



*Eucalyptus* leaves are low in nutrients, tough to digest and can be toxic, so koalas must make complex choices about which trees to feed in.

dangerous because some foods are toxic.

In the past two decades, American rangeland scientists have led the way in demonstrating some of the ways in which animals learn how to assemble a safe and nutritionally balanced diet. In essence, they learn from experience. Animals sample novel foods cautiously, and learn to associate the flavour of that food either with positive effects (like the feeling of well-being we experience after a satisfying meal) or with negative effects (feelings of malaise resulting from nutritional deficiencies or poisoning).

Many animals can also learn what to eat by watching their neighbours and their mums. We know that some flavours, such as bitter tastes, can provide important clues that plants may contain toxins. Ultimately, however, animals' diets are most strongly influenced by their own personal experience with ingesting the food.

It is easy to imagine that this whole learning process could be easily avoided if animals stuck to a single reliable food source, as does the koala, which feeds almost exclusively on *Eucalyptus* leaves. Unfortunately for the koala, life is not so simple.

By specialising on this foliage, koalas ensure that they have access to a widespread and easily obtained food source. However, getting by on *Eucalyptus* leaves presents other problems. The foliage is very low in nutrients, particularly protein and energy, is very tough to chew, contains a large proportion of indigestible material (fibre) and can possess a veritable smorgasbord of toxins. These include essential oils, which give gum leaves and the Australian bush their characteristic smell; tannins, which prevent animals from digesting much of the leaves' protein and thus reduce the availability of this essential nutrient; and phenolic

## Why Did the Koala Cross the Forest Floor?

Koalas are fussy eaters. Ben Moore discovers why.

When we shop in the supermarket, we can generally be confident of finding food that is both safe and nutritious. This task is made easy for us by packets that list each food's ingredients and a raft of nutritional information, and by manufacturing processes that are regulated and carefully monitored.

But life is not so straightforward for wild animals, and this is especially true for herbivores. Wild herbivores face two problems that we avoid when we shop in a supermarket. First, plants are not labelled as food and non-food items, so the animals must learn for themselves which plants are good sources of nutrition. Second, this process is inherently

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compounds called formylated phloroglucinol compounds (FPC). On top of all this, some eucalypts contain sugar compounds called cyanogenic glycosides, which are broken down to release toxic cyanide gas when the leaf is chewed!

Given that the koala and its ancestors have evolved alongside the eucalypts for perhaps as long as 25 million years, it's not surprising that koalas are remarkably tolerant of most of these nutritional shortcomings, even in comparison with other eucalypt-feeding marsupials such as common ringtail and common brushtail possums and the greater glider. Nonetheless, not all gum leaves are created equal, and not even a specialist like the koala can avoid facing up to some tough decisions about what to eat.

If you have ever tried to assign a *Eucalyptus* tree to one of the 900 or so recognised species, you will know that there is no such thing as a "typical" gum tree. In fact, the problem runs deeper than this for foraging folivores, because individual *Eucalyptus* trees, even those growing in the same locality and belonging to the same species, can differ markedly in the chemical makeup of their leaves. This variation is especially striking for concentrations of toxic FPCs.

The strong effect of FPCs on the feeding behaviour of possums was identified by Bill Foley, Dave Pass and Ivan Lawler in an innovative series of experiments at James Cook University and then the Australian National University (ANU) in the late 1990s. These experiments suggested that FPCs cause serotonin to be released into the possums' bloodstream, triggering nausea and deterring the marsupials from further feeding.

Trees that contain only low concentrations of FPCs never provoke illness, so possums can eat their fill. In other trees, however, higher FPC concentrations limit the amount that a possum can eat before nausea sets in and the feeding bout ends.

Tree-to-tree differences in FPC concentrations occur in concert with differences in the concentration of aromatic and strongly flavoured essential oils, so possums learn to associate the smell and taste of each tree with the likelihood of an unpleasant outcome.

In conjunction with Foley and Ian Wallis at the ANU, I have investigated whether FPCs also influenced the feeding behaviour of koalas, which I expected would be less susceptible to these toxins than possums. A series of experiments with captive Victorian koalas showed that although koalas ate foliage from some trees that possums rejected, the amount of leaf that they willingly ate when no other food was available was nonetheless determined by the concentration of FPCs.

This result came as no great surprise. I already knew that these compounds influenced feeding by possums, and the literature contains many other examples where toxins have deterred captive animals from feeding. What was lacking from the scientific record, however, was proof that plant toxins shape the way in which wild herbivores use the environment.

The canopy of a eucalypt woodland may look like a homogeneous sea of green to you and I, but to the animals that make a living in the treetops it is a highly complex and chemically variable foraging environment. I built on previous work by Lawler and others in a eucalypt woodland at Phillip Island, Victoria, to understand just how complex it is. The 7.6 ha patch of remnant vegetation contained more than 1000 trees ranging in size from saplings to ancient giants from three different species: blue gum (*Eucalyptus globulus*), Gippsland manna gum (*E. viminalis* subspecies *pyroriana*) and swamp gum (*E. ovata*).

