A most unusual mammal.

The koala's quandary

Take a walk through almost any Australian forest at night and, if you're armed with a good spotlight, you'll have a fair chance of seeing at least one of our tree-dwelling marsupials.

The most famous of these is of course the koala, but probably the most often seen is the common brushtail possum. Our trees also play home to a host of other furry creatures ranging from tree-dwelling kangaroos (in the rainforest of northern Queensland) to the tiny feathertail glider and the even smaller 'little pygmy possum' that weighs in at about 7 g.

The koala is well known for the fact that it eats the leaves of *Eucalyptus* species exclusively. Do the other arboreal marsupials live solely on gum leaves too? No. Although eucalypts make up more than 90% of Australia's forest trees, their foliage is important in the diet of only four marsupials — the koala, brushtail possum, ringtail possum, and greater glider. The two possums often supplement their diet with the fruits of other plants, and indeed the brushtail is happy to become quite omnivorous given the opportunity.

The other tree-dwellers do not, in the main, eat eucalypt or other leaves. Why this is so and how any mammal manages to live by eating such apparently hopeless fodder as tough oily gum leaves are two questions now being examined by a number of scientists, among them Dr Steven Cork of CSIRO's Division of Wildlife and Rangelands Research and a group at the University of New England.

The koala's slow movements and sleepy demeanour are valuable behavioural strategies.

Dr Cork wanted to find out how koalas can survive on eucalypt leaves, and what factors make life easy or difficult for a tree-dwelling leaf-eater — or, in latinised jargon, an arboreal folivore. Why don't more animals choose to occupy this particular niche in the treetops, which contains abundant food, and few large predators? What constraints affect the biology of the eaters of tree leaves?

Size is the first and most obvious constraint. Much as vegetarian animals such as cows or horses may like certain leaves they cannot climb up and get them. (A possible solution, as practised by the giraffe, is the development of an exceedingly long neck.)

The koala is the largest Australian arboreal leaf-eater and one of the largest in the world. Adults can range in weight from about 5 to 13 kg, the heavier ones being found in cooler regions. If they grew any bigger, climbing onto the ends of young

Three more of our arboreal mammals — the ringtail possum (above), the brushtail possum (above right), and the pygmy possum (right).

branches would become very risky. And the koala may well have problems in this regard, as the evidence of broken bones frequently found during autopsies of wild specimens attests.

So arboreal animals need a relatively small size, to make for easy mobility. But small size can also cause problems.

In warm-blooded creatures, the smaller the animal is, the more energy, proportionally, it requires to support the metabolic reactions that generate heat inside it. In part, this is because a small object has a greater surface : volume ratio than does a larger one, and if the object is a warm-blooded organism its body heat escapes from the surface. The smaller its insides are in relation to that surface, the more heat has to be made to compensate for the amount lost. So the animal needs more energy and has to eat more.

Very small mammals and birds must eat several times their own body weight each day that they are active. It is for this reason that we find a lower limit on the size of warm-blooded organisms — Nature has been unable to produce mammals or birds as small as insects, for example.

The problem is particularly acute for a leaf-eater because plant material has a lower energy 'density' than other food sources. (Because leaves or grass have much less extractable energy per gram than, say, meat, most herbivores must spend almost the entire day eating, whereas an efficient carnivore can live off a kill for days.)

A diet consisting only of eucalypt leaves is exceedingly unpromising because these leaves are nutritionally poor. Relative to other food sources, they contain very little nitrogen, which is essential in the diet for making proteins and nucleic acids. They have a large amount of fibre (in the form of cell-wall material) — many times more than in the highest of high-fibre diets for humans — but not a great deal of usable energy. Also present is lignin — a general name for a complex group of hard-to-digest molecules from which wood is made. Eucalypt and other trees' leaves contain lignin in greater quantities than grass or herbs.

Even worse for an aspiring folivore is the presence of poisonous compounds in gum leaves — for example, the bitter-tasting tannins, which seem to latch onto proteins and render them biologically useless, and the eucalypt oils, which may smell nice, but need to be 'disarmed' by means of detoxification in the liver. Although gum leaves contain more lipid — a good source of energy — than many other types of green plant material, much of it is in the form of indigestible waxes that coat the leaves.

Dr Cork and others have found that young foliage generally has more nitrogen and less cell-wall material than older leaves, but analysis shows that — strangely, in view of what we may think of as fresh soft material — it also contains more lignin. All in all, to obtain enough energy and essential nutrients, our brave little eaters of gum leaves must make use of a few cunning adaptations in order to survive.

