NATIVE AQUATIC PLANTS

Kuta: a special sort of spike-rush

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One of the most distinctive and ecologically important members of New Zealand's freshwater flora – tall spike-rush, or kuta – is the deepest-growing of our emergent plants, thanks to its spectacular network of internal gas transport canals – canals that form a fascinating, elaborate ventilating system.

WITH THE ONGOING concern about aquatic "weed" problems in New Zealand's lakes and rivers, it's easy to forget that most aquatic plants play beneficial roles in our freshwater ecosystems. And given the enormous cost and inconvenience suffered as a result of the weedy behaviour of introduced aquatic species, it's not surprising that little attention has been given to the biology of our native aquatics, and the benefits they provide.

Of all New Zealand's native aquatic plants, one of the most easily identified, widespread and fascinating species is kuta, or tall spike-rush. It is emergent – that is, part of the plant protrudes above the water surface – and is found at the margins of many lakes as well as in shallow wetlands. It is rather more common in the North Island than in the South Island. Among the most attractive of our emergent plants, it is easily identified by its vivid bright green, cylindrical shoots that protrude a metre or more out of the water. The shoots are hollow with transverse septa ("cross walls") at regular intervals and are much softer and more easily crushed than those of the few other large emergent plants with which kuta could be confused.

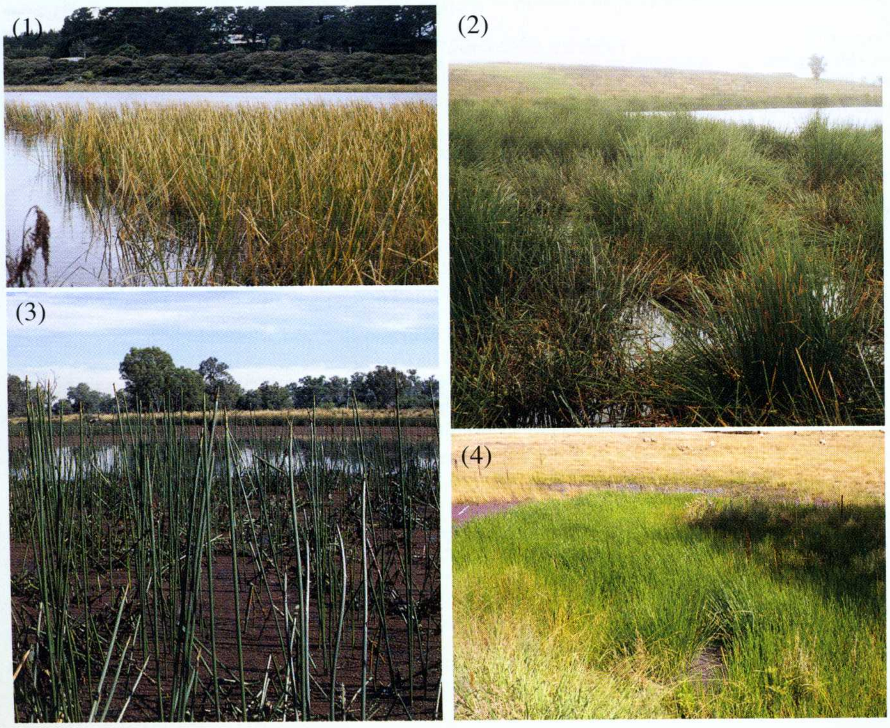
Spike-rush structure and strategy

Spike-rushes get their name from their flowers, which are borne in a single, spike-shaped inflorescence at the tip of each shoot. These produce small, nut-like seeds that germinate on damp ground. The seedlings then spread vegetatively by creeping rhizomes.

Spike-rushes are sedges (family Cyperaceae) belonging to the genus *Eleocharis*, which has about 200 species worldwide. Most *Eleocharis* species are small, wiry plants that grow in boggy soil or shallow water, but there are a few taller, more robust species. Our kuta (*E. sphacelata*) – which is also found in Australia and New Guinea – is the largest of all. Indeed, it seems that everything about it is outsized in comparison with its relatives. The visible protruding shoots, which can be as thick as a human finger, are exceptional enough. However, the bulk of the biomass is in the underground rhizome, which can be up to 3 cm in diameter, considerably stouter than most other spike-rush species. As these rhizomes can form a very dense, overlapping mat, excluding other plants, kuta commonly occurs in large, monospecific clumps or bands. Even the seed is unusually large, being up to 2.5 mm long. As in many other sedges and rushes, the cylindrical shoots are the photosynthetic organs. The leaves have been lost during evolution except for a few protective sheaths at the tip of the rhizome and base of the shoots.

