Bako's carnivorous plants

R. L. Bieleski[1]

Fig. 1 Typical Malaysian water transport, a large canoe with an outboard motor. The group leader, Prof. Carrick Chambers, an AHRIH, is the one with his hand up to a floppy white hat.

In late 1990 I was fortunate to join a group of botanists led by Professor Carrick Chambers on a visit to Malaysia's National Parks, immersing ourselves in their plant life. For me a highlight was the short visit to Bako, on the northwestern coast of Borneo. The annual rainfall at the park office is around 4300 mm (similar to our New Zealand Westland's, and three times Auckland's rainfall) with a seasonal peak during the monsoon season from November to February. Extended rainless periods in the dry season from May to September contribute to the harshness of the plateau environment. Temperatures range between 20°C and 32°C. Despite being Sarawak's oldest National Park, Bako is also its smallest at only 27 km^2, just a whisker bigger than Rangitoto and only 30% larger than Kapiti Island. Bako's small area packs an extremely rich flora distributed over seven distinct ecosystems ranging from tropical dipterocarp rainforest to the heath

Fig. 2 The golden sand beaches of Bako are a major attraction to day visitors from Kuching. With dusk, some are boarding the canoe back to Kuching. The mountain in the mist is Santubong, where Alfred Russel Wallace is believed to have lived while writing the 'Sarawak Law', his contribution towards development of Darwin's theories.

Fig. 3 The trail through the kerangas, showing the impoverished and sandy nature of the soil.

forest or kerangas, reminiscent of Australia's and California's semideserts despite the seasonal heavy rainfall. On the tops where the 'soil' is thinnest, the vegetation is stunted scrub, and this is called the padang. It was the kerangas and padang that we came to see, and they did not disappoint. They sit on the shoulder and top of an uplifted and heavily weathered block of basement sandstone; the soils are very sandy, leached, very low in nutrients and humus, acidic at pH 4, and podsolised. Those conditions have created a rich and unusual flora, despite (or rather, because of) the harsh growing environment, in which highly adapted carnivorous plants flourish.

There was no road in to Bako, so the way to get there from Kuching was by the standard method of water transport in Malaysia, a canoe with an outboard motor (Fig. 1), on a trip that was an adventure in itself. We arrived through the mangroves into a small jetty and noodled around for the rest of the day (Fig. 2). The following day we started off on our kerangas adventure. To make the most of our time, rather than going out and back on the same track, we opted to go by boat up to the end of the trail where it came down to a lovely sandy beach, and then walk back slowly at botanist's pace. We were dropped off at the beach, but as the canoe disappeared around the headland, our guide (Ken Ruebli) said in an anguished voice "hell, we're at the wrong beach". Indeed, inspection soon showed no trail as well as no boat. In a hasty conference as to what to do, we soon established (using our inadequate maps) that the proper beach was the next one up the coast, around the headland. Initial attempts at rock-hopping around the shoreline to where we should be made it clear that this was not going to work, and nobody fancied the option of waiting there until the next morning when they missed us. Aussies and New Zealanders all, the traditional methodology for our intrepid breed poked its head up – bush-crashing. The approach was pretty simple: we knew the track went along the highest part of the kerangas, running parallel to the coast. Logic said that if we headed up the steep slope in front of us, at right angles to the beach, we should cut across it sooner or later. Compass bearings established, we headed up the slope. It was really only when we got well into the scrubby heath that the thoughts came "Are there snakes? Leopards? Apes?". Our guide, with heaps of experience of Malaysian forests, assured us that with the amount of noise we were making, any respectable animal life would have been long gone. And so it transpired, with only a few scratches here and there, mild panic attacks, and a blessed lack of leeches.

Finally we reached the track (Fig. 3), and stepped into a world of carnivorous plants.

[1] 33 William Bond Street, Stanley Point, Auckland 0624, New Zealand; rbieleski@ihug.co.nz

Fig. 4 *Nepenthes albomarginata*, showing how the pitcher forms part of a modified leaf.

Fig. 5 *Nepenthes ampullaria.* **A,** pitchers half buried in leaf litter on the ground surface. **B,** a pitcher suspended up in the air.

Fig. 6 A vine of *Nepenthes gracilis*, with the hanging pitchers revealing their status as the end of a modified leaf.

Fig. 7 *Nepenthes rafflesiana*, with its characteristic tiger markings, again showing the modified leaf form.

