bring them into competition (they seem indifferent to one another).

Proximity to the ringtail possum does not influence the occurrence of the other arboreal marsupials. In its turn, whether ringtail possum occurs or not is does not seem to be influenced by proximity to other arboreal marsupials, so hypothesis 1 has to be rejected for ringtail possum & koala, ringtail possum & brushtail possum and ringtail possum & greater glider. Ringtail possum, as all other arboreal marsupials, rank *E. lavopinea* as most important tree species. In addition, no niche differentiation is found based on the measured tree characteristics between ringtail possum, koala and greater glider, which also rejects hypothesis 2 for ringtail possum & koala and ringtail possum & greater glider. However, niche differentiation does occur between ringtail possum and brushtail possum, which is consistent hypothesis 2. This means that habitat selection of ringtail possum is affected by competition with brushtail possum at tree scale, but not at landscape scale. No competition seems to occur with other arboreal marsupials based on the variables measured in this study.

Competition between koala and brushtail possum affects their habitat selection at landscape scale and tree scale (hypothesis 1 & 2 confirmed). Competition between brushtail possum & greater glider and brushtail possum & ringtail possum affects their habitat selection at tree scale (hypothesis 1 rejected, hypothesis 2 confirmed). Koala, ringtail possum and greater glider do not seem to be affected by competition in their habitat selection and seem indifferent to each other (hypothesis 1 & 2 rejected).

This study did not find evidence that competition between koala, ringtail possum and greater glider affects their habitat selection: they seem to co-exist without segregating their habitat at tree scale. Four explanations can be given. Firstly, niche differentiation at tree scale between koala, ringtail possum and greater glider might not be detected because it is based on variables that are not included in this study (e.g. number of hollows). Secondly, niche differentiation might occur by habitat segregation between the species at a smaller scale that was not included in this study. Foliar nutrient / toxins levels are known to be explanatory variables in predicting probability abundance of arboreal marsupials (Foley 1981; Braithwaite et al. 1983; Braithwaite et al. 1984; Pausas et al. 1996; Stockwell et al. 1990; Lindenmayer et al. 1994). Eucalypt leaves contain many difficult digestible fibres and are of low nutritional quality due to high concentrations of indigestible and potentially toxic constituents, and low concentrations of energy sources and protein (Lee and Martin 1988; Cork & Sanson 1990). Koalas are found to select foliage that contain at least a minimum or threshold level of water and essential oils (Hume & Esson 1993) and to select for higher crude protein levels (Ullrey et al. 1981). It has also been suggested that level of nitrogenous food available to koala is the major limiting factor influencing their abundance (Martin & Lee 1984; Pahl & Hume 1990; Hume 1995). A third explanation might be that differential habitat utilization may express itself as a temporal segregation between the species: niche differentiation in time. This study indicates that ringtail possum, koala and greater glider do not show territorial behaviour towards each other (their home ranges overlap), since ringtail possum does not seem to be influenced by proximity to other arboreal marsupials and koala and greater glider are even positively correlated. Several studies have shown that tree preference of koalas change seasonally (e.g. Hindell et al. 1985; Moore et al. 2000). This might be explained by flushes of new growth on the species that is being shifted towards or by seasonal changes in the koala’s physiology and nutritional demands associated with altered needs for thermoregulation (Moore et al. 2000). No such studies have been conducted on ringtail possum or greater glider and it is not known whether these species might have shifting habitat selection in time. The faecal pellet survey used in this study did not include an assessment of scat age and therefore no potential temporal segregation can be identified. A fourth explanation is that the species do not segregate their habitat, but that they use the same habitat (trees) after any period of time (possibly days or weeks) after each other. In this way they would avoid interference competition. This explanation seems to only be possible at low species densities. When densities are high this phenomenon is assumed to eventually result in competition.

Thus, competition might affect habitat selection of koala, ringtail possum and greater glider when they differentiate their niches at tree scale by variables not included in this study or when they differentiate their niches at leaf scale or at temporal scales. In addition, these species possibly do not segregate their habitat but simply use trees after each other. This way they would avoid interference competition: however this seems only possible at low species densities.

Environmental variables

Rockiness and tree density are the most important environmental variables in predicting the probability of the presence of arboreal marsupials. High tree density was expected to be positively associated with the presence of arboreal marsupials since it allows for easier movement within the forest, easier access to nests for non-gliding species (Pausas et al. 1995) and may decrease predation risks. In addition, a high tree density indicates high food availability in general which has also been considered the main factor predicting the occurrence of arboreal marsupial occurrence (Pausas et al. 1995). Tree density is suggested to be linked with levels of foliage nutrients (Braithwaite 1983) and with the primary production of the habitat (Cook 1989), which in turn determines the available amount of young foliage. Greater glider, ringtail possum and koala are known to generally prefer young eucalypt leaves over older leaves (Pahl & Hume 1990; Moore et al. 2000). Although younger leaves generally contain more nitrogen and water and less fibre than mature leaves, they also have higher concentrations of total phenolocis and so far, there is no clear reason why arboreal marsupials should select younger rather than older leaves of *Eucalyptus* (Moore et al. 2000).

Rockiness was expected to be positively associated with the presence of arboreal marsupials because it seemed to increase with slope. This means that arboreal marsupials do not necessarily select areas with high rockiness *per se*, but rockiness might be a surrogate measure for other factors. Rockiness was found to highly correlate with slope. Slope has been found a factor predicting the occurrence of arboreal marsupial occurrence in several studies (Cook 1989; Stockwell et al. 1990; Lindenmayer et al. 1991a; Cork et al. 1996). Roberts (1996) found koalas to be positively associated with steeper slopes at Dorrigo (New South Wales). He suggests that the disturbance factor (e.g. logging) might be affecting the apparent response of koalas to slope, where koalas may be favouring the steeper sites that have not been disturbed for a long time compared to more accessible flatter sites, which has been supported by Cork & Catling (1996). Braithwaithe et al. (1983) concluded that tree species with low foliage nitrogen occurred in areas of steep slope, presumably because soils in these areas were deficient in nutrients due to runoff and leaching. This is in contrast with Faithfull (1983), who studied soils on the south side of Mount Duval where significantly higher clay content was found in the A horizon at the summit and on steeper slopes than at the mid- and lower-slopes which are less steep. Since soils with high clay contents are known to have greater affinity for nutrients than soils of low clay content (Attiwill & Leeper 1987, quoted in Cook 1989 unpublished) this indicates higher nutrient levels occur at steeper slopes. Moreover, Lambert and Turner (1983) found that tree species with high nutrient levels coincided with soils of high nutrient status in the top 10 cm.

Rockiness and tree density are the most important environmental variables in predicting the probability of the presence of arboreal marsupials. This study suggests that these environmental variables might both be surrogate measures for the nutrient status in leaves of eucalypt trees.

CONCLUSIONS AND RECOMMENDATIONS

Published studies which attempted to gain a better understanding of the habitat of large arboreal marsupials using GIS are both few and relatively recent (Cork et al. 1990; Norton and Neave 1996; Bryan 1997; Lunney et al. 1998). The use of GIS as a tool to study habitat selection is highly recommended, since it gives the opportunity to store, model and analyze all types of spatial data without the use of time and labour intensive field work. Its use in ecology has not been explored to full extend.
The models created in this study can be used to predict the distribution of koala, common brushtail possum, common ringtail possum and greater glider in the landscapes for which they were developed, but they may be of limited value in other landscapes. To test the validity of the models and its usefulness in other regions they will need to be validated with independent data. Due to the limited geographical range of this study, there is relatively little variation in some environmental variables that might influence the occurrence of arboreal marsupials. For the models to be effective at larger scale it is therefore recommended for future research to use a larger study site that represents the surrounding region. This study has not assessed the direct influence of available tree hollows or forest disturbance on the distributional patterns of arboreal mammals, which are known to influence their local occurrence. Factors known to be a major influence on the distribution of arboreal mammals are recommended to be included in the study design and to be measured directly instead of through a surrogate measure; otherwise results might prove difficult to interpret. Environmental variables at landscape level predicting the probability of occurrence of arboreal marsupials are suggested to be surrogate measures for nutrient levels in tree leaves. Therefore, nutritional factors at leaf scale are recommended to be included in future studies on competition and habitat selection.

The complexity in habitat selection and the lack of information of how the species interact means that predicting the ultimate distribution of the species is difficult. This study is the first to conduct research on competition in large arboreal marsupials. It is concluded that competition between koala and brushtail possum does affect their habitat selection at landscape scale as well as at tree scale (hypothesis 3 confirmed). In addition, competition between brushtail possum & greater glider and brushtail possum & koala affects their habitat selection at tree scale (hypothesis 2 confirmed). Koala, ringtail possum and greater glider do not seem to be affected by competition in their habitat selection and seem indifferent to each other (hypothesis 1 & 2 rejected). For these arboreal marsupials competition might affect habitat selection at tree scale by variables that were not included in this study, at the smaller leaf scale (e.g. leaf age, leaf nutrient / toxins levels, leaf structure), or at a temporal scale. In addition, these species possibly do not segregate their habitat but simply use trees after each other. This way they would avoid interference competition: however this seems only possible at low species densities. Interspecific competition is shown to be an active force in habitat selection in some species. Further research needs to be conducted to study to what *extend* interspecific competition is an active force in habitat selection for these species. Moreover, this study may describe the outcome of competition, but it does not provide understanding of the competitive process. For this, the competitive process between competing species needs to be further examined.

