Nutritional ecology of the Mumbulla koala

Spatial variation in habitat quality effects fine-scale resource use by a low-density koala population

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Background

Koalas are arguably Australia's most iconic and enigmatic animals. They specialise in eating *Eucalyptus* leaves and are renowned to have very discerning tastes when it comes to gum leaves. Koalas will only eat leaves of certain *Eucalyptus* and will even shy away from individual trees of a favoured species. Koala's feeding habits have been widely studied in captivity, but there is still much to learn about dietary needs and motivations of koalas in the wild.

Koalas and other *Eucalyptus* leaf-eaters need a minimum amount of nutrients including protein (or nitrogen), energy and water from leaves to stay healthy; but they also must avoid being poisoned by a myriad of leaf toxins. A leaf's nutritional quality is determined by the balance of nutrients and toxins – known in biology as 'leaf chemistry'. Leaf chemistry varies between the different *Eucalyptus* subgenera, between species and can also be surprisingly variable between neighbouring trees of the same species within a small area. Leaf chemistry is determined by environmental influences like soil and climate and is also genetically programmed. These environmental and genetic influences can result in 'patches' of trees with distinct nutritional quality across forested areas. Wild koalas must make constant decisions at different spatial scales to maintain a balanced quality diet – first, by deciding which areas to feed in and second, by choosing to feed from particular trees. Leaf chemistry is important for influencing which trees koalas use and their movements across a landscape, and may ultimately determine if the forest can sustain koalas in the long-term.

Koala numbers have declined across much of their historical range. Excluding a handful of high-density populations in Victoria and on offshore islands, koalas now mainly occur in scattered populations that are small and low-density across eastern Australia [1]. Many of these remaining populations live in forests in very rugged terrain and often on nutrient-poor soils. Koalas on the Far South Coast of NSW are no exception. In 1865, Bega District News famously reported that it was possible to "catch a Koala or Native Bear in the main street of Bega" [2]. Hunting for skins, and extensive land-clearing led to the rapid decline in the range and abundance of koalas and now only a handful of very small and low-density populations survive between Narooma and Eden. Poor habitat quality is frequently cited as the reason that these small koala populations have failed to thrive [2]; however, given there is still much to learn about the requirements of wild koalas, there is likely to be much more to the story of the koala decline in these areas.

This study: the Bermagui-Mumbulla koala

My study examined the nutritional ecology of a Far South Coast koala population located in the coastal forest between Tathra and Bermagui (Bermagui-Mumbulla). At approximately 22 000 hectares, this large forest stretches over multiple land tenures including National Park, State Forest and private property. Until recently, surveys of koala numbers in the Bermagui-Mumbulla forests have been sporadic and haphazard although there has long been a consensus that numbers were very low. From 2007 to 2009, I was involved in a comprehensive study of koala numbers and distribution in these forests carried out by the Department of Environment, Climate Change and Water (DECCW), Forests NSW and community volunteers. The surveyors used the grid-based Spot Assessment Technique (Gridsat)[3, 4] and at each Gridsat plot, field teams searched the base of 30 trees for koala faecal pellets. In total, the teams completed 590 plots and found faecal pellets at 60 different plots. From this survey, the population is estimated to be between 30 and 50 animals each with a large home range of about 50-100 hectares [5].

The information collected by the Gridsat survey provided a unique opportunity for me to find out why the koalas were choosing particular trees and particular areas over others. More generally, the objective was to determine the influence of leaf chemistry on the foraging decisions of a low-density population of koalas at two scales: within plots (fine-scale tree preferences) and between plots (broad-scale plot preferences).

The key questions I addressed were:

1. Do differences in leaf chemistry between neighbouring trees influence which trees koalas visit within a plot?
2. Do differences in leaf chemistry, slope, tree species composition or vegetation cover between plots relate to whether koalas visited different areas or their broader distribution?

Methods

Sampling approach

Mr Ross Cunningham of the Statistical Consulting Unit at the Australian National University (ANU) provided statistical guidance for the design of this study and the analysis of the data. Presence of koala faecal pellets found at the base of trees during the Gridsat survey indicated trees that koalas had visited. I chose twenty Gridsat plots where koala pellets were found: ‘occupied’ plots, and paired each with one plot where no koala pellets were found: ‘unoccupied’ plots. The paired occupied and unoccupied plots had similar tree species composition and elevation and all unoccupied plots were located within 1 km of an occupied plot (see map Appendix 1).

