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# The Ghost of Herbivory Past

BY KEVIN BURNS

**Predation by the now-extinct moa could explain why New Zealand's lancewoods undergo one of the most remarkable transformations in the plant kingdom.**

It was an easy mistake to make. After all, he'd never seen anything like it before. In fact, there isn't anything like it anywhere else on Earth.

As the botanist on James Cook's famous voyage on the *Endeavour*, Sir Joseph Banks had the job of cataloguing all the new plants they encountered. But in New Zealand he was faced with a plant like no other.

Lancewood (*Pseudopanax crassifolius*) goes through what is arguably the most remarkable metamorphosis in the plant kingdom, so it's understandable that Banks mistakenly named the juvenile and adult forms of lancewood as two separate species.

Banks was one of the most influential botanists the world has ever seen. He was even knighted by the Queen for his efforts, so his mistake in naming lancewood twice is testimony to this plant's almost unbelievable metamorphosis.

After germination, lancewood seedlings are immediately unusual. Instead of being green like most other plants, the leaves of lancewood seedlings are mottled brown.

No two seedlings are alike. Each has its own pattern of brown speckles and swirls, which are generated by pigments called anthocyanins that reflect light rather than

absorbing it for photosynthesis. Looking more like miniature soldiers in fatigues than plants, lancewood seedlings are extremely difficult to locate on the forest floor, where they are surrounded by a sea of similar-looking dead, brown leaves.

However, once lancewoods grow above the leaf litter they transform into an entirely new form. So different from the seedling is this juvenile form that Banks didn't recognize them as lancewoods – and who could blame him?

The juvenile plants refrain from branching and grow straight up from the forest floor on stiff, slender, furrowed stems. They also produce very odd leaves that are unlike nearly all others on Earth – dark green and strikingly long for their width. Some grow to be nearly a metre long.

Most also have distinctive thorny spines along their margins, giving the overall appearance of saw blades. The spines are much lighter in appearance than the rest of the leaf, making them easy to spot from a distance.

Once lancewoods reach reproductive maturity, they undergo a second and final metamorphosis. This time, however, it's as though they suddenly want to fit in with

the rest of the trees in the forest, and their appearance becomes altogether unremarkable.

At about 3 metres in height, lancewoods abruptly begin to branch and their leaves change in size, shape and colour. These adult leaves are soft, rounded and oblong in shape. They lack spines and any unusual colours, and their dull green appearance makes adult lancewoods look just like any other tree in the forest.

For years it was thought that lancewood's incredible metamorphoses had a physiological cause. Many environmental factors such as light and temperature change considerably as plants grow through the leaf litter on the forest floor and into the canopy above, so the three stages in lancewood's development could be adaptations to vertical gradients in environmental conditions. However, recent research suggests that different processes may be at work.

New Zealand was a very different place prior to the arrival of humans. Isolated from the rest of the world for millions of years, it was a land dominated by birds. Apart from two species of bat, New Zealand lacked mammals so the empty



A typical lancewood seedling's brown, mottled colour helps it to hide among the leaf litter.

niches that are normally filled by mammals elsewhere in the world were instead filled by birds.

The plants here didn't have to worry about being eaten by deer or other hoofed browsers as they do elsewhere. Instead they had to contend with giant flightless birds called moa, which had voracious appetites for plants and roamed the land in search of greenery to eat.

All plants defend themselves against animal enemies. Plants often fill their leaves with toxic compounds or cover them with tiny hairs to thwart herbivorous insects. Thorny branches are common in continental settings, where they deter mammalian browsers, but these are basically absent from the New Zealand flora. This makes sense given the absence of mammals.

So how might New Zealand's plants have defended themselves against moa? Birds and mammals attack plants in very different ways. Browsing birds lack teeth and therefore can't chew plants before swallowing them. Instead they must pluck leaves from their stems and swallow them whole. Although birds can manoeuvre around the thorns, they can be thwarted in other ways.

All across the globe, most plants change the way they look as they grow up. In New Zealand these developmental changes in morphology are taken to an extreme that is unparalleled on Earth.



A juvenile lancewood has long, blade-like leaves that advertise sharp spines on their margins with brightly coloured patches of leaf tissue.

A large number of plant species from a diverse array of evolutionary backgrounds show this sudden, striking change in morphology. "Heteroblasty" is the term botanists use to describe these changes, and the phenomenon is more common in New Zealand than just about anywhere else.

