Mapping the palatability of *Eucalyptus* forests for leaf-eating marsupials using near infrared reflectance spectroscopy[*]

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Introduction

Eucalyptus and marsupials

Australian forests and woodlands are dominated by more than 800 species of *Eucalyptus* that vary in size from tall forest trees to small shrubs. Few insects, and even fewer mammals, feed on *Eucalyptus* foliage to any appreciable extent and those that do are constrained by the relatively low nutritional quality of *Eucalyptus* leaves, including its low protein concentration, high content of indigestible lignified fibre and the presence of large concentrations of terpenoid and phenolic secondary metabolites. Most prominent among the mammal fauna are the koala (*Phascolarctos cinereus*) an obligate eucalypt folivore (5–13 kg live weight), the greater glider (*Petauroides volans*), a smaller (1–1.7 kg) obligate eucalypt folivore, the common ringtail possum [*Pseudocheirus peregrinus* (0.7–1.0 kg)] and the common brushtail possum [*Trichosurus vulpecula* (2–5 kg)].

These species do not occur in all forest types and in fact their distribution is highly patchy. For example, Braithwaite *et al.*[1] found that in the south-eastern forests of NSW, about 60% of the animals occurred in just 10% of the forest area. The areas where animals did occur were on fertile soils but these areas are also sought for farming and forestry activities and are poorly represented in National Parks and other reserves. Consequently, methods are needed to identify the critical areas of forest that support viable populations of these species.

In this paper we want to demonstrate our approach to the measurement of the nutritional quality of eucalypt forests for marsupial herbivores. In short, we use near infrared (NIR) reflectance spectroscopy to predict the potential dry-matter intake of foliage from each tree in our study areas.[2] We argue that the appropriate scale for measurements of the nutritional quality of *Eucalyptus* forests is not the taxonomic species but individual trees within a species. Therefore, we need to sample a large number of trees in the forest in order to understand how suitable food trees are distributed in the landscape.

This concept, which we call "palatability mapping", depends upon three assumptions that we have studied and reported on elsewhere. These are:

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- That individual trees vary markedly in their nutritional quality as foods for marsupials[3,4]
- That dry-matter intake is the best measure of nutritional quality of *Eucalyptus* foliage for folivorous marsupials [3–5]
- That NIR is a valid tool for estimating dry-matter intake in folivorous marsupials[2,6]

Since previous studies have shown that these three assumptions are valid, we are able to assign a single palatability rank to each tree in a forest and so map the palatability of habitats for free-ranging marsupials.

Nutritional ecology of *Eucalyptus*-marsupial interactions

Food quality for leaf-eating marsupials is driven largely by intraspecific differences in the concentration of a well characterised group of plant secondary metabolites called formylated phloroglucinol compounds (FPCs).[3,7,8] These compounds act as antifeedants, probably by stimulating the emetic system of the animals, but other toxic effects have not been identified. For example in *E. polyanthemos*, 86% of the variation in dry-matter intake by common ringtail possums is explained by the concentration of a single FPC called sideroxylonal A.[5] All the FPCs are terpene–phenol adducts[9] and are widely distributed in eucalypts.[8]

Commonly used measures of the quality of foliage for herbivores, including the concentration of foliar nitrogen, fibre fractions and concentration of "tannins", have little power to explain short-term captive measurements of food intake in these marsupials,[3] (B.D. Moore, unpublished). Consequently, the best measure of nutritional quality for leaf-eating marsupials is dry-matter intake or more precisely, the potential dry-matter intake.

Near infrared spectroscopy as a prediction of foliar nutrients and of relative feeding rates

Many studies have shown that NIR can be used to predict the concentration of both nutrients and plant secondary metabolites in plant material.[2] The same is true in *Eucalyptus*[6] and this includes the antifeedant compounds that govern food intake.

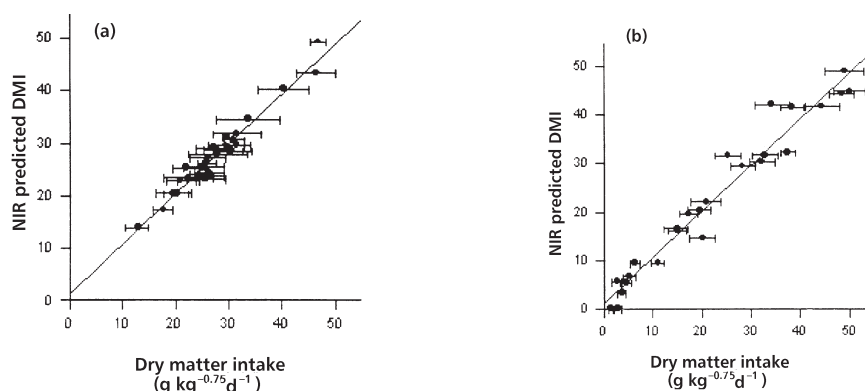**Figure 1. Relationship between mean voluntary dry matter intake (DMI) (± standard errors) of foliage for (a) greater gliders and (b) common ringtail possums and the potential intake predicted by a model based on partial least squares regression relating the near infrared spectra of *Eucalyptus* foliage to the measure of intake of *Eucalyptus* foliage. Significant relationships between actual and predicted intake were found for both greater gliders ($r^2 = 0.94$, *s.e.* = 1.80, $n = 30$; $F_{1,29} = 272$, $P < 0.0001$) and common ringtail possums ($r^2 = 0.95$, *s.e.* = 3.79, $n = 25$; $F_{1,24} = 505$, $P < 0.0001$).**