Visited trees at the occupied plots were classed as Category A trees. For every Category A tree, I also identified and collected leaves from two unvisited trees of a similar size from within the occupied plot: one of the same species (Category B) and one of a different *Eucalyptus* subgenus (Category C). At each unoccupied plot, I identified and collected leaves from two unvisited trees for every visited tree from the paired occupied plot: one from the same species (Category D) and one from a different *Eucalyptus* subgenus (Category E). Therefore, every visited tree was grouped with four unvisited trees. This approach is shown in Figure 1.

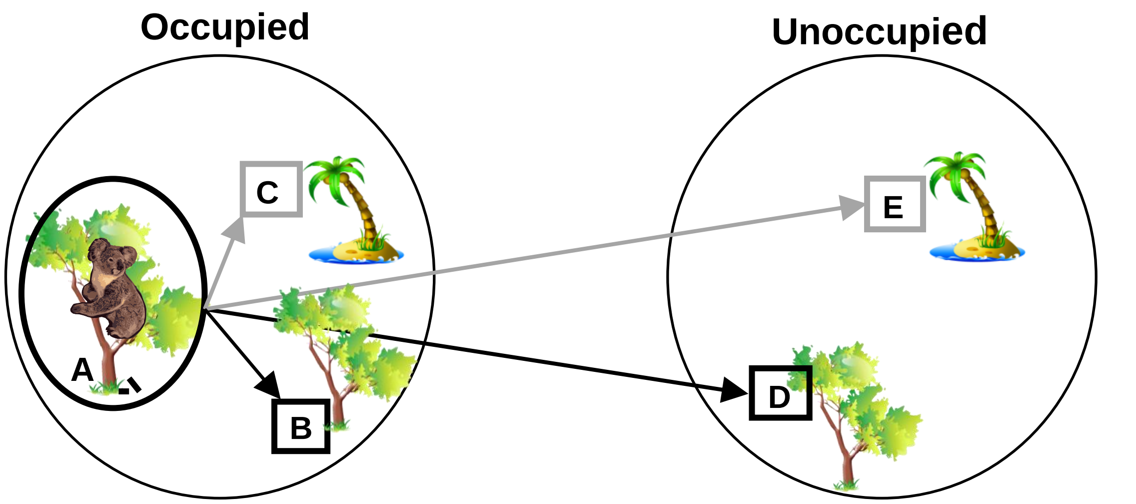


Figure 1. Sampling approach. Trees visited by koalas (A) were grouped with one nearby, similar tree that had not been visited (B) and with one nearby tree of a different *Eucalyptus* subgenus (C). A visited tree of the same species (D) and one of a different subgenus (E) to Category A trees were also collected from a matched unoccupied plot.

Field survey

I carried out field work from October to November 2009 with the help of NPWS and NSW Forests staff and members of the Bermagui community. Leaves were obtained from trees using firearms and all trees were searched for koala faecal pellets. I also recorded the vegetation composition, structure and slope of each plot. The final leaf collection consisted of leaf samples from 310 trees of 12 eucalypt species from the two main groups or subgenera of *Eucalyptus:* the *Symphyomyrtus* (common name symphyomyrtles) and the *Eucalyptus* (common name monocalypts).

Laboratory analysis

Leaves were analysed at the ANU to obtain concentrations of leaf chemical compounds including:

Available nutrients

- Available nitrogen: Nitrogen is an important component of protein, however not all nitrogen in leaves is available to animals. A considerable proportion of nitrogen is bound up in tannins and in indigestible fibre. Available nitrogen measures the actual amount of obtainable nitrogen once the effects of tannin and fibre are taken into account [6].
- Digestible energy: Digestible energy is the total amount of digestible matter, or energy in leaves that is available to animals, measured in biology as dry matter digestibility.