Although lancewood is a great example of heteroblasty, the types of morphological changes exhibited by this plant are different from most other heteroblastic plants in New Zealand. Instead of producing long, serrated leaves on unbranched stems when they are young, most heteroblastic species in New Zealand do the opposite – they produce very small leaves on strikingly long, wiry branches that are at right angles to one another. This results in a distinctive matted appearance that botanists term "divaricate". Most heteroblastic plant species in New Zealand are divaricate as juveniles and, like lancewood, suddenly transform into a normal-looking tree at maturity.

The existence of moa was unknown to science until about a century after the voyage of the *Endeavour*, and it took biologists another century or so to realise that some of the odd features of the New Zealand flora may represent adaptations to them. Experiments testing whether moa avoid eating heteroblastic plants are no longer possible because they became extinct soon after humans arrived in New Zealand approximately 750 years ago.



An adult lancewood blending in among the other trees in a North Island forest.

However, DNA analyses of their sub-fossil bones have revealed that moa were closely related to ostriches and emus, and recent experiments have shown that emus avoid eating divaricates. This is because it takes a lot of energy to eat leaves attached to wiry branches that unravel when you pull on them. The branches act as a kind of spring that demand a protracted, strong tug if the leaves are to be removed. Once they are removed, the small leaves don't contain enough energy to compensate the bird for its effort. Most heteroblastic species in New Zealand lose their odd appearance once they reach a height of 3 metres, which coincidentally was about as high as the tallest known moa species could reach.

So what about lancewood? Could its strange appearance be linked to moa herbivory?

Detailed spectrometric analyses – estimates of what the leaves would have looked like from a bird's perspective – show that lancewood seedlings would have been nearly invisible to moa in leaf litter. Then imagine what it would have been like for a moa to swallow the juvenile leaves of lancewood, which look more like saw blades than photosynthetic machinery, remembering that they can't chew their food like mammals do.

Spectrometric analyses of the different-coloured patches of tissue surrounding the spines also point to moa. To the human eye, the spines look like they're just a different shade of green. But the different colour isn't due to a change in hue, or the

wavelength of light bouncing off the spines – it's due to a change in brightness, or the amount of light bouncing off the spines. The hue isn't different at all.

Our mammalian eyes don't see brightness very well, so we perceive the change in appearance as a change in hue. Birds, on the other hand, have a specialised structure in their eyes that is specifically designed to help them perceive changes in brightness.

The colour of lancewood spines therefore seems to be a signal that is designed specifically for birds. Many species of animals, such as poison arrow frogs and brightly coloured venomous snakes, also use this strategy to advertise their defences so that would-be predators learn to avoid them.

Analyses at the cellular level indicate that the increased brightness of the spines is due to a sharp reduction in chlorophyll in the tissue surrounding the spines. Chlorophyll is synthesised by plants to absorb light at the initial stage of photosynthesis. Without it, photosynthesis grinds to a halt and plants essentially starve to death.

The reduction of chlorophyll in juvenile leaf spines indicates that lancewood juveniles are prepared to go a little hungry in an effort to show off their defences to bird browsers. Given the energetic cost associated with the colour of spines, you would expect that this colour-based defence would be lost in places that lacked moa, and this is exactly what appears to have

happened in the Chatham Islands, which lie 800 km east of New Zealand.

The Chatham Islands uplifted out of the sea only a few million years ago, and their flora is largely derived from overwater dispersal from New Zealand. Lancewood seedlings arrived by chance in the Chathams at some point in the distant past, where they were free from marauding moas.

Chatham Island lancewoods have changed so much in appearance since their arrival that Banks probably wouldn't have been confused had the *Endeavour* visited there. The seedlings are green, not mottled brown. Juvenile leaves are oblong in shape, uniformly green and lack sharp thorns, while the adult leaves remain unchanged.

In the absence of moa, the Chatham Island lancewood has lost its unusual metamorphoses. Since moa are gone forever, the New Zealand lancewood is presumably now at an earlier stage of the same evolutionary trajectory as the Chatham Island lancewood, and thousands of years from now both lancewoods might very well look similar.

All the signs seem to point to moa as an explanation for the extraordinary metamorphoses of lancewood, and ultimately Banks' famous mistake, but we will never know for sure. It would be great to experiment with moa to test whether their behaviour matches our physiological understanding of how birds see the world, and to find out if they really did have trouble locating seedlings and swallowing those thorny, brightly coloured juvenile leaves.

So, are the present-day lancewoods in New Zealand still fighting an ancient foe that no longer exists? We are left with no other option than to make an educated guess that they are, based on indirect evidence.

If we have got it wrong though, at least we can be comforted that we're in good company.

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