After analysing leaf samples from each of these trees, I produced a map describing the chemistry of the eucalypt canopy throughout the reserve. Each eucalypt species has its own typical

chemical profile, so patterns in the distribution of the three species create one layer of complexity in the distribution of preferred food resources. Variation in the chemical makeup of individual trees then imposes another level of spatial complexity on top of this. The result is that the highest quality food resources for koalas are scattered in an intricate way among surrounding trees of moderate and low value to koalas.

It was in this complex landscape that I asked how plant chemistry influenced patterns of tree use by koalas. Given the clear results of the experiments with captive marsupials, why should there be any doubt that wild koalas would be similarly influenced by plant chemistry as they navigated their way around the forest?

In fact there is no shortage of possible reasons. My captive feeding experiments, which only gave koalas the choice of eating or not eating from a single tree at a time, did not reproduce the choices that wild koalas are faced with. Free-ranging animals must weigh up the benefits of staying in a tree and feeding there against the pros and possible cons of moving to another tree.

A koala might conceivably remain and feed in a tree with moderate or even high levels of undesirable compounds for a number of reasons. For example, the tree may offer greater amounts of young, soft foliage, lower concentrations of other toxins or higher concentrations of nutrients than are to be found elsewhere. It may also offer more easily reached leaves than other trees in areas where many trees are overbrowsed, or it may offer more sunny patches in winter, or greater shade or a refreshing breeze in summer. A tree may be temporarily favoured or shunned because of the presence of another koala, depending on a koala's social inclinations at a given time.

And given the koala's reputation for laziness, we can also ask: why be bothered moving? Not only do koalas have limited energy reserves for movement,



In south-eastern Australia, koalas from overabundant populations have often been translocated to areas with fewer koalas. A stronger understanding of the challenges that the chemistry of eucalypt canopies present to koalas should help to ensure that these animals are not moved to unsuitable habitat.

while on the ground they are also at increased risk of attack from dingoes and wild dogs. For all these reasons, wild koalas might be prepared at times to put up with a diet that is less than ideal.

The woodland that I had mapped at Phillip Island is part of the Koala Conservation Centre, and is usually home to approximately 20 koalas. For the past decade the local “Friends of the Koalas” group, Kath Handasyde of the University of Melbourne and Phillip Island Nature Park rangers have conducted monthly surveys of the koalas in the reserve. Over that period a very large number of observations of tree use by koalas has been recorded, including the identity of the individual trees used. This allowed me to compare the selection of trees used by koalas over that period with the pattern that I expected to see if koalas had used trees randomly.

Right from the start it was clear that koalas were not using trees completely at random, as koalas had been seen in fewer trees than I expected – meaning that many trees were avoided and some trees were particular favourites.

However, the strongest reasons for this were a lot more obvious than foliar chemistry. As any Australian schoolkid will tell you, koalas are fussy eaters and

prefer some types of eucalypts over others, and the data showed that the koalas at Phillip Island had greater and lesser favourites among the three species present.

The other obvious factor behind the preferences koalas showed for some trees over others was tree size. As you might expect, it is more common for a large tree to have a koala in it than for a small tree – after all, there’s more leaves on a big tree!

Having described the influences of these factors on tree use by koalas, I was able to narrow my focus. Considering one eucalypt species at a time, and allowing for the roles played by the species and size of each tree, I asked again whether foliar chemistry influenced which trees koalas had used.

For both manna gum and blue gum, which together had provided more than 80% of koala sightings, the answer was a definite yes. In both cases the average concentration of FPCs in trees used by koalas was less than would be expected if koalas had foraged randomly. This difference came about because koalas had avoided the most toxic trees, making up the shortfall by visiting trees with moderate FPC levels more than expected.

However, FPC concentrations were not the only aspect of leaf chemistry that had influenced tree use by the koalas. Because *Eucalyptus* leaves contain so little protein, it has often been suggested that protein concentrations limit what koalas can eat and where they can be found. However, robust evidence for this has always been lacking. Happily, we found that koalas had avoided trees that contained low concentrations of protein in their foliage.

Despite the bewildering variety of foliage available to each koala in its home range, and the array of potential factors influencing their movements, these animals use their habitat in a sensible and efficient way. At last we have an answer to the question: “Why did the koala cross the forest floor?” The answer: to get to a better tree! More importantly, though, this research offers hope of further breakthroughs in understanding the role that plant toxins play in the ecology of herbivores.

We already know that the chemistry of eucalypts and other trees changes across the landscape. In tallowwood, a common eucalypt along the mid-east coast of Australia, FPC concentrations differ with site quality, temperature and the concentration of nitrogen in the canopy. Could chemical differences between different populations of tallowwood determine the numbers of leaf-eating marsupials found at each site?

A long-standing debate in ecology surrounds the question of whether the quality or quantity of plant food has a greater effect on the ability of herbivores to breed successfully and exist at high population densities. However, my results show that plant toxins effectively limit both the quality and quantity of food produced by a plant population. The average quality of food decreases as animals are exposed to more toxins, and the quantity of food decreases because animals are forced to remove many trees from the menu.

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