Toxins

- Tannins: A toxic compound present in all eucalypt leaves which binds to nitrogen and can also have other toxic effects if eaten.
- Formylated Phloroglucinol Compounds (FPCs): A group of toxic compounds only present in eucalypt trees of the symphyomyrtle subgenus. FPCs can induce nausea and be poisonous if consumed in high concentrations.

Statistical analysis

General Linear Mixed Modelling (GLMM) and Analysis of Variance (ANOVA) were used to analyse the data. The models compared the chemistry of visited trees to unvisited trees of the same species both within and between-plots. The ANOVA compared the differences between the two different *Eucalyptus* subgenera and between the tree species.

Findings

The koala: a shrewd food critic

My study shows that koalas do not just eat any *Eucalyptus* leaves, but are actually quite strategic and discerning and will choose one tree over a nearby tree of the same species based on leaf chemistry.

Koalas at Bermagui-Mumbulla chose to visit trees of 'higher quality' which contained higher concentrations of available nutrients and lower toxins when compared with nearby trees of the same species. They visited eight different eucalypt species, four of the subgenus monocalypt and four of the subgenus symphyomyrtle. All the species had highly variable chemistries and I often encountered two neighbouring trees of the same species that had such different leaf chemistry that, to a koala, one might have had leaves that tasted like chocolate and the other like cardboard. The monocalypts that koalas visited had leaves with higher concentrations of available nitrogen, higher digestible energy and lower tannin concentrations when compared with a neighbouring tree of the same species. Koalas showed a similar preference for trees of the subgenus symphyomyrtle, again preferring those that had higher leaf nitrogen, energy and tannins; however more significant was the presence of a single FPC: sideroxylonal. Significantly lower concentrations of sideroxylonal were found in the leaves of symphyomyrtles chosen by koalas when compared with neighbouring trees of the same species. Symphyomyrtles generally had leaves with higher concentrations of available nitrogen and lower tannins than the monocalypts, as shown in Figure 2. However the symphyomyrtles also contained the toxins - FPCs, where as the monocalypts did not. This meant that even though leaves of the species monkeygum and coast grey box generally had the highest concentrations of nutrients of all the species chosen by koalas, their leaves were not always good to eat because of the toxins.

Koalas avoided trees of all species with very low quality foliage (low nitrogen, low digestible energy and high tannins or high sideroxylonal concentrations); but they did not necessarily choose to visit the highest quality trees in a survey plot. This trend suggests that koalas are able to meet their nutritional requirements by eating the more common moderate quality trees and do not need to waste time and energy finding the very best quality trees available Although koalas still visited species that had lower average nutrient concentrations, like silver-top ash, the individual trees that koalas chose to visit had leaves that had much higher nutrient concentrations than the average for that species. This difference suggests that when koalas eat these lower quality species, they must seek out individual trees with exceptionally high quality foliage in order to meet their minimum nutrient requirements. Other studies on captive and wild koalas have also found that koalas to avoid trees with leaves that have low nitrogen and high tannin and sideroxylonal concentrations [e.g.7, 8], however this has never before been demonstrated in a wild low-density population.

On a broader scale, I found that plots that koalas did and did not visit (occupied and unoccupied plots) contained trees with a similar range of nutrient levels. Thus the plots that koalas currently occupy are not necessarily special feeding areas because the unoccupied plots also carried trees of acceptable nutritional quality. As the unoccupied plots were adjacent to occupied areas, they may simply be areas that the population have not yet colonised. If the population increases we may well see these areas becoming occupied in the future. To find out if there are parts of the forest further afield that provide suitable or unsuitable nutritional habitat, we will need to understand more about how leaf chemistry varies across the landscape.