The exceptional size and structure of kuta are mirrored by its distribution, which is also extreme. Whereas most spike-rushes, and indeed most emergent plants, cannot tolerate water more than half a metre deep, kuta thrives in water a metre deep or more, thus qualifying as a true aquatic plant. Far more tolerant of deep water than any of our other emergent plants, it can grow in depths of up to 3 m in clear waters such as the dune lakes of Northland. Not surprisingly, this unusual plant has a range of special adaptations to allow it to grow in such places.

Although kuta will grow almost anywhere there is standing water, its soft green shoots usually collapse and dry up if the water table falls below the soil surface. The underground rhizome allows the plant to survive droughts by lying quiescent during dry periods and then producing new shoots once the soil is re-flooded. This ability to wait out droughts serves kuta especially well when growing in the arid zones of Australia, where the ephemeral pools it inhabits can disappear for months at a time during hot summers. When this happens, the soil is quickly colonised by dryland species once the water disappears and there is often no visible sign of the



Kuta growing in a range of sites in New Zealand and Australia. (1) Marginal lake-edge wetland at Lake Ngatu, near Kaitaia, Northland. (2) Lush growth in a wetland constructed for wastewater treatment, near Tauranga. (3) An extensive bed in a shallow floodplain lake near the River Murray, SE Australia. (4) Fresh new growth of shoots in a roadside drain in autumn after a summer drought, Narrandera, southern NSW, Australia.

spike-rush during a long hot summer. However, the dryland species are quickly killed once the pools are re-flooded by autumn rains, and within days the flooding allows the kuta rhizomes to produce a fresh new crop of shoots to reclaim the pool.

Kuta rarely experiences such long dry periods in New Zealand, but the ability to produce new shoots rapidly is still important. Being so soft and spongy, the shoots are easily damaged by storms and waterfowl and decompose more quickly than the woodier shoots of many other emergent plants. All of this contributes to a relatively high turnover of shoots. Damaged shoots can be quickly replaced thanks to two important features of the rhizome. First, the rhizome tissues are rich in starch, which can be quickly metabolised to speed new shoot growth. Second, the shoots grow from the base, where they are attached to the rhizome, rather than from the tip like most plant shoots. The basal growth points, buried safely in the sediment, are protected from any damage experienced by the aerial shoot tissue.

High starch concentrations in rhizomes and basal growth are common features of emergent aquatic plants. Where kuta again excels is the extent to which it has developed these adaptations. Its rhizome has a particularly large core of pith, the main starch-storing tissue, and its cells are heavily packed with starch grains at all times. Also, packed within its basal growth points are large numbers of compressed shoot sections, which can expand extremely quickly, either to produce a new shoot or to extend a damaged one. Some kuta shoots, if cut underwater, can extend more than 5 cm in length in less than 12 hours, as the compressed sections rapidly stretch and extend in length.

These kinds of adaptations are essential for plants that grow in deep water, as they need to keep some shoots protruding out of the water for photosynthesis and to transport oxygen from the atmosphere down to the rhizomes. However, it is its particularly efficient ability to transport oxygen that really separates kuta from other emergent plants in New Zealand, and allows it to be our deepest-growing emergent plant.

Pressurised gas flow and air-conditioning

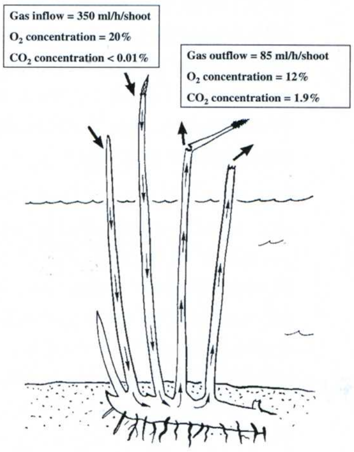
The aquatic environment is an inhospitable place for flowering plants like kuta to grow. These plants have all evolved from terrestrial ancestors, and their large, bulky tissues experience considerable difficulty getting enough carbon dioxide for photosynthesis and oxygen for respiration from water.