REFERENCES

BANKS, P.B. and DICKMAN, C.R. (2000) Effects of winter food supplementation on reproduction, body mass, and numbers of small mammals in montane Australia. *Canadian Journal of Zoology* 78 (10), 1775 – 1783.

BEGON, M., HARPER, J.L. and TOWNSEND, C.R. (1996) Ecology: Individuals, populations and communities. Third edition by Blackwell Science Ltd.

BENNET, A.F., LUMSDEN, L.F., ALEXANDER, J.S.A., DUNCAN, P.E., JOHNSON, P.G., ROBERTSON, P. and SILVERIA, C.E. (1991) Habitat use by arboreal mammals along an environmental gradient in North-eastern Victoria. *Wildlife Research* 18, 125 – 146.

BLANCHARD, W.H. (1991) Growth and development of the koala from birth to weaning. Biology of the Koala. (Eds. Lee, A.K., Handasyde, K.A. and Sanson, G.D.) 193 – 202.

BRAITHWAITE, L. (1983) Studies on the arboreal marsupial fauna of eucalypt forest being harvested for woodpulp at Eden, New South Wales 1. The species and distribution of animals. *Australian Wildlife Research* 10 (2), 219 – 229.

BRAITHWAITE, L., DUDZINSKI, M.L. and TURNER, J. (1983) Studies on the arboreal marsupial fauna of eucalypt forest being harvested for woodpulp at Eden, New South Wales 2. Relationships between the fauna density, richness and diversity, and measured variables of the habitat. *Australian Wildlife Research* 10 (2), 231 – 247.

BRAITHWAITE, L., BINNS, D. and NOWLAN, R. (1988) The distribution of arboreal marsupials in relation to Eucalypt forest types in the Eden (NSW) Woodchip Concession Area. *Australian Wildlife Research* 15, 363 – 73.

BRYAN, B.A. (1997) A generic method for identifying regional koala habitat using GIS. *Australian Geographical Studies* 35 (2), 125 – 138.

BURKHARDT, J.F., SCHLUND, W. and STRAUSS, M.J. (1998) Scale effects of habitat selection in breeding Nuthatches (*Sitta europaea*) in two different woodlands. *Journal of Ornithology* 139, 37 – 48.

CARNEY, S. (1995) A premliminary survey of the habitat preferences and distribution of a population of the Koala (Phascolarctos cinereus) at Newholme research station, on the New England Tablelands. Bachelors degree Armidale: University of New England. Unpublished.

CLARKE, J.S. (1983) Utilisation of Eucalyptus trees by free-roaming koalas, Phascolarctos cinereus (Goldfuss), near Nowendoc. MSc. Thesis Armidale: University of New England. Unpublished.

COCKRAN, G.A. and STAINS, H.J. (1961) Deposition and decomposition of fecal pellets by Cottontails. *Journal of Wildlife Management* 25 (4), 432 – 435.

CORK, S.J. and CATLING, P.C. (1996) Modelling distributions of arboreal and ground-dwelling mammals in relation to climate, nutrients, plant chemical defenses and vegetation structure in the eucalypt forests of southeastern Australia. *Forest Ecology & Management* 85, 163 – 175.

CORK, S.J. and SANSON, G.D. (1991) Digestion and nutrition in the koala: a review. Biology of the Koala (Eds. A.K. Lee, K.A. Handasyde and G.D. Sanson) Surrey Beatty & Sons: Sydney, 129 – 144

DANKS, F.S. and KLEIN, D.R. (2002) Using GIS to predict wildlife habitat: a case study of muskoxen in northern Alaska. *International Journal of Remote Sensing* 23 (21), 4611 – 4632.

DAVEY, S.M. (1990) Methods for surveying the abundance and distribution of arboreal marsupials in a south coast forest of New South Wales. *Australian Wildlife Research* 17, 427 – 445.

DICKMAN, C.R. AND WOODSIDE, D.P. (1983) A test of a competition model with reference to 3 species of small mammals in Southeastern Australia. *Oecologia-Berlin* 60 (1), 127 – 134.

DICKMAN, C.R. (1986) An experimental manipulation of the intensity of interspecific competition effects on a small marsupial. *Oecologia-Berlin* 70 (4), 536 – 543.

ELLIS, W., SULLIVAN, B., LISLE, A. and CARRICK, F. (1998) The spatial and temporal distribution of koala faecal pellets. *Wildlife Research* 25, 663 – 668.

ELLIS, W.A., HALE, P.T. and CARRICK, F. (2002) Tree use, diet and home range of the koala (*Phascolarctos cinereus*) at Blair Athol, central Queensland. *Wildlife Research* 29, 303 – 311.

FIELD, A. (2000) Discovering statistics using SPSS for Windows. SAGE Publications Inc.

FLEISHMAN, E., MACNALLY, R. FAY, J.P. and MURPHY, D.D. (2001) Modeling and predicting species occurrence using broad-scale environmental variables: an example with butterflies of the Great Basin. *Conservation biology* 15 (6), 1674 – 1685.

FOLEY, W.H. (1984) The utilization of Eucalyptus foliage by the Greater Glider (Petauroides volans) and the brushtail possum (Trichosurus vulpecula). Bachelors Hons. II Armidale: University of New England. Unpublished.

GORDON, G., BROWN, A.S. and PULSFORD, T. (1988) A koala population crash during drought and heat wave condition in south-western Queensland. *Australian Journal of Ecology* 13, 451 – 61.

GORDON, G. MCGREEVY, D.G. and LAWRIE, B.C. (1990) Koala populations in Queensland: major limiting factors. In: Lee, A.K., Handasyde, K.A. and Sanson, G.D. 1990, 85 – 95. *Biology of the koala*. Surrey Beatty & Sons, Sydney.

HASEGAWA, M. (1995) Habitat utilization by koalas (*Phascolarctos cinereus*) at Point Halloran, Queensland. MSc Thesis, University of Queensland, Brisbane. Unpublished.

HAWKES, N.H. (1978) Identification and management of koala Eucalypt trees in New South Wales. The Koala, Proceedings of the Taronga Symposium on koala biology management and medicine. (Ed. T.J. Bergin) Sydney, the Zoological Parks Board of NSW 89 – 96.

HINDELL, M.A. and LEE, A.K. (1987) Habitat use and tree preferences of koalas in a mixed Eucalypt forest. *Australian Wildlife Research* 14 (4), 349 – 360.

HINDELL, M.A. and LEE, K. (1988) Tree use by individual koalas in a natural forest. *Australian Wildlife Research* 15, 1 – 7.

HINDELL, M.A. and LEE, A.K. (1991) Tree preferences of the koala. The Koala: A Natural History. (Eds. Lee, A.K. and Martin, R.W) Kensington, New South Wales University 117 – 121.

HUME, I.D. and ESSON, C. (1993) Nutrients, antinutrients and leaf selection by captive koalas. Australian Journal of Zoology 41, 379 – 392.

INCOLL, R.D., LOYN, R.H., WARD, S.J. CUNINGHAM, R.B. and DONNELLY, C.F. (2001) the occurrence of gliding possums in old-growth forest patches of mountain ash (*Eucalyptus regnans*) in the Central Highlands of Victoria. *Biological Conservation* 98, 77 – 88.

JOHNSON, C.N. and JARMAN, P.J. (1987) Macropod studies at Wallaby Creek. VI. A validation of the use of dung-pellet counts for measuring absolute densities of populations of macropodids. *Australian Wildlife Research* 14, 139 – 145.

JURKSIS, V., ROWELL, D. and RIDLEY, D. (1994) Survey techniques and aspects of the koala near Eden. Research paper no. 22, p 58. State Forests of New south Wales, West Pennant Hills.

JURKIS, V. ROWELL, D. and RIDLEY, D. (1997) Survey techniques and aspects of the ecology of the koala near Eden. Research paper 22. Forest research and development division – State forests of New South Wales, Sydney.

JURKIS, V. and POTTER, M. (1997) Koala surveys, ecology and conservation at Eden. Research paper 34. Forest research and development division – State forests of New South Wales, Sydney.

KAVANAGH, R.P. (1987) Floristic and phonological characteristics of a eucalypt forest in relation to its use by arboreal marsupials. MSc thesis, Australian National University, Canberra.

KEHL, J. and BORSBOOM, A. (1984) Home range, den tree use and activity patterns in the greater glider, *Petauroides volans*. In: *Possums and Gliders* (1984) 229 – 236. (Smith, A.P. and Hume, I.D.) Surrey Beatty and Sons, Sydney.

KERLE, J.A. (2001) Possums: the brushtails, ringtails and greater glider. University of Sydney Press Ltd – Sydney.

KHAEMBA, W.M. and STEIN, A. (2000) Use of GIS for a spatial and temporal analysis of Kenyan wildlife with generalized linear modeling. *International Journal of Geographical Information Science* 14 (8), 833 – 853.