Energy and nitrogen

If you can't acquire as much energy through your food as ideally you may want, an obvious adaptation is to use less energy. Marsupials in general are considered to

The koala's sleepy demeanour — proof of a lazy nature or a clever strategy for energy conservation in an animal living at the limit of its energy budget?

have a lower basal metabolic rate (BMR) than placental mammals, although some controversy exists about this. (The BMR is the quantity of energy used just to keep all the cells alive and the body 'turning over', physiologically speaking, without any extra activity.)

Among the marsupials themselves, the koala is noted for having a BMR 25% lower than average, which means it uses about 50% less energy to stay alive than most comparably sized placental mammals would. Brushtail and ringtail possums, and greater gliders, have average rates for marsupials.

The koala's slow movements and sleepy demeanour (in the past considered as evidence of intoxication with eucalypt oils, or just of a wickedly lazy nature) are therefore valuable behavioural strategies in the fight to conserve energy. Similar strategies are seen in the placental leaf-eating tree-dweller the sloth (whose name of course describes its behaviour).

But energy isn't the only commodity required from a diet. Nitrogen, as already mentioned, is important for building proteins and nucleic acids. Scientists had thought that mature *Eucalyptus* foliage on its own provided insufficient dietary nitrogen for koalas. They based this belief on theoretical grounds, knowing the nitrogen concentration in the foliage and using figures for nitrogen metabolism derived from the well-studied domestic herbivores.

Dr Cork, while at the University of New South Wales, decided to investigate the situation in koalas. Eight captive koalas were fed solely on the foliage of the grey gum (*Eucalyptus punctata*), the nitrogen concentration of which varies from 1·1 to 1·5% of dry matter. From measurements of the nitrogen in their urine and faeces, Dr Cork found that the animals lost less of the element than they took in from the gum leaves — so extra nitrogen was available for growth.

How did the koalas manage to end up 'in credit' on a diet with so little nitrogen? Surprisingly, the loss through their faeces was relatively high. Most of this was not derived from their diet but instead represented their own nitrogen, or that from their gut bacteria. Dr Cork thinks that this loss may be caused by the exceedingly high quantity of fibre, which would knock off an unusually large number of cells from the inside of the intestine as it passed through.

But the koalas saved nitrogen by reducing the loss of it in their urine. They excreted less urinary nitrogen than most other marsupials that were kept on similar levels of dietary nitrogen.

A quite different adaptation occurs in another folivore: the ringtail possum has the laudably thrifty habit of eating some of its faeces! These special droppings do not drop, but instead are consumed with relish straight from the anus. They come from the caecum, the enlarged part of the hindgut used as a fermentation chamber to allow bacteria to break down cellulose (similar in function to the rumen of sheep and cattle, but placed at the other end of the system). The ingested contents of the caecum, rich in bacterial nitrogen, are processed through the gut once again to avoid losing that precious element.

Nobody has ever seen the koala practise coprophagy — the eating of faeces — and its adaptations to a low-nitrogen diet appeared to be only its slow metabolism (which slows its body's turnover of protein) and its ability to produce a urine exceptionally low in the element. Dr Cork's work shows that the critical level for nitrogen balance probably occurs at about 1% nitrogen in the dry matter of the diet, which is lower than levels occurring naturally in most eucalypts for which data exist. Of course, pregnancy and lactation would add to the requirement, and must be taken into account for wild populations, but the idea that a shortage of nitrogen is an important limiting factor for koala populations now carries less credence.