In water, gases diffuse 10,000 times more slowly than in air. Oxygen in particular has a very low solubility, so that a given volume of water contains less than one-thirtieth of the oxygen in the same volume of air, when the water and air are physically in equilibrium. So there is simply not enough oxygen available in the water to satisfy the respiratory oxygen demand of the underwater part of the kuta plant. This is especially so for the rhizomes and roots because intense bacterial respiration in lake sediments strips oxygen from water within the sediment. The result is an anaerobic habitat lacking oxygen and rich in products of bacterial fermentation that are toxic to plants, such as volatile fatty acids and reduced iron and manganese.

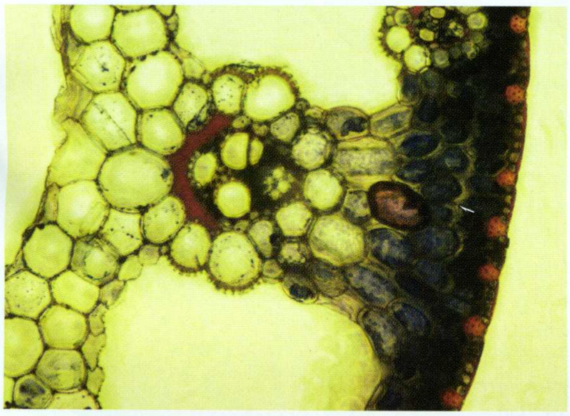
Aquatic plants have solved this problem by taking their own atmosphere with them when colonising water, in the form of a highly developed internal system of gas-filled canals that run continuously from their shoots, down through rhizomes, and into their roots (see photomicrograph, left). This gas transport system, which is present in almost all aquatic plants, ensures that oxygen can be passed from the atmosphere to even the furthest tips of the roots, allowing them to grow in the anaerobic sediment. However, some species can transport oxygen through these canals more quickly and efficiently than others, giving them a competitive advantage where oxygen is limiting for growth.

Most emergent plants transport oxygen along this pathway by diffusion alone. This is adequate for plants that only live in shallow water, a few centimetres deep, where the transport distance from the atmosphere to the roots is short. But diffusion is simply too slow, even in the gas phase, for a plant like kuta with rhizomes and roots that can be separated by metres of water from the oxygen source in the atmosphere. Were kuta to rely on diffusion alone for its gas transport, it would be restricted to water less than 50 cm depth – any deeper, and it could not keep its bulky rhizomes alive.

Kuta, and other emergent plants that grow in deep water, have overcome this problem by finding a faster way than diffusion to move oxygen through their air canals. The gas spaces in their shoots generate small pressures that blow a mass flow of air down to the rhizomes. They can do this by taking advantage of a little-known quirk of gas physics. Because the gas inside the shoots is more humid than the surrounding air, atmospheric gases



Pressurised gas flow in kuta: Humidity gradients between the atmosphere and the internal gas of the intact shoots produce a pressurised gas flow through the entire plant. Air enters the intact shoots, is blown down through the rhizome and is returned to the atmosphere through older, broken shoots. The lower flow rate in the outflow shoots occurs because there are more of them. The composition of the exhaust gas differs from the inflow gas because the underwater parts of the plant consume oxygen and produce carbon dioxide during respiration. Data from 2.5-m depth at Lake Ngatu, Northland.



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Photomicrograph of a cross-section of a shoot, showing large air spaces that are the pathway for pressurised gas flow. The colours are artificial, produced with diagnostic stains.

(primarily oxygen and nitrogen) are more dilute inside than outside. This drives a continuous flux of these gases into the shoots, large enough to slightly increase the internal pressure. The pressure elevation is very small – about one thousandth of an atmosphere – but its consequences for oxygen transport are profound.

Pressurised gas flow works because all shoots are not equally good at generating pressure. Higher pressures develop in the younger, healthy shoots, than in the older, dying shoots, especially those that are cracked or damaged. This means that gases flowing down the younger shoots and into the rhizomes can be exhausted back to the atmosphere through the older shoots (see diagram). So a bed of kuta shoots consists of a mixture of inlet and outlet pipes, with gas flowing down some shoots and back up others. The importance of this pressurised air-conditioning system for kuta is evident from the change in composition of the gas as it flows through the pathway. The in-flowing gas has about the same amount of oxygen as the atmosphere (*ca.* 20%), but respiration by the underwater plant tissues substantially lowers the oxygen concentration and increases the carbon dioxide concentration in the exhaust gas.

The deeper the water, the harder it is for the gas flow to maintain high internal oxygen concentrations in the plant. This can be seen in Lake Ngatu, near Kaitaia, where kuta grows in depths of up to 3 m (see graph). In deep water (> 2 m) the stems are thicker, which increases the amount of oxygen flowing into the plant (black line), and much more of this oxygen is consumed than in shallow water (as shown by the difference [shaded area] between the black and blue lines). Even so, kuta cannot keep its internal oxygen concentration (red line) as high in the deep water as it can in shallow water.