LEE, A.K. and MARTIN, R. (1998) The Koala: A Natural History. Australian Natural History Series. Australian Print Group, Victoria.

LEOPOLD, B.D., KRAUSMAN, P.R. and HERVERT, J.J. (1984) Comment: The pellet-group census technique as an indicator of relative habitat use. *Wildlife Society Bulletin* 12, 325 – 326.

LINDENMAYER, D.B., CUNNINGHAM, R.B., TANTON, M.T., SMITH, A.P. and NIX, H.A. (1990) The conservation of arboreal marsupials in the montane ash forest of the central highland of Victoria, south-east Australia: I Factors influencing the occupancy of trees with hollows*.* *Biological Conservation* 54, 111 – 131.

LINDENMAYER, D.B., CUNNINGHAM, R.B., TANTON, M.T., SMITH, A.P. and NIX, H.A. (1991) The conservation of arboreal marsupials in the montane ash forest of the central highland of Victoria, south-east Australia: III The habitat requirements of Leadbeater's Possum, *Gymnobelideus leadbeateri* and models of the diversity and abundance of arboreal marsupials.*. Biological Conservation* 56, 295 - 315.

LINDENMAYER, D.B. (2000) Factors at multiple scales affecting distribution patterns and their implication for animal conservation – Leadbeater's Possum as a case study. *Biodiversity and Conservation* 9, 15 – 35.

LINDENMAYER, D.B. et al. (2001) How effective is spotlighting for detecting the greater glider (*Petauroides volans*)? *Wildlife Research* 28, 105 – 109.

LUNDIE-JENKINS, G (1993) Ecology of the rufous hare-wallaby, *Lagorchestes hirsutus* Gould (Marsupialia: Macropodiae), in the Tanami Desert, Northern Territory. I. Pattern of habitat use. *Wildlife Research* 20, 457 – 476.

LUNNEY, D., PHILLIPS, S., CALLAGHAN, J. and COBURN, D. (1998) Determining the distribution of koala habitat across a shire as a basis for conservation: a case study from Port Stephens, New South Wales. *Pacific Conservation Biology* 4, 186 – 196.

LUNNEY, D., MATTHEWS, A., MOON, C. and FERRIER, S. (1999) Incorporating habitat mapping into practical koala conservation on private lands. *Conservation Biology* 14 (3), 669 – 680.

MARTIN. R.W. and HANDASYDE, K. (1988) The koala: natural history, conservation and management. University of New South Wales Press Ltd Sydney.

MARTIN, R.W. and LEE, A.K. (1984) The Koala Phascolarctos cinereus, the largest marsupial folivore. Possums and Gliders. (Eds. Smith, A.P. and Hume, I.D.) Surrey Beatty and Sons, Chipping Norton (NSW).

MELZER, A. and LAMB, D. (1994) Low density populations of the koala (*Phascolarctos cinereus*) in central Queensland. Proceeding of the Royal Society of Queensland 104, 9 – 93.

MOORE, B.D. and FOLEY, W.J. (2000) A review of feeding and diet selection in koalas (Phascolarctos cinereus). *Australian Journal of Zoology* 48, 317 – 333.

MUNKS, S.A. CORKEREY, R. and FOLEY, W.J. (1996) Characteristics of arboreal marsupial habitat in semi-arid woodlands of northern Queensland. *Wildlife Research* 23, 185 – 196.

PAHL, L.I. and HUME, I.D. (1990) Preferences for Eucalyptus species of the New Engalnd Tablelands and intial develpmetn of an artificial diet for koalas. In: Biology of the Koala. 123 -128 Eds. Lee, A.K., Handasyde, K.A. and Sanson, G.D. Surrey Beatty & Sons: Sydney.

PAUSAS, J.G., BRAITHWAITE, L.W. and AUSTIN, M.P. (1995) Modeling habitat quality for arboreal marsupials in the South coastal forests of New South Wales, Australia. *Forest Ecology and Management* 78, 39 – 49.

PERIRA, J.M.C. and ITAMI, R.M. (1991) GIS-based habitat modeling using logistic multiple regression: a study of the Mt. Graham red squirrel. *Photogrammetric Engineering & Remote Sensing* 57 (11), 1475 – 1486.

PHILIPS, S. and CALLAGHAN, J. (2000) Tree species preferences of koalas (Phasolarctos cinereus) in the Campbelltown area south-west of Sydney, New South Wales. *Wildlife Research* 27, 509 – 516.

PHILIPS, S., CALLAGHAN, J. and THOMPSON, V. (2000) The tree species preferences of koalas (Phasolarctos cinereus) inhabiting forest and woodland communities on Quaternary deposits in the Port Stephens area, New South Wales. *Wildlife Research* 27, 1 – 10.

PRIBIL, S. and PICMAN, J. (1997) The importance of using the proper methodology and spatial scale in the study of habitat selection by birds. *Canadian Journal of Zoology* 75, 1835 – 1844.

PÖYSÄ, H., ELMBERG, J., SJÖBERG, K. and NUMMI, P. (1998) Habitat selection rules in breeding mallards (*Anas platyrhynchos*): a test of two competing hypotheses. *Oecologia* 114, 283 – 287.

PUTMAN, R.J. (1983) Facts from faeces. *Mammal Review* 14 (2), 79 – 97.
REED, P.C., LUNNEY, D. and WALKER, P. (1990). A 1986 – 1987 survey of the koala in New South Wales and an ecological interpretation of its distribution. 55 – 73 In: Biology of the Koala. Ed Lee, K.A., Handasyde, K.A. and Sanson, G.D. Surrey Beatty & Sons: Sydney

RIGHETTI, J., FOX, B.J. and CROFT, D.B. Behavioural mechanisms of competition in small dasyurid marsupials. *Australian Journal of Zoology* 48 (5), 561 – 576.

ROBERTS, P. (1998) Associations between Koala faecal pellets and trees at Dorrigo. MSc. Thesis Armidale: University of New England. Unpublished.

ROBINS, M. and RUSSEL, E. (1978) Observations on movement and feeding activity of the koala in a semi-natural situation. In ‘The koala – Proceedings of the Taronga Symposium’. (ed. T. Bergin) 29 – 41. Zoological Parks Board of New South Wales: Sydney.

RUNCIE, M.J. (1999) Movements, dens and feeding behaviour of the tropical scaly-tailed possum (*Wyulda squamicaudata*). *Wildlife Research* (26), 367 – 373.

RUSHTON, S.P., LURZ, P.W.W., FULLER, R., and GARSON, P.J. (1997) Modeling the distribution of the red and grey squirrel at the landscape scale: a combined GIS and population dynamics approach. *Journal of Applied Ecology* 34, 1137 – 1154.

SKIDMORE, A.L., GAULD, A. and WALKER, P. (1996) Classification of kangaroo habitat distribution using three GIS models. *International Journal of Geographical Information Systems* 10, 441 – 454.

SMITH, A.D. (1964) Defecation rates of mule deer. *Journal of Wildlife Management* 28 (3), 435 – 444.

SMITH, A.P., ROW, M.D. and ANDREWS, S.P. (1987) Newholme: A progress report on the Newholme Field Laboratory, Faculty of resource Management. University of New England, Armidale.

SMITH, A.P. and LINDENMAYER, D. (1988) Tree hollow requirements of Leadbeater's possum and other possums and gliders in timber production ash forests of the Victorian central highlands Australia. *Australian Wildlife Research* 15, 347 – 362.

SMITH, A.P. and MURRAY, M. (2003) Habitat requirements of the squirrel glider (Petaurus norfolcensis) and associated possums and gliders on the New South Wales central coast. *Wildlife Research* 30, 291 – 301.

STEPHERD, K.A., WARDELL-JOHNSON, G.W., LONERAGAN, W.A. and BELL, D.T. (1997) Diet of herbivorous marsupials in a Eucalyptus marginata forest and their impact on the understory vegetation. *Journal of the Royal Society of Western Australia* 80 (2), 47 – 54.

SULLIVAN, B.J., BAXTER, G.S. and LISLE, A.T. (2002) Low-density koala (Phascolarctos cinereus) populations in themulgalands of south-west Queensland. I. Faecal pellet sampling protocol. *Wildlife Research* 29, 455 – 462.

SULLIVAN, B.J., NORRIS, W.M. and BAXTER, G.S. (2003a) Low-density koala (Phascolarctos cinereus) populations in themulgalands of south-west Queensland. II. Distribution and diet. *Wildlife Research* 30, 331 – 338.

SULLIVAN, B.J., BAXTER, G.S. and LISLE, A.T. (2003b) Low-density koala (Phascolarctos cinereus) populations in themulgalands of south-west Queensland. III. Broad-scale patterns of habitat use. *Wildlife Research* 30, 583 – 591.

TRIGGS, B. (1996) Tracks, scats and other Traces: a field guide to Australian mammals. Oxford University Press.

ULLREY, D.E., ROBINSON, P.T. and WHETTER, P.A. (1981)Composition of preferred and rejected Eucalyptus browse offered to captive koalas. *Australian Journal of Zoology* 29, 839 – 846.