Meat, three veg, fruit, salad and a vitamin supplement

A common assumption among ecologists and land managers is that wild koalas will feed predominantly from one or two tree species because leaves of these trees will fulfil all their nutritional requirements. While this is a useful rule of thumb for management purposes, the feeding ecology of the Bermagui-Mumbulla koalas, and perhaps other low-density populations, is much more complicated. The variation of leaf chemistry of the species at Bermagui-Mumbulla shows that a diet of one tree species is not enough. Koalas visited a wide variety of trees of different species with different types and concentrations of nutrients and toxins. This diverse combination of foods almost certainly amounts to a balanced diet for the koalas; equivalent to a human meal of meat, three veg, fruit, salad and a vitamin supplement. To further complicate the matter, the metabolic requirements of wild animals can change seasonally to cope with changing temperatures, water availability, leaf growth and to cope with the demands of reproduction. The nutritional quality of trees may also change over longer periods of time due to changes in the environment. For example, plants grown in conditions of elevated atmospheric CO_2 have increased concentrations of toxins in their leaves [9-11]. Accordingly, human-induced climate change could have long-term negative effects on the suitability of leaves for koalas. My study suggests that koalas need a diversity of tree species with varied quality foliage so they can pick and choose their foods. This need for diversity may become even more important with climate change as a choice of trees will provide koalas with the capacity to alter their feeding patterns to respond to changing leaf chemistry and maintain a balanced diet over time.

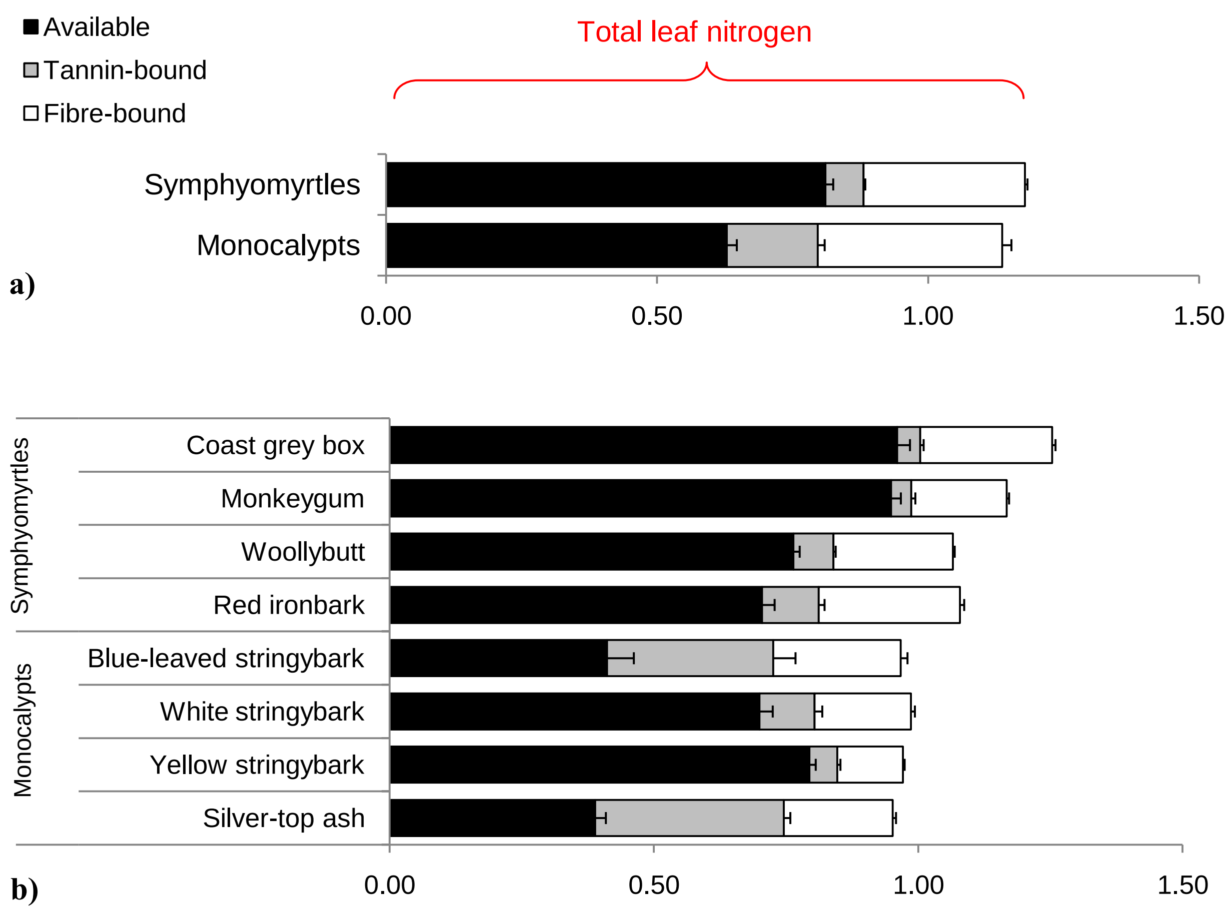


Figure 2. Components of total leaf nitrogen in a) the average for each subgenus and b) eight species visited by koalas. The concentrations of available nitrogen (black columns), tannins (grey) and fibre (white) sum to total leaf nitrogen concentrations. Values are the average concentrations for each species with standard error bars.