We reasoned then that if NIR could adequately predict concentrations of foliar components that affect food intake, then it should equally be able to directly predict potential dry-matter intake as measured in our laboratory experiments. Several previous studies had shown that NIR could predict dry-matter intake by domestic animal species fed hays and forages (summarised in Coleman *et al.*).[10] In these cases, composition of the food is an important determinant of food intake but probably not to the same extent as in *Eucalyptus* where a single chemical constituent is of overriding importance. Accordingly, it was not surprising that NIR could predict *potential dry matter intake* (as defined above) by koalas, greater gliders and common ringtail possums. Figure 1 shows two examples of the fit between observed dry matter intake and that predicted by a model based on the NIR spectrum. These models explain up to 94% of the variation in food intake by greater gliders, common ringtail possums and koalas (data not shown) fed *Eucalyptus* foliage, respectively.

Initially, we were concerned that these models might be entirely empirical and not based on wavelengths associated with foliar sideroxylonal concentrations. In other words, we needed to assess whether the model had any mechanistic basis. Therefore, we identified the most important wavelengths[11] in the predictive model for foliar sideroxylonal and potential dry-matter intake (Figure 2). First, wavelengths that were important for predicting sideroxylonal (with the direction of the effect indicated in brackets) were 1756 nm (–), 2188 nm (+), 2220 nm (–), 2260 nm (–) and 2364 nm (+). The wavelengths that contributed most to calibrations of feeding by common ringtail possums were 1652 nm (+), 2188 nm (–), 2220 nm (+), 2364 nm (–) and 2404 nm (+). Note the importance of wavelengths 2188 nm, 2220 nm and 2364 nm, which are used in both predictions but which have opposite signs. This result provided independent but clear evidence that foliar concentrations of sideroxylonal are a major determinant of feeding in common ringtail possums and that our model of potential dry-matter intake was, in fact, based on a defined and known mechanism.

Estimation of potential dry-matter intake by sheep and cattle, using NIR calibrations, has had some success[12–15] but in most cases the accuracy of the predictions has been lower than that achieved here. We believe that this may be because in *Eucalyptus*, single compositional factors are more important determinants of intake than in hays and grasses. This is certainly true for *Eucalyptus polyanthemos* but remains to be tested in other species of eucalypt.
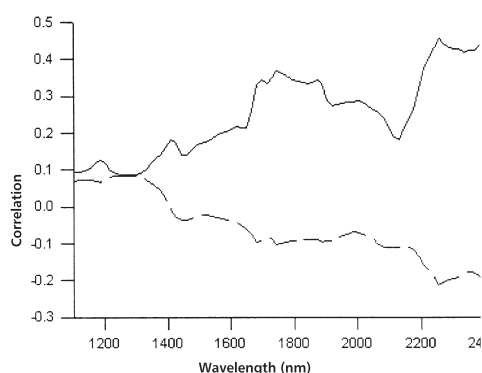

Figure 2. Correlation between individual wavelengths of near infrared spectra of *E. polyanthemos* foliage and sideroxylonal concentration (solid line) and dry-matter intake of common ringtail possums (dashed line).