Coping with fibre

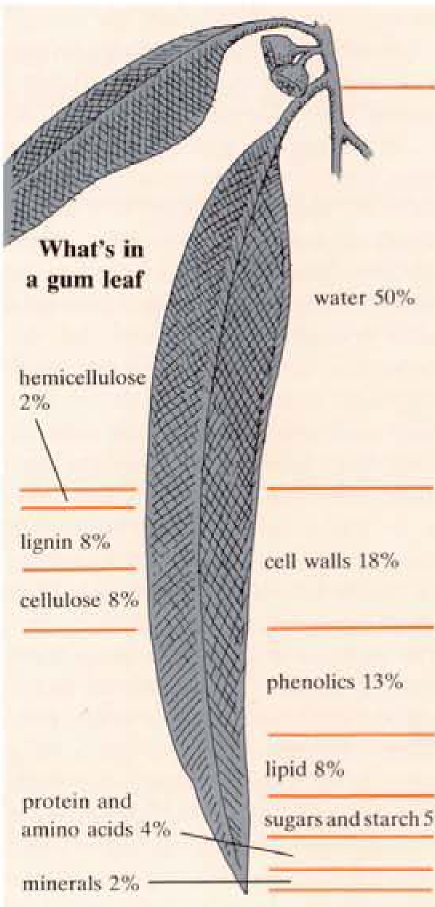
Herbivores cannot digest the cell walls of plants (mainly composed of cellulose) and, in order to obtain sufficient energy from their diet, rely on micro-organisms to do this for them. The micro-organisms ferment the cellulose, producing various simpler organic molecules that the mammal can absorb and use. The process needs a large vat or chamber, and takes time. Herbivores have a specialised gut with such an area provided, either at the front (ruminants) or the back (horses).

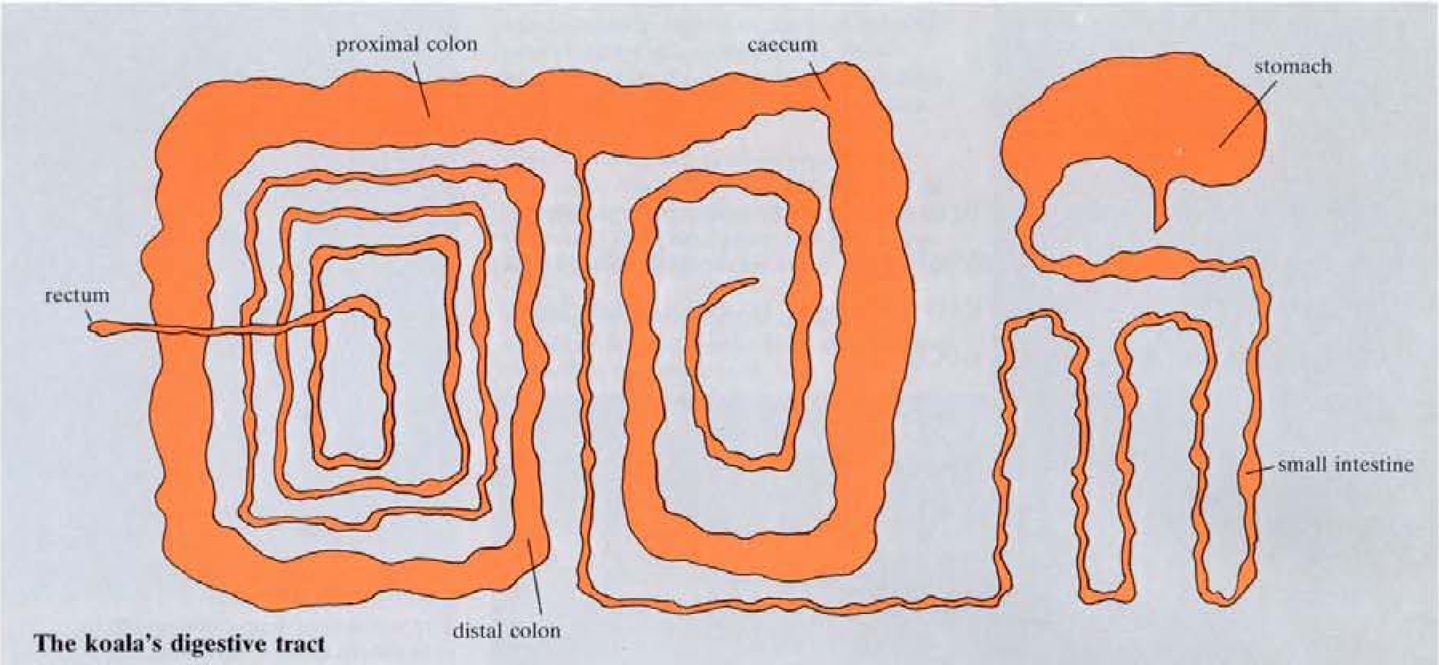
The fermentation yields energy rather slowly, but this doesn't present a problem for a big animal, provided it can eat a large amount. But mathematics works against small herbivores; as body weight decreases, relative energy requirements increase, but the volume available for fermentation does not.