Several other emergent plants also have this pressurised gas flow, including raupo (*Typha orientalis*) and club rush (*Schoenoplectus validus*). That they are unable to grow as deeply as kuta is because their pressurised gas flow is considerably less efficient. Following good engineering principles, the rate of gas flow that the pressures can generate depends on the resistance to flow through the pathway, as determined by the diameter and openness of the canals. This is where kuta outdoes most other emergent plants – its gas transport canals are wider and have fewer internal obstructions.

Although no native aquatic plants can match kuta in gas flow efficiency, a few overseas species are even better at it. The common reed (*Phragmites australis*) has the fastest, most efficient pressurised flow of any emergent plant studied so far. Interestingly, rather than just colonising deep water, reed seems also to use its pressurised flow for growing deeply into the sediment. Its hollow, tubular rhizomes have been found more than a metre underground in some sediments.

Pressurised gas flow reaches its zenith not in emergent plants like kuta, but in floating-leaved plants like water lilies. Whereas in kuta the rate of gas flow in an inflow shoot is usually less than 10 ml per minute, it is 60 ml per minute in the yellow water lily (*Nuphar lutea*), the plant in which pressurised gas flow was first discovered. Water lilies need these higher flow rates because only a very small proportion of their leaves is capable of pressurising. Not surprisingly, the world record for pressurised gas flow goes to the giant amazon water lily (*Victoria amazonica*), with an inflow rate of 120 ml per minute!

Emergent plants in freshwater ecosystems

New Zealand has no native water lilies and few other plants with floating leaves, which characteristically dominate the 0.5- to 3-m depth range in other countries. Here, that niche is largely the preserve of kuta, the only native species with internal oxygen transport that is efficient enough to allow it to grow in such deep water. This plant therefore occupies a special place in our freshwater ecosystems, as it effectively extends the marginal wetland zone deeper than would otherwise be the case. The significance of this is that emergent plants in marginal zones filter nutrient runoff entering lakes and rivers, enrich habitat diversity, and encourage wildlife. As well as providing nesting sites and material for birds, they also offer refuge for fish and invertebrates. Aquatic insects, for example, use them as oxygen sources, boring holes in the shoots and tapping the gas in the internal air spaces for their own purposes.

In fact, emergent plants like kuta alter the entire structure of food webs in freshwater ecosystems. The submerged parts of their shoots are ideal surfaces for colonisation by algae, and these epiphytic algal films are usually the main food source for herbivorous aquatic invertebrates, many of which only occur in association with emergent plants. Even humans have found uses for them. In pre-European times, the shoots of kuta and similar species were widely used by Maori for floor mats, while the starchy rhizomes were an important food source in some areas.

With over 90% of New Zealand's wetland areas lost to development, and emergent vegetation having been removed from many lakeshore areas to "improve" shorelines for human access, there are now far fewer places our emergent plants can be seen. Fortunately this trend is being reversed with an increasing public appreciation of the fascinating biology of these plants and the benefits emergent vegetation provides in freshwater habitats. ■

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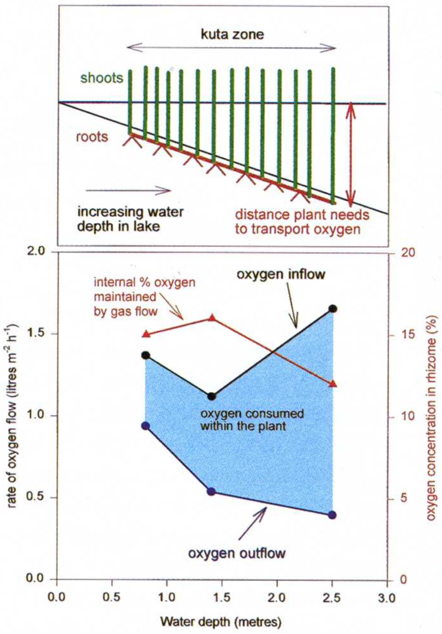

Graph showing how the oxygen inflow, oxygen outflow, and the internal oxygen concentration maintained inside the plant change with depth at Lake Ngatu. Note how the oxygen concentration is lower in deep water, despite the higher inflow rate. The light-blue shaded area represents the amount of oxygen consumed underwater.

Further reading

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