'Carnivorous plants' are ones that can catch and digest insects. They will also digest meat if you give them some, but they can't go out and get it, whereas all they have to do with the insects is wait till they come by and trap them – or even put out a scent to attract them. That's why they are also called 'insectivorous plants'. There are different types, which depend on rather different methods for trapping and digesting; but they all have one thing in common – they grow in places that are very short of plant nutrients, particularly nitrogen. The thing is, insects have a lot of protein in their bodies, and can go out and about, scavenging the nitrogen they need from a wide area (including bodies of dead animals). This sort of low nutrient situation is found in swamps, under epiphytic conditions, on podsolised soils, or on sandy soils in the tropics. Bako's kerangas soil is a highly podsolised sand derived from the weathered basement sandstone, and it supports four of the five main groups of carnivorous plants, missing only the Venus flytrap (*Dionaea muscipula*, a snap trap) native to North and South Carolina. In comparison, the whole of New Zealand has only two rather small, unspectacular carnivorous genera that grow mainly on the edges of swamps; the bladderworts (*Utricularia*, bladder trap mechanisms) and sundews (*Drosera*, flypaper traps).

But in Bako the insectivorous plants were not humble and hidden, and the pitcher plants (*Nepenthes* species) in particular were a highly visible part of the flora. *Nepenthes* have pitfall traps where the end of the leaf is modified into a deep tube or pitcher. The mouth of the pitcher is covered with a partly-open lid, to keep out the rain and to help trap the insect. The inside walls of the pitcher are very smooth and slippery (or may have hairs pointing backwards down the pitcher like a Viet Cong bamboo trap). The pitcher secretes a tasty-smelling liquid that attracts the insects, which push past the lid to start drinking the delectable soup. Silly insects! The plant is smarter than they are. The soup contains compounds that make the insect a bit dopy, so it can't get organised to get out. There is also a thixotropic material that gums up the legs and wings of the insect. And then of course those digestive enzymes that are in the soup start pulling the insect flesh apart into the basic nutrients the plant requires. The pitcher thus acts like a stomach: it can be up to 15 cm long and 8 cm wide, and can handle a small mouse (not a common catch, but it has happened). There is a wide range of form in the plants – they can be creepers growing up through the trees, with the pitchers held up in the branches where they catch flying insects like flies and moths; they can be erect woody herbs, up to 2 m tall, or they can even be half-embedded in the ground, where they catch insects that crawl or walk to get places. In Bako the species occurring there cover all of these forms – *Nepenthes albomarginata* (Fig. 4), *N. ampullaria* (Fig. 5A–B), *N. gracilis* (Fig. 6), and *N. rafflesiana* (Fig. 7).

Fig. 8 *Drosera spatulata* var. *bakoensis***,** a sundew growing in a low hollow where permanent water lies.

In the second group of insectivorous plants, the sundews, we saw *Drosera spatulata* var. *bakoensis* (Fig. 8), a highly local subspecies of New Zealand's own *D. spatulata*[2]. It forms a small rosette 1.5–2 cm in diameter. The small red leaves are 3–7 mm long, spatulate in outline (broad at the apex, tapered to the base), and 3-nerved. On each leaf are about 50 glandular hairs that are 1 mm long and glisten in the sun (hence the common name sundew). The glistening is due to little droplets of liquid at the tips of the hairs – pretty, but deadly to small insects. The droplets are sticky enough to trap an insect that walks across them, much as the sticky drops on a spider's web do the same job. Once an insect is caught, all the hairs on the leaf surface bend towards the trapped insect, making sure it can't wiggle free. And then the leaf bends up to partly enclose the insect, and the surface of the leaf starts secreting those digestive juices which gradually dismantle the insect corpse, so that the soluble nutrients formed can be absorbed through the leaf surface and used in further plant growth.

We saw but did not photograph the third group of carnivorous plants, the small bladderworts. *Utricularia caerulea*, *U. hirta*, *U. minutissima* and *U. uliginosa* have all been reported for Bako. The species we saw was probably *Utricularia hirta*, almost submerged in water in the swampy seepages that also supported *Drosera*. They are insignificant plants that have tiny bladders or sacs on their roots, and each sac has a small hole that is partly covered by a lid, or half-closed by hairs that point back into the sac. Minute water insects wiggle into the sacs (or are sucked in when they touch sensitive hairs), and can't escape before they get attacked by the digestive juices that the sac secretes. If you like, you can think of it as being like a very small stomach, about 2 mm across. As the insect body is digested, the walls of the sac absorb the nutrients that have been released.

But for my money, the fourth group that we saw contained the cleverest sort of insectivorous plants.