VOETEN, M.M. and PRINS, H.H.T. (1999) Resource partitioning between sympatric wild and domestic herbivores in the Tarangire region of Tanzania. *Oecologia* 120, 287 – 297.

WALLISDEVRIES, M.F., LACA, E.A. and DEMMENT, M.W. (1998) From feeding station to patch: scaling up food intake measurements in grazing cattle. *Applied Animal Behaviour Science* 60, 301 – 315.

WHITE, N.A. and KUNST, N.D. (1990) Aspects of the ecology of the koala in south-eastern Queensland. In: Biology of the Koala. 109 – 116. Ed. Lee, A.K., Handasyde, K.A. and Sanson, G.D. Surrey Beatty & Sons: Sydney.

WORMINGTON, K.R., LAMB, D., MCCALLUM, H.I. and MOLONEY, D.J. (2002) Habitat requirements for the conservation of arboreal marsupials in dry sclerophyll forest of southeast Queensland, Australia. Forest Science 48 (2), 217 – 227.

APPENDIX I – Description of study species

(All text in this appendix is quoted from the following web-site: Animal Diversity Web. http://animaldiversity.ummz.umich.edu/site/accounts/classifications/Diprodontia.html)

Koala (*Phascolarctos cinereus*):

The koalas live in eastern Australia and range from northern Queensland to southwestern Victoria. They have been introduced to western Australia and nearby islands. Koalas from the southern end of the range are generally larger in size than their northern counterparts. In both areas they exhibit sexual dimorphism with the males being larger. In the south, males have an average head-body length of 78 cm and females 72 cm (MacDonald, 1984). The koalas have a vestigial tail. Average weights are: in the south, males 11.8 kg, females 7.9 kg; in the north, males 6.5 kg, females 5.1 kg (MacDonald, 1984). Males are up to 50% heavier than females, have a broader face, somewhat smaller ears, and a large chest gland (MacDonald, 1984). Koalas have dense, wooly fur that is gray to brown on top and varies with geographic location. There is white on the chin, chest and inner side of the forelimbs (MacDonald, 1984). The rump is often dappled with white patches and the ears are fringed with long white hairs (MacDonald, 1984). The coat is generally shorter and lighter in the north of range. The paws are large, and both fore and hind feet have five strongly clawed digits. On the forepaw the first and second digits oppose the other three which enables the koala to grip branches as it climbs. The first digit of the hind foot is short and greatly broadened while the second and third digits are relatively small and partly syndactylous but have separate claws (Nowak, 1997). Females have two mammae; and rather than a chest gland, have a pouch that opens to the rear and extends upward and forward (Nowak, 1997).

Common Brushtail Possum (*Trichosurus vulpecula)*:

Trichosurus vulpecula has the widest distribution of any Australian mammal. It can be found throughout most of Australia and Tasmania. It also thrives in New Zealand, where it was introduced in 1840. *Trichosurus vulpecula* has large eyes and tall rounded ears. Its fur is short but dense, and its tail is typically long and is covered in long bushy fur. In some subspecies, the fur on the tail is the same length as on the rest of the body. Size: 1.7 – 2.4 kg (mainland) – 3.8 kg (Tasmania), 37 – 55 cm head-body length. Throughout its range, there is considerable variation in the coat color of *Trichosurus vulpecula*. Color seems to vary according to habitat, and several subspecies have been identified. In this study we looked at the subspecies *Trichosurus vulpecula vulpecula*, which is typically grey in color and found throughout southern Australia. In all subspecies, the underside is lighter in color. A scent gland located on the chest is used to mark territories. The reddish secretions from this gland give the fur around it a brown or reddish appearance. Like most marsupials, the females have a small, forward opening pouch that is used in reproduction.

Common Ringtail Possum (*Pseudocheirus peregrinus*):

Common ringtail possums are found along the eastern coastline of Australia, Tasmania, and the southwestern corner of western Australia (Marsupial Society of Victoria Inc. 2000). Common ringtail possums are the smallest of eight species of ringtail possums that live in Australia. The adults of this species typically are between 30 and 39 cm head-body length, with a tail length that is roughly equal to the body length. They weigh between 660 – 900 grams. Common ringtail possums have brown or reddish fur on the upper surfaces of the body and light colored or gray fur on the ventral surfaces. Common ringtail possums have large eyes which are well adapted to seeing at night. Two of the claws found on the front feet are opposable and the pads, as well as the tips, of the toes are grooved. They possess a strong, but relatively hairless, prehensile tail. This tail is carried tightly curled when not in use. These animals can be distinguished from other possum species in several ways. Their ears are smaller and more rounded and they typically have patches of white fur both on and above the ears. The tail of common ringtail possums has a white tip and is tapered (Marsupial Society of Victoria Inc. 2000; Wildlife Welfare Org. of S.A. 2000).

Greater Glider (*Petauroides volans*):

Greater gliders are found along the eastern coast of the Australian mainland, from eastern Queensland to southern Victoria (Nowak, 1999; Troughton, 1966). Greater gliders are the largest of the gliding possums. Females have a well-developed pouch and two mammae. *P. volans* are about the size of a domestic cat, weighing 0.9 - 1.8 kg as adults. The head-body length is 35 – 45 cm and the tail is 45 - 55 cm long (Nowak, 1999). These marsupials have a short snout and large round ears covered by thick fur (Strahan, 1995). The patagium, which is also covered with fur, extends from the knee to the elbow, (unlike the Petauridae, in which it extends from the ankle to the wrist), giving the glider a triangular shape when in the air (Berra, 1998). The long, furred tail, which is not prehensile, is used as a rudder (Grzimek, 1972). Color varies more than that of any other marsupial. The very long, dense fur is typically brownish-black, but can range from pure black with a creamy underside, to dusky browns and grays, cinnamon, red, yellow, and completely white (Grzimek, 1972; Troughton,1966).

APPENDIX II – Scat description of study species

(All text in this appendix is quoted from Trigs, 1996)

Koala:

Scats are hard and firmly packed. Scats are long, oval or cylindrical shaped with a slightly ridged surface. Colour: brown or red-brown (sometimes blue-green, grey-green, yellow-brown). Contain fairly coarse fragments of eucalyptus species. When scats are fresh they smell like eucalypt oil.

Common Brushtail Possum:

Cylindrical shaped pellets, sometimes fragments of insects and other food, sometimes dark and contain fine powdery material (sap from eucalyptus). Variable in size and colour: red-brown to black, fat round cylinders to narrow rat-like scats. Groups of single pellets or in clumps or strings (sometimes connected by hair or plant material). Mild musty smell.

Common Ringtail Possum:

Smaller than common brushtail possum scats. Granulated surface, mostly red-brown (but also dark green, brown or grey). In groups of 3-6 at the base of the (den) tree, more regularly and cylindrical than greater glider scats. When scats are fresh they have a mild smell of eucalyptus.

Greater Glider:

Very fine leaf fragments, generally small and cylindrical, however, diversity in scat shape. Red-brown to brown and little to no odour. All found in large numbers under (den) trees under base of or tree or stuck in rough bark.

The following herbivore species occur in Newholme region: hare, rabbit, kangaroo and wallaby. Very little to no doubt can exist between scats of the study species and other species in the study area:

Hare:

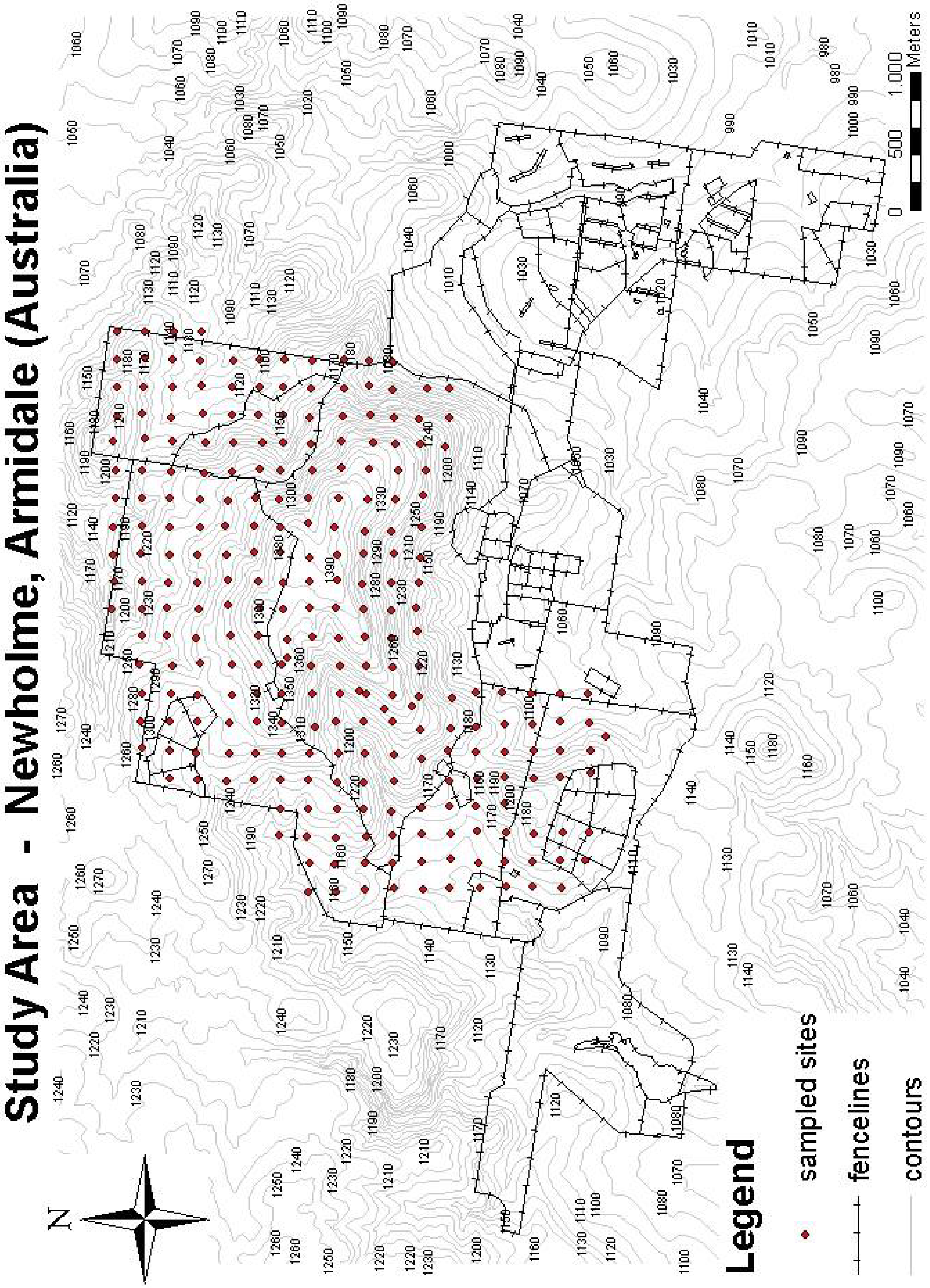
Rabbit:

Kangaroo:

Wallaby:

Scats are as kangaroo but smaller.