Distribution of palatable trees in the field

We are in a position to extend consideration of these concepts into detailed studies of foraging by marsupial folivores in the field using NIR. Our first study was of an area of *Eucalyptus polyanthemos* forest near Queanbeyan in southeastern Australia. We chose an area of 100 m × 50 m because it is the size of a single home range of the common ringtail possum that lives in these forests. There was no difference in soil type, water availability or aspect across the plot. We collected foliage from all 87 *E. polyanthemos* trees within the area and used NIR spectroscopy to predict the foliar sideroxylonal concentration and the potential dry-matter intake of each sample. Details of the procedures are published elsewhere.[5]
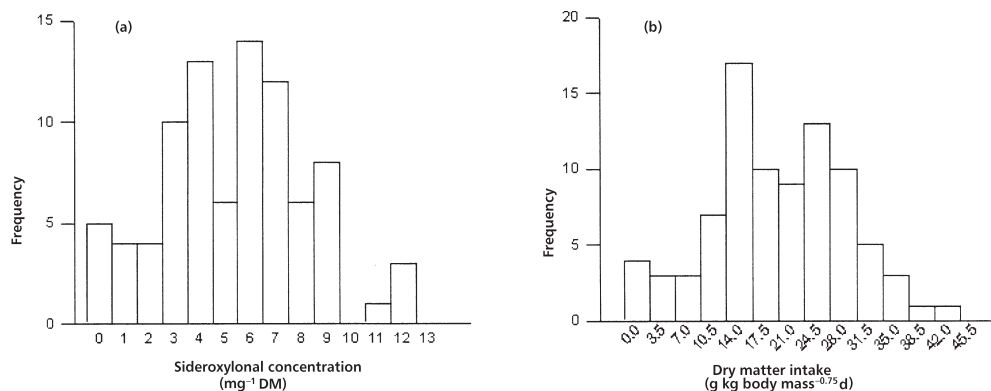
Figure 3. Frequency distributions of varying leaf chemistry between individual *E. polyanthemos* trees within one population; (a) foliage sideroxylonal concentrations, (b) near infrared spectroscopic prediction of dry-matter intake by common ringtail possums.[5]

Predicted foliar sideroxylonal concentration varied from 0 to 12.6 mg g^{-1} dry matter and potential dry-matter intake varied from 0 to 43 g kg body mass$^{-0.75}$ d^{-1} (Figure 3). Based on studies in which common ringtails were fed acceptable *E. polyanthemos* foliage for long periods, the digestible energy intake needed to maintain body mass was 320 kJ kg body mass$^{-0.75}$ d^{-1} (W.J. Foley and S.J. Cork, unpublished data). This equates to a dry-matter intake of about 30 g kg body mass$^{-0.75}$ d^{-1}. We therefore regard this as the critical intake necessary for a single tree to support feeding so that animals could maintain themselves (Figure 3).

Given these requirements, of the 87 trees in this site, only six had potential intakes that could allow an animal to feed exclusively on that tree and maintain body mass. The food preferences of common ringtails at this and other sites is currently being assessed but it seems certain that animals do not feed solely from a single tree but eat from several trees of several species. Although our long-term goal is to evaluate the role of food quality in population density, we have to devise a way to integrate the whole feeding effort.

In a second, larger area inhabited by koalas, ringtail possums and brushtail possums on Phillip Island near Melbourne, we have mapped the potential dry-matter intake of about 1400 individual trees of *E. globulus*, *E. viminalis* and *E. ovata*. At Phillip Island, trees covering the full spectrum of palatability are distributed throughout the area studied, which is inhabited by a managed population of about 15–20 koalas. *E. globulus* is the most common tree species present and is also the species most favoured for use by koalas. The only tree-use data we have obtained to date is from diurnal observations of koalas in trees, which does not necessarily indicate the use of trees for feeding. A preliminary analysis of the potential dry-matter intake of those *E. globulus* trees that were used by koalas seems to indicate that koalas' selection does not differ from random (B.D. Moore unpublished data). Both palatable and unpalatable trees are used in approximately the same proportions as they are available.

More detailed information is required about koalas' use of trees before firm conclusions can be drawn concerning the role of palatability in tree selection. It may be that koalas do not show selection for palatable trees as long as those trees are above a palatability threshold. We are also yet to validate our NIR model of potential dry-matter intake using an independent set of trees.

Difficulties and outlook

It is important to validate predictive models such as these by making detailed observations of the foraging behaviour of koalas and other leaf-eating marsupials. However, if we want to apply these

ideas more widely, we must work on a larger scale. In particular, if we want to assess foliage quality on a scale valuable to conservation managers, then in the longer term we need to be able to collect spectra remotely from either an airborne or satellite platform.

Several studies have shown that it is possible to acquire remotely sensed compositional information from tree canopies[16,17]—most notably with the NASA airborne infrared spectrometer (AVIRIS) but there are a number of other instruments such as HYMAP. To this end, we have shown that the crucial biochemical information needed to assess nutritional quality of *Eucalyptus* leaves can be extracted from samples of fresh, intact leaf. Although this is a necessary first step to developing a method of remotely sensing nutritional quality of tree canopies, the complexities introduced by atmospheric interference and canopy architecture must be addressed before the method can be applied. Future developments in multi-spectral remote sensing will provide tools to address this issue but it will require close collaboration between nutritionists and the remote sensing community.

Acknowledgements

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