They are not carnivorous in that they do not set out to kill insects, but rather to help them live. There are several 'ant plants' that as they grow develop special hollow structures in the swollen roots, stems or leaves that make perfect residences for the local ant species. Ant colonies set up in these chambers, and the ants fan out every day foraging around for food. They cart this food back to the chambers to feed the colony of workers, soldiers and developing larvae. All the time they are in the chamber (during the night, and the hottest part of the day) they excrete on the floor, creating a lovely fertiliser soup for the plant to feed on. And of course, when the ants die their bodies add to the fertiliser pile, tucked away inside the chambers where no other plant can reach, helping the ant farm to grow. These plants are truly symbiotic with each partner in the combination helping the other to grow and survive. There must be a moral in it: despite the lovely adaptations that have allowed various plants to use the bodies of insects to supply their nutrient needs, the cleverest is the one that does this by cooperation rather than by death and dismemberment. The three ant plants we saw in Bako were totally unrelated, meaning that the technique has evolved several times. *Dischidia major* (Fig. 9; syn. *D. rafflesiana*) is in the Apocynaceae (Asclepiaceae), *Hydnophytum formicarum* (Fig. 10A–B) is in the Rubiaceae, while the third, *Lecanopteris* (syn. *Phymatodes*) *sinuosa* (Fig. 11), is not even a flowering plant but a fern in the Polypodiaceae.

Fig. 9 The swollen structure of *Dischidia major*, Apocynaceae (Asclepiaceae), sliced open to show the chambers supporting the ant colonists. Note the latex droplet characteristic of the plant family.

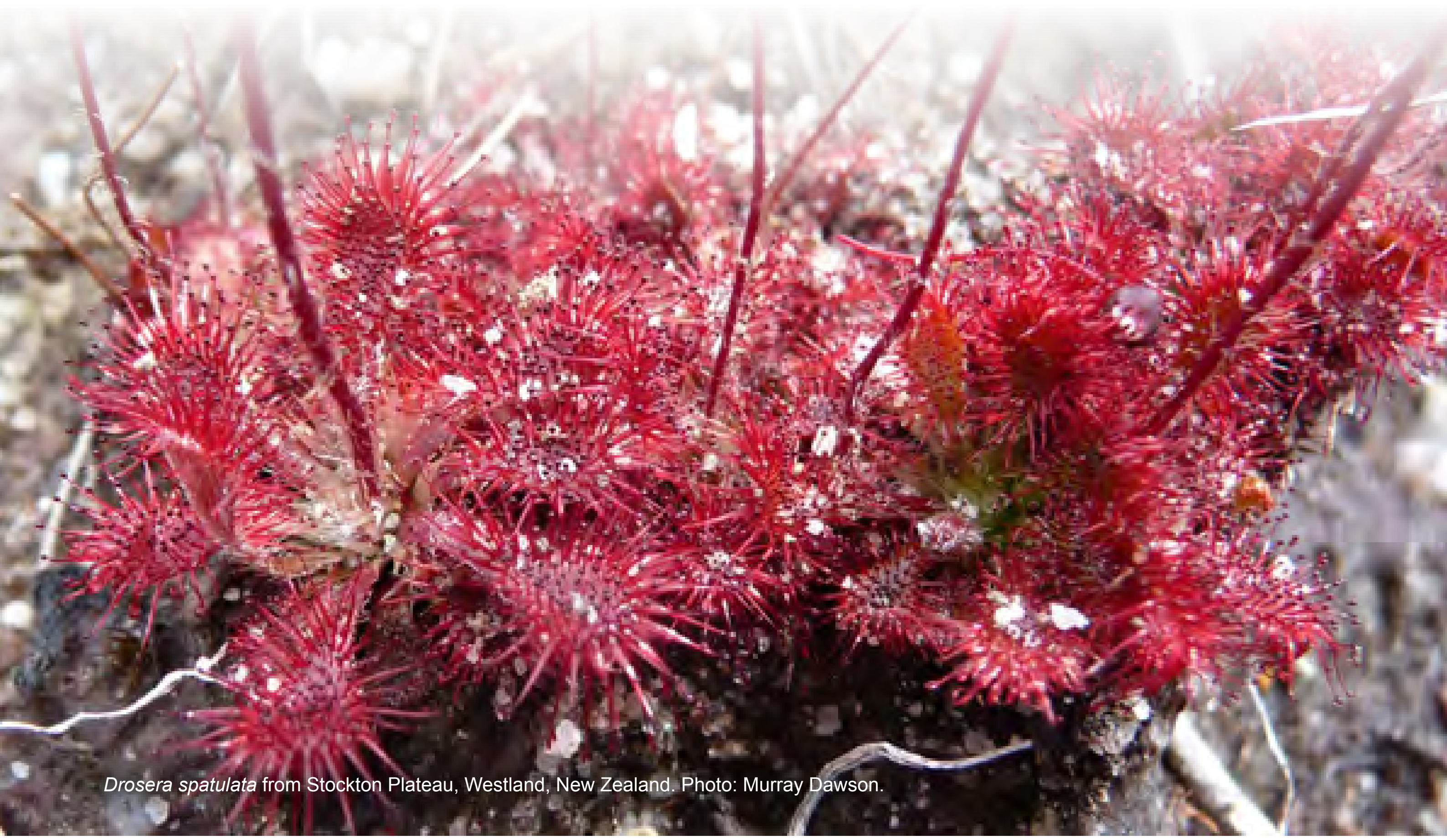
Fig. 10 A, *Hydnophytum formicarum*, an epiphytic ant plant (myrmecophyte) in the Rubiaceae. The genus extends to northern Queensland, Australia. **B,** one of the swollen 'tubers' sliced open to show the chambers which house the ants.