APPENDIX III – Map of study area

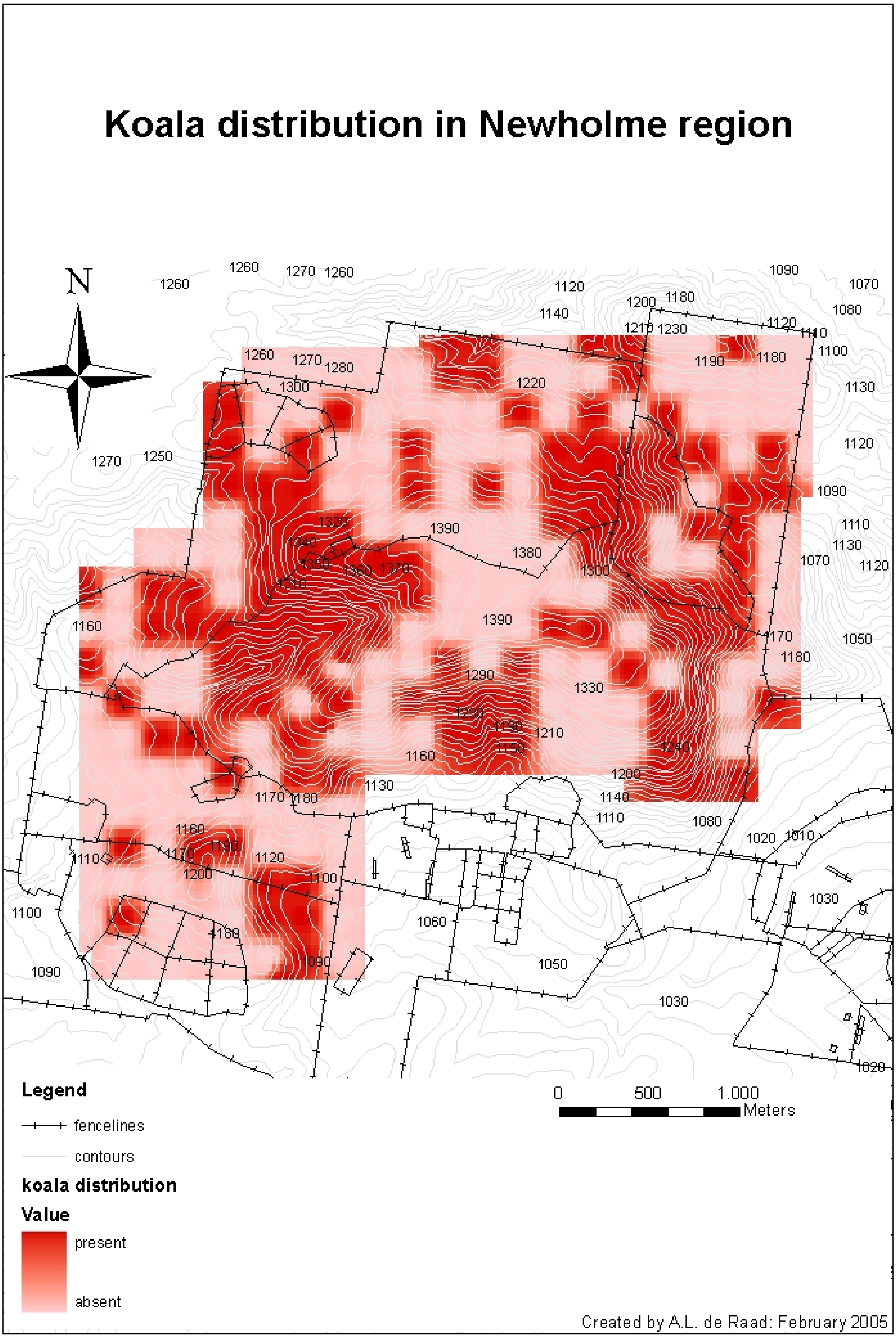


APPENDIX IV – Arc Macro Language

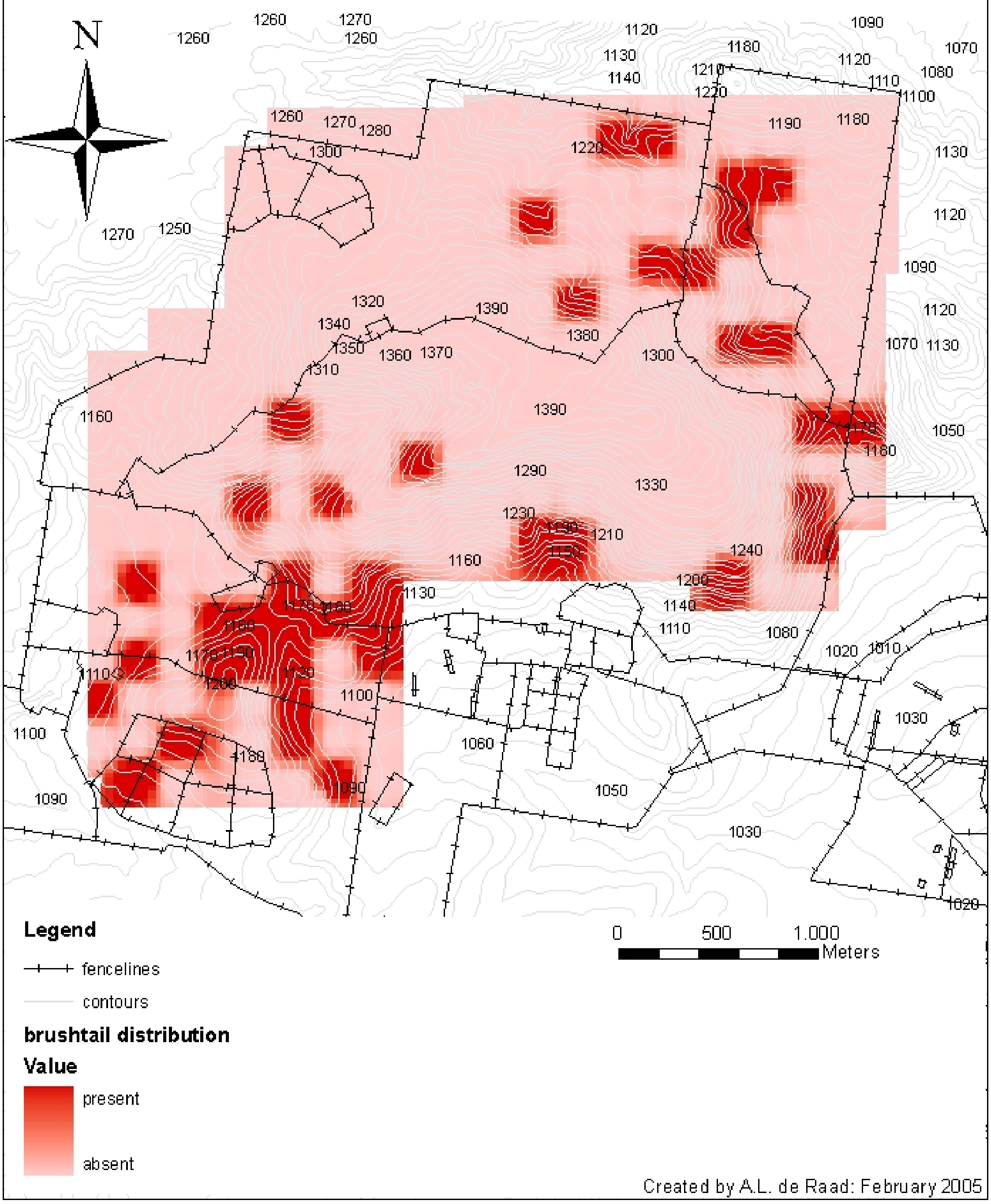
```
&if [exists point_r -cover] &then kill point_r all
&if [exists point_b -cover] &then kill point_b all
&if [exists point_k -cover] &then kill point_k all
&if [exists point_g -cover] &then kill point_g all
&if [exists point_ra -cover] &then kill point_ra all
&if [exists point_ba -cover] &then kill point_ba all
&if [exists point_ka -cover] &then kill point_ka all
&if [exists point_ga -cover] &then kill point_ga all
&if [exists dist_r -grid] &then kill dist_r all
&if [exists dist_b -grid] &then kill dist_b all
&if [exists dist_k -grid] &then kill dist_k all
&if [exists dist_g -grid] &then kill dist_g all

gridpoint p_r point_r value
gridpoint p_b point_b value
gridpoint p_k point_k value
gridpoint p_g point_g value

reselect point_r point_ra points
resel value gt 0
[unquote '']
n
n
reselect point_g point_ga points
resel value gt 0
[unquote '']
n
n
reselect point_b point_ba points
resel value gt 0
[unquote '']
n
n
reselect point_k point_ka points
resel value gt 0
[unquote '']
n
n

/* Ringtail
pointdistance point_r point_ra point_ra.dat 10000
tables
sel point_ra.dat
calc distance = distance / 1000
resel distance gt 0
calc distance = 1 / distance
asel
statistics point_r# point_ra.stat
sum distance
[unquote '']
n
n
quit
joinitem point_r.pat point_ra.stat point_r.pat point_r#
pointgrid point_r dist_r sum-distance
30
y
[unquote '']
```

```
/* Greater glider
pointdistance point_g point_ga point_ga.dat 10000
tables
sel point_ga.dat
calc distance = distance / 1000
resel distance gt 0
calc distance = 1 / distance
asel
statistics point_g# point_ga.stat
sum distance
[unquote '']
n
n
quit
joinitem point_g.pat point_ga.stat point_g.pat point_g#
pointgrid point_g dist_g sum-distance
30
y
[unquote '']

/* Brushtail
pointdistance point_b point_ba point_ba.dat 10000
tables
sel point_ba.dat
calc distance = distance / 1000
resel distance gt 0
calc distance = 1 / distance
asel
statistics point_b# point_ba.stat
sum distance
[unquote '']
n
n
quit
joinitem point_b.pat point_ba.stat point_b.pat point_b#
pointgrid point_b dist_b sum-distance
30
y
[unquote '']

/* Koala
pointdistance point_k point_ka point_ka.dat 10000
tables
sel point_ka.dat
calc distance = distance / 1000
resel distance gt 0
calc distance = 1 / distance
asel
statistics point_k# point_ka.stat
sum distance
[unquote '']
n
n
quit
joinitem point_k.pat point_ka.stat point_k.pat point_k#
pointgrid point_k dist_k sum-distance
30
y
[unquote '']
```

APPENDIX V – First set of distribution maps based on presence-absence data only using IDW