The symphyomyrtles include: coast grey box (*Eucalyptus bosistoana*), monkeygum (*E. cypellocarpa*), woollybutt (*E. longifolia*) and red ironbark (*E. tricarpa*); and the monocalypts include: blue-leaved stringybark (*E. agglomerata*), white stringybark (*E. globoidea*), yellow stringybark (*E. muelleraina*) and silver-top ash (*E. sieberi*).

The three tiers of feeding

The Bermagui-Mumbulla site has historically been considered a low or moderate quality forest habitat on soils of low fertility that is capable of supporting only low-density koala populations [12-14], however my data does not lend support to this assumption. The NSW Koala Recovery Plan ranks different eucalypt species in order of preference as food trees and their relative importance to koalas in each region of NSW [15]. The Plan separates tree species into three tiers of importance: primary, secondary and supplementary, starting at the most important primary species capable of supporting high-density koala populations and ending in supplementary species that would not support a koala population on their own. However, when I compared the leaf chemistry of south coast tree species from the three food tree rankings, there was no apparent difference in the nutritional quality of the leaves. Primary food tree species listed for the South Coast region are extremely rare in the Bermagui-Mumbulla forests, which is instead dominated by secondary and supplementary species. Stringybark trees are all classed as 'supplementary' food tree species, but the yellow and white stringybarks I collected from the Bermagui-Mumbulla site had leaves with the same average nitrogen concentrations as the secondary food tree species woollybutt. After woollybutt, white stringybark was in fact koala's second favourite species to visit, which suggests that it play more than a supplementary role in the koala's diet. A comparison of species from other regions also revealed interesting results. Six of the eight tree species visited by koalas at Bermagui-Mumbulla had similar concentrations of available nutrients and toxins to primary feed species preferred by koalas in Victoria and other areas including manna gum (*E. viminalis*), Tasmanian blue gum (*E. globulus*) and Sydney blue gum (*E. saligna*). This suggests that the tree species at Bermagui-Mumbulla have similar nutritional quality to well-known koala favourites which gives us hope that the area has potential to support higher density populations than previously thought.