Fig. 11 The swollen stems of *Lecanopteris sinuosa*, a fern in the Polypodiaceae, are hollow and house the ant colonies. Note the pores that provide access.

[2] *Drosera spatulata* (*spathulata*) is a variable sundew with a wide natural distribution (south-east Asia, southern China and Japan, Micronesia, New Guinea, eastern Australia, Tasmania and New Zealand). Variants are often known by the localities where they are found. Curiously, var. *bakoensis* is thought to be closest to New Zealand's "alpine form" described by Salmon in 2001, which may be equivalent to Colenso's *D. triflora*.

There is a sting to the tail of this tale. In keeping with the perceived wisdom about carnivorous plants, I have been writing about the plant's drive to acquire nitrogen in a low-nitrogen environment. But a standard sin of research scientists is that they tend to see the world in terms of their own research specialty, and I studied phosphorus nutrition and deficiency for 20 years. So here's where it relates to us in New Zealand. Most of our soils are very deficient in phosphate in their natural state. The tactic used by most of our native species has been to develop associations with mycorrhizal fungi, and it is now well established that a major advantage for the plants is greatly improved phosphate nutrition through the action of the fungal hyphae. One of the RNZIH's Associates of Honour, the late Professor Geoff Baylis, was one of the first scientists anywhere in the world to begin studying mycorrhizas, starting with *Griselinia* and *Leptospermum*, and start unravelling their role by revealing their significance to the phosphorus nutrition of the host. In this respect, New Zealand native species can be regarded as the granddaddies of mycorrhizal science! When Baylis started mycorrhizas were seen as a complete curiosity; now they have become serious tools for foresters and recognised as major players in plant ecology.

But mycorrhizas can only go so far, and they are much more effective where there is plenty of phosphate-binding clay in the soil. Hence when I looked out over the podsolised kerangas, what I saw was a place dominated above all by phosphorus deficiency, hit by a double whammy. The high proportion of sand and acidic conditions means the soil has little capability to retain phosphate, while the powerful leaching under the high rainfall and high temperature conditions has led to severe podsolisation, in which a deep hard pan tightly locks up phosphate as highly insoluble ferric phosphates. The main forms of soil nitrogen are ammonium and nitrate salts which are freely soluble, but most phosphate salts are at best sparingly soluble (e.g., calcium phosphate). Thus plants have evolved highly effective pumps that uptake phosphate, typically at 3×10^{-6} molar in the soil, and lift it 5000 times higher to 1.5×10^{-2} molar in the plant cells. But the pumps do have their limitations, and once the concentration in the soil drops below 3×10^{-7} molar, most plants become seriously phosphorus deficient. Those numbers may not mean much, so picture it this way: a tablespoon of potassium phosphate stirred into an Olympic-sized swimming pool gives you that critical concentration of 3×10^{-7} molar phosphate. And here's where the iron pan comes in. Iron phosphates, depending on pH and composition, even when fully dissolved produce only 10^{-14} molar phosphate, equivalent to 2 micrograms of potassium phosphate in that Olympic pool, giving you an idea of how effectively a podsol locks up phosphate. Once I saw the kerangas and had my insight, if I'd still been active in plant nutrition research and free to follow my nose I would have set out to look closely at the role of phosphorus nutrition in plant carnivory. We know the pitcher plant soup contains phosphatases and RNAases as well as proteases, so the enzymes for utilising phosphorus are there; and from the soil studies of Katagiri, Yamakura and Lee (*Southeast Asian Studies*, Vol. 29, pp. 35–48, 1991) we do know the Bako kerangas soils, besides being depleted and very low in pH, have only about 1% as much available phosphorus as nitrogen. Maybe one day someone else will take up the task, and my betting is that phosphorus will be found to be the key to plant carnivory, with nitrogen nutrition just a secondary player.



Drosera spatulata from Stockton Plateau, Westland, New Zealand. Photo: Murray Dawson.