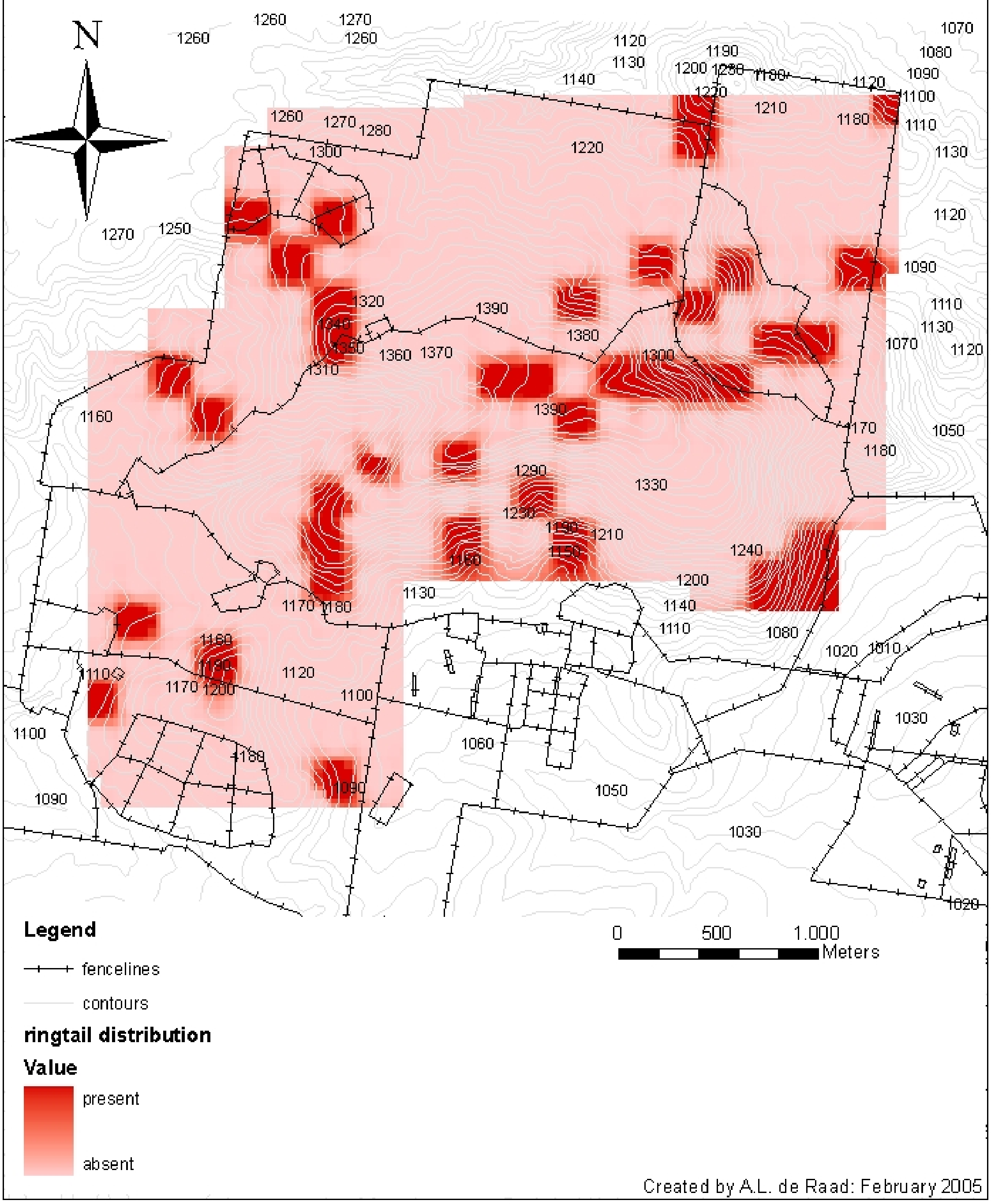


Common brushtail possum distribution in Newholme region



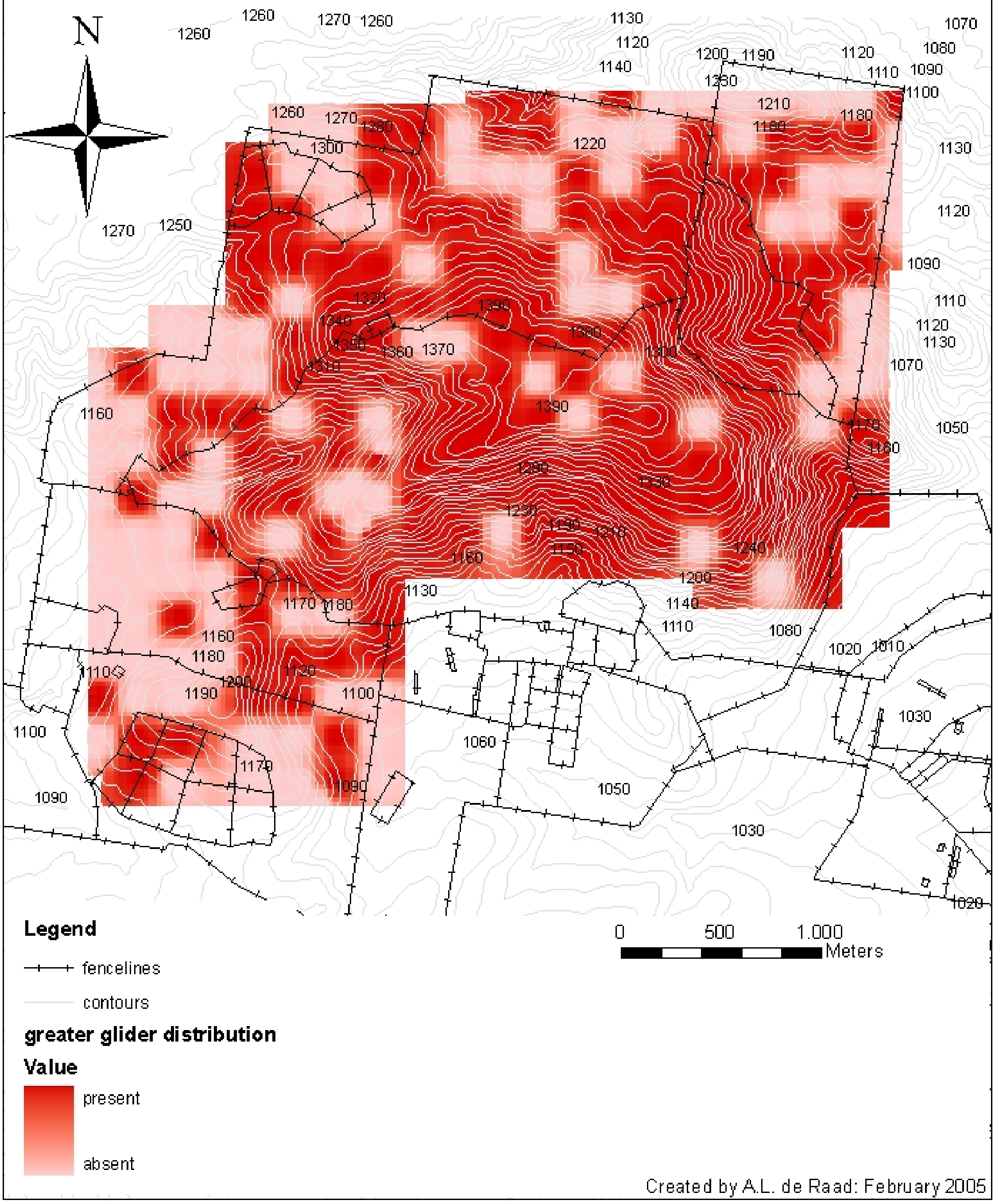
Created by A.L. de Raad: February 2005

Common ringtail possum distribution in Newholme region



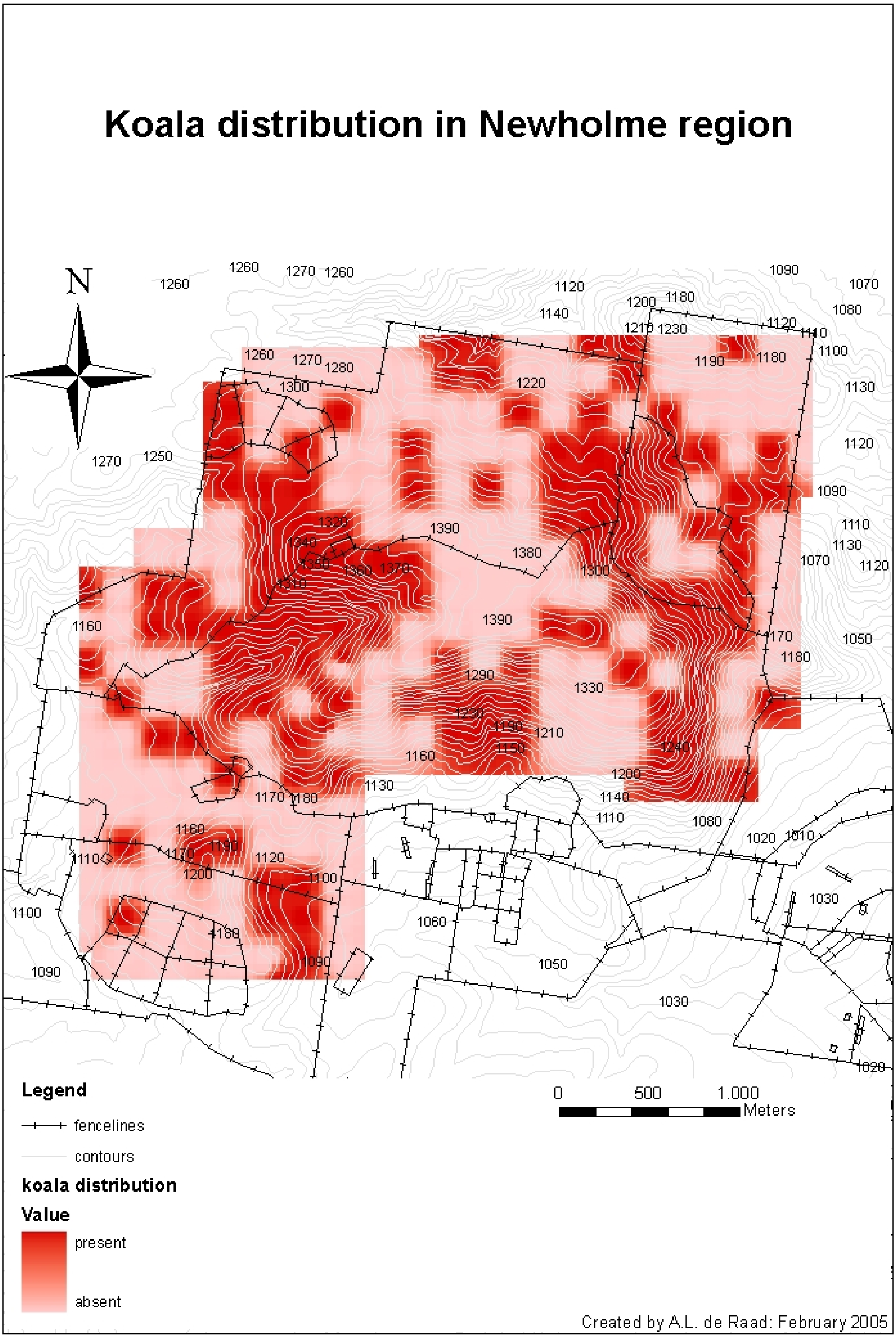
Created by A.L. de Raad: February 2005

Greater glider distribution in Newholme region



Created by A.L. de Raad: February 2005

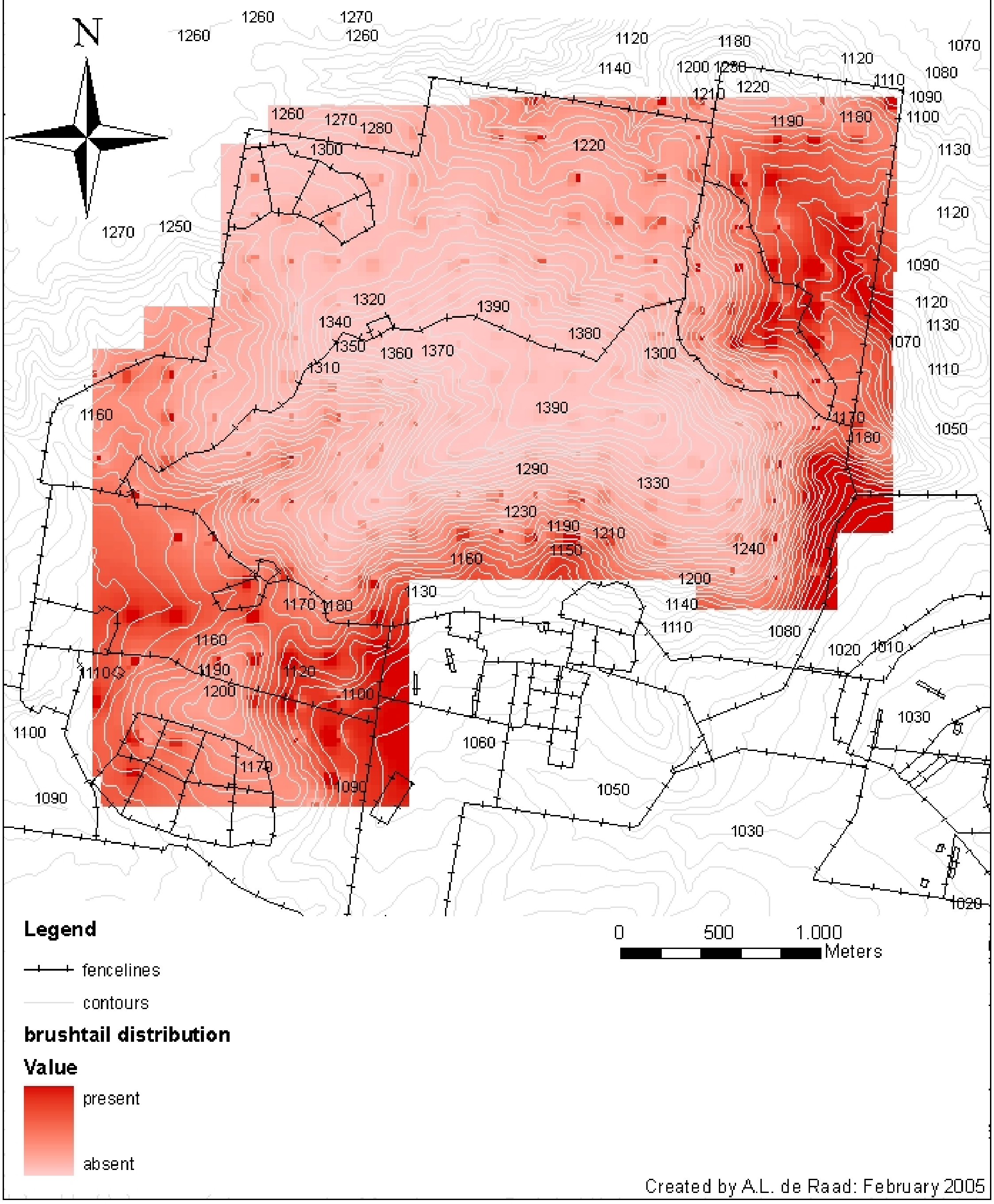
APPENDIX VI – Second set of distribution maps based on the regression model