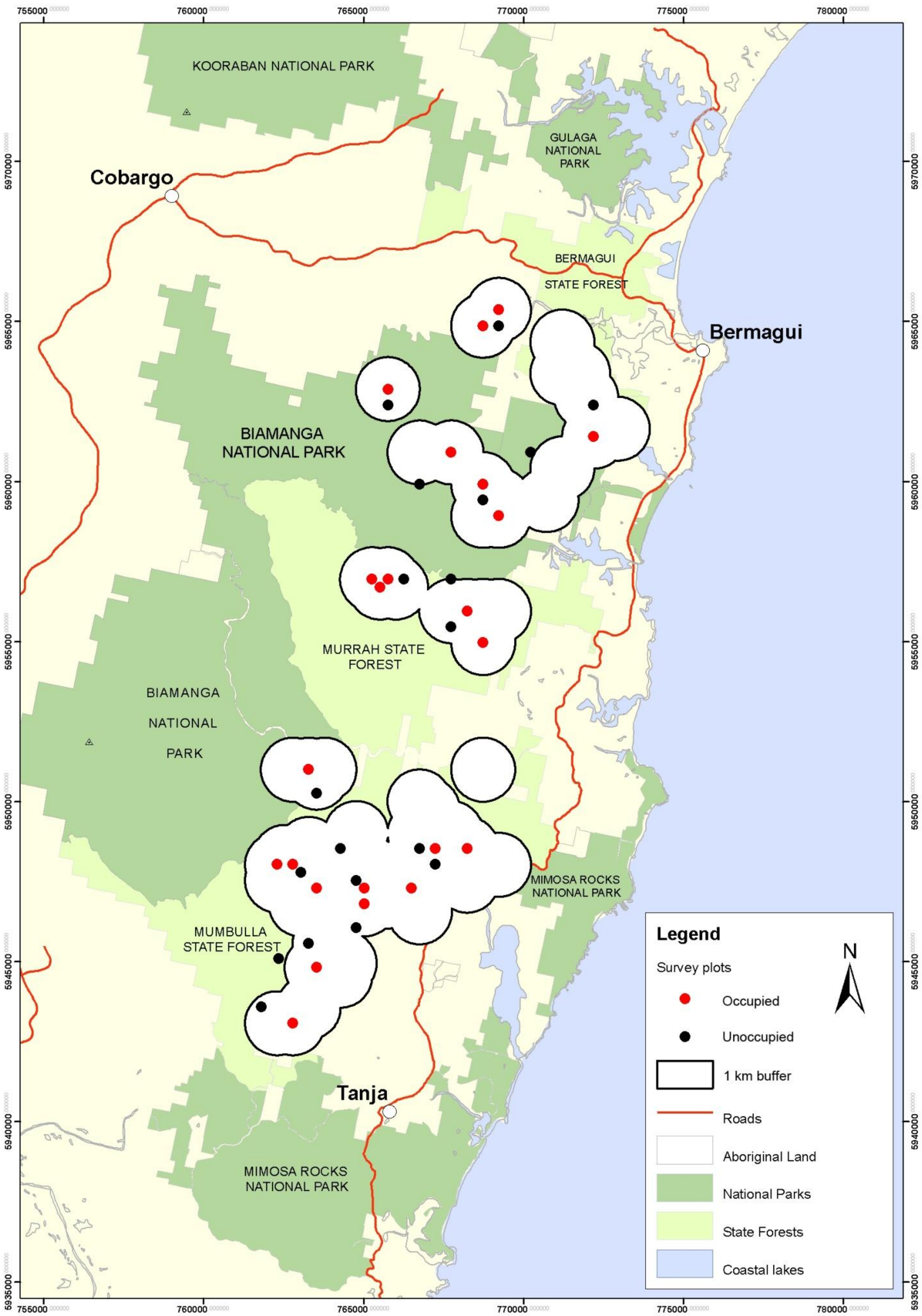
The mystery remains: why are koalas at such low numbers in the Bermagui-Mumbulla forests? The answer potentially lies with the impacts from historical and ongoing disturbances from land clearing and fragmentation, forestry activities and fire. Additionally, the region has experienced prolonged drought which can suppress leaf flushing, decrease leaf water content and lead to tree die back; thereby reducing the availability of higher quality foliage.

Conclusions

Although forests may appear uniform and harmonious to us, the koala sees a forest of patchy nutritional quality and diverse food types which can even be toxic to eat. To survive in this hostile and variable environment, koalas need to be vigilant and perceptive. Koalas in these low-fertility forests have particularly complex feeding strategies that are not solely based on tree species, but rather on the concentrations of particular chemicals in the leaves of individual trees. Leaf chemistry can vary even between trees of the same species and only some trees of each species will be suitable food. Koalas at Bermagui-Mumbulla visited a high diversity of eucalypts to maximise nutrient intake and manage the high and variable toxicities in their foliage. This suggests that effective management of these low-density populations is not just about retaining one or two tree species, but preserving this diversity. The challenge now is to pursue methods that can recognise which trees are nutritionally suitable without the need to collect leaves and analyse them in the laboratory. A new and exciting method of remote sensing is currently being explored to analyse leaf chemistry more efficiently. This method will allow managers to create a map of the nutritional quality of eucalypt forests from high-resolution aerial photography.

This study brings us a step closer to understanding the feeding ecology of low-density koala populations, however there is still much to learn about the south coast koalas and their habitat across the Far South Coast region. To develop our knowledge in this area, we are currently undertaking a pilot feeding study of feeding behaviour with captive koalas in Merimbula. This captive study, and future work in this region, will ultimately help to answer the broader question of why koalas thrive in some areas and decline in others across their natural range.

Appendix 1: Map of occupied and unoccupied plots



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