Most small herbivores avoid this problem by choosing a diet with less fibre (that is, plant cell walls) and relying more for their energy on other components of the plant, which do not require bacterial treatment. They need foods with higher energy densities — berries, nuts, fruits, and roots.

That's fine down on the ground, but not if your ecological niche is up a gum tree, where you are forced to eat fibrous gum leaves. A mammal can cope with that if it is large enough, but the tree-dwelling habit imposes limits on body size — hence the koala's quandary.

The ingredients of koala fare.





The koala's digestive tract

Micro-organisms carry out digestion of cellulose and other plant components in the blind-ending caecum.

Scientists have calculated that any species small enough to be mobile in forest tree-tops — less than about 15 kg in weight — and highly or exclusively folivorous, must live permanently on the edge of an energy crisis. We have already seen various ways in which the koala deals with the problem, but Dr Cork, by investigating the animal's digestion, uncovered another adaptation.

Using a well-established technique, he measured the lengths of time that particles and fluid, respectively, remained in the digestive systems of six adult koalas. The technique relies on the use of radioactive 'markers' attached to two organic compounds: the compound with chromium-51 remains in the solute phase of the gut contents, and that with ruthenium-103 marks the particles, by adsorbing to their surfaces.

Both markers started to appear in the koalas' faeces about 10–18 hours after dosing; but then the excretion of ruthenium-103 — representing the particles — overtook the chromium. The koalas' guts took about 62 hours to clear half the particle marker, and about 135 hours to do the same for the solute-phase marker. In other words, they were selecting out particles (anything with a diameter greater than about 320 μm) and rapidly excreting these, while retaining the 'liquid' (fluid and fine particles) resulting from food that had been ingested at the same time.

Examination of the hindgut revealed how this probably occurred. Backward and forward contractions of the colon kept the fluid in the blind-ending caecum, and in the proximal colon (see the diagram), while the heavier particles, partly by the action of gravity, accumulated further down in the distal colon, whence they passed into the rectum for excretion in the faeces.

The advantage of this sorting out is obvious, given the koala's energy problems. Most of the fibre remains in the larger particles derived from the cell-walls. As the koala cannot obtain a great deal of its energy from cell-wall breakdown (because eucalypt cell walls are so indigestible), this fibre is not a potential energy source and wastes space; the sooner it can be removed the better, as more space then becomes available for new food to enter the system. The selective excretion of particles therefore represents a way of dealing with a high-fibre diet.

Dr Cork, in collaboration with Dr Ian Hume of the University of New England, has shown that, contrary to what scientists had believed, rates of fermentation in the hindgut of koalas and greater gliders are slow compared with those in the hindgut of grazing or omnivorous animals. The two men think this is due to the high contents of lignin and tannin in *Eucalyptus* foliage, both of which slow down microbial breakdown of cell walls. According to their estimates, only 10% of the energy that koalas feeding on mature foliage absorb from their gut comes from microbial fermentation.

Thus, the koala relies heavily for sustenance on the cell contents rather than the cell walls of its foliage. The fibre in the latter dilutes the desired components of its diet, so its mechanism of relatively rapid fibre excretion undoubtedly helps.

By studying the energy balance and diet of these animals, we gain a better idea of what makes a good habitat for them. Already we know, thanks to the work of Dr Wayne Braithwaite, also of the Division, that the level of leaf potassium serves as an indicator of an area that is good koala country. Why it does remains to be discovered, as do the differences — perhaps in the levels of nitrogen or tannin in the leaves — that make certain forests less suitable than others for koalas.

Knowing more exactly what koalas and our other tree-dwelling marsupials require would allow scientists to advise foresters on the suitability of felling in certain areas, and raise the possibility of manipulating some environments to improve them for koalas, possums, and gliders. Knowledge of koala nutrition is also of use to the many koala 'animal parks' where most people get to see the cuddly creatures. All of this helps in the conservation and management of an animal that has become a world-wide symbol of Australia, as well as being a strong draw-card for tourists.

Roger Beckmann

More about the topic

Foliage of *Eucalyptus punctata* and the maintenance nitrogen requirements of koalas, *Phascolarctos cinereus*. S.J. Cork. *Australian Journal of Zoology*, 1986, **34**, 17–23.

Digestion and metabolism of a natural foliar diet (*Eucalyptus punctata*) by an arboreal marsupial, the koala (*Phascolarctos cinereus*). S.J. Cork, I.D. Hume, and T.J. Dawson. *Journal of Comparative Physiology*, 1983, **153**, 181–90.