Koala distribution in Newholme region

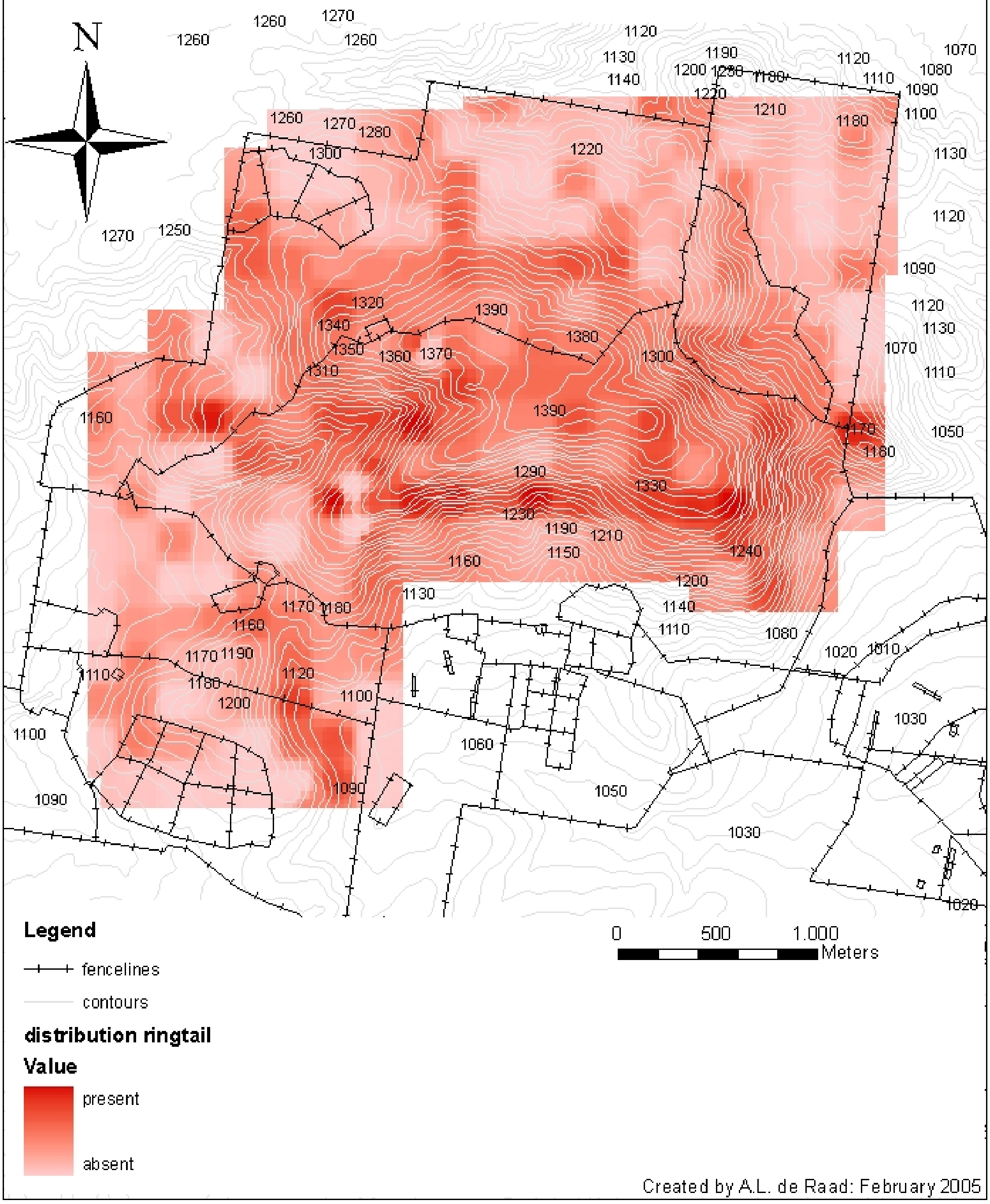
Created by A.L. de Raad: February 2005

Common brushtail possum distribution in Newholme region



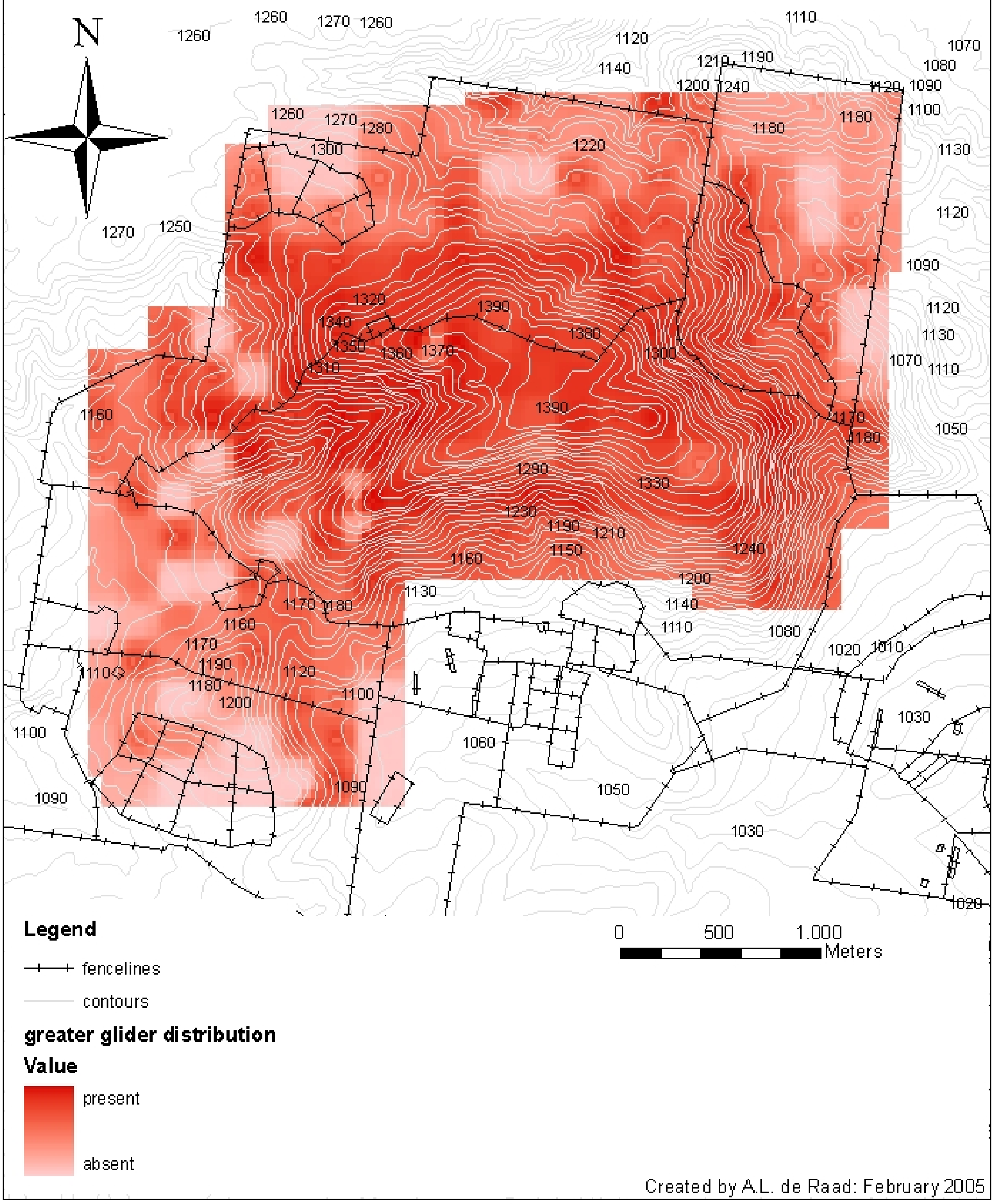
Created by A.L. de Raad: February 2005

Common ringtail possum distribution in Newholme region



Created by A.L. de Raad: February 2005

Greater glider distribution in Newholme region



Created by A.L. de Raad: February 2005