PLANTS "THINK"

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INTRODUCTION

Plants use their climatic history and the soil fertility level in which they are growing, to try to predict their future. This article is intended to encourage botanists and palaeobotanists to be more sensitive towards plants and their fossils, and is based on my personal observations over many years of watching plants living and dying.

The word think is defined in Collins English Dictionary (1979 edition) as meaning (6b) "to be considerate or aware enough (to do something): "*he did not think to thank them*". Thus, in the present work it is used in the sense of responding to a set of stimuli.

Givnish (2002) showed that "a whole-plant perspective is required to demonstrate an energetic advantage of evergreen *vs.* deciduous leaves in many circumstances". He also recognizes a third strategy: leaf exchangers. Roger Dungan (2002) calls the last annual evergreens, and comments that leaf habit (evergreen *vs.* deciduous) is a 'canopy–level' trait, whereas leaf lifespan is a property of individual leaves. Thus, it is possible for two species to have leaves with lifespans < 1year, but for one to be evergreen and the other deciduous. Givnish (op. cit.) relates both evergreen strategies to infertile soils, with temperate rain forests being dominated by "evergreen conifers in North America, *Eucalyptus* in Australia, and *Nothofagus* in southern South America". (It would have been better to cite our evergreen *Nothofagus* in New Zealand, as most South American *Nothofagus* forests are deciduous).

Vogel (1993) describes the shapes of leaves required to withstand wind. This is another example of leaves adapting to their environment i.e. using their DNA "memory" to shape their physiognomy.

EXTINCT PLANTS ALSO THOUGHT ABOUT THEIR ENVIRONMENT

The categorization of fossil forests as either evergreen or deciduous appears to be overly simplistic, since it assumes similar function in all evergreen leaves, irrespective of their longevity. This is unlikely to be correct because leaf lifespan is strongly correlated with physiological, whole-tree and ecosystem processes (Royer et al. 2003).

The shape and size of fossil leaves provide clues about their environments, because shape is determined by climate, and size depends on availability of nutrients, especially N and P (Givnish 2002). Large flat, membranous leaves are easily damaged by wind and rain, are typical of low-wind, closed-canopy conditions, and are most likely to be preserved close to their source. Most such leaves, especially those with long petioles, were probably deciduous. Long petioles increase the ability to change the attitude of the leaf with respect to the sun. Non-petiolate leaves, especially those of monocots (except *Nepenthes*) and conifers, do not have this ability, though some conifers have a ‘pseudopetiole’, that is, the leaf base narrows without becoming flexible. Deciduousness depends on climatic history and soil fertility (Royer et al. 2003). Leaves of large dimensions deposited in mudstone, with no attachment to twigs or branches, were almost certainly deciduous, especially those preserved as a mat of numerous flat-lying overlapping fossil leaves in water, without mud between them.

Fossil leaves from the West Coast Eocene coal measures dated to 45 Ma (million years ago) present several styles of preservation. The most common are carbon films showing the thicker veins and sometimes the cuticular pattern of one side of the leaf. Other fossils are imprints (part and counterpart) in the sediments in which they are embedded.

THINKING BY FOSSIL AGATHIS

Agathis seymouricum and *A. clarencianum* lived near the South Pole at about 80°S in the mid Cretaceous at around 100 Ma (Daniel 1989). They therefore grew in reduced sunlight, with about four months total darkness each year. A comparison of their characters (Table 1) shows the first species coping with this environment through being evergreen, and the second through being deciduous. An advantage of the evergreen habit is that trees do not need to grow new leaves each year, thus reducing the need for nutrients (Royer et al. 2003), whereas deciduous leaves, being renewed each year, can be fashioned to fit the most advantageous tree architecture (Mosbrugger & Roth 1996).

Table 1. Comparison of two fossil *Agathis* species

Character	**A. seymouricum**	**A. clarencianum**
Habit	evergreen	deciduous
Phyllotaxis (leaf arrange.)	spiral	?
Stomata	both surfaces (most on lower)	all on lower surface
Cuticle	thick	thin
Juvenile leaves	8 or more pairs in 2 ranks	4 pairs in 2 ranks
Matrix	sandstone	mudstone
Preservation of leaves	scattered among other leaves	in thick mats*

*The mats *of A. clarencianum* leaves are vertically interspersed with mats of leaves of an unnamed *Ginkgo* species.

Both species had dehiscing twigs, which suggest that the branches of the adult trees were also self-dehiscing. This should lead to young trees having the shape of narrow cylinders, like the 'ricker' stage of modern kauri (*A. australis*), and as depicted by Creber & Chaloner (1984, Fig. 9). From c. 120 years they developed clear, straight trunks surmounted by horizontal branches forming the canopy, as depicted by Jefferson (1982, text-fig 2), so developing the spreading crown characteristic of kauri and other Southern Hemisphere conifers, but unlike the conical crowns of Northern Hemisphere conifers which serve to shed snow. Jefferson's figure shows the spatial distribution and diameters of actual trunks of closed-canopy forest from Alexander Island (70°S, 70°W). Creber & Chaloner (1984 Fig. 10) depict "the shadows cast by one tree......during an Antarctic summer day", but put the 9 a.m shadow to the right of the tree and the 3 p.m. shadow to the left, a common reversal for Northern Hemisphere botanists of that time. Their tree density is grossly exaggerated, compared with Jefferson's figure. Hill and Scriven (1995, Fig. 12) used Jefferson's density, but their tree shape unfortunately wrongly reinforced that of Creber & Chaloner (1984), so both their tree shapes and their direction of shadows were wrong.

According to Stockler et al. (2002) *A. seymouricum* is ancestral to *A. australis*. It grew under a mean annual temperature of 10°C (Parrish et al. 1998) and the "memory" of this climate in its DNA, pre-adapted it to the warm temperate range of kauri in present-day New Zealand. In contrast, the deciduous *A. clarencianum* became extinct as New Zealand moved north.

SOME MODERN EXAMPLES OF PLANTS "THINKING"

In Northland, kowhai (*Sophora microphylla*) flowers in September and fruits are ready to be distributed by water in January. Maori folklore says that if kowhai flowers a month early, in August, there will be floods in December. I bought the property at 2/85 Mandeville Street, Christchurch on 7 July 2000 and removed the automatic sprinkler system that summer. A leafy shrub planted by the previous owners produced white flowers in spring. In spring 2001, it had a reduced number of leaves and flowers. By spring 2002, it had no leaves, but had numerous flowers, each with two sepals, no petals and a reduced "pea-pod shaped" ovary. Presumably they were unfertilised. I had not noticed if anthers were lacking because I mistook the sepals for leaves. It "knew" it was dying, so was trying to reproduce by seed. By spring 2003, the plant was dead, through not receiving enough water.

In another evergreen shrub that the previous owners had planted, the foliage has decreased from year to year. However on 28 October 2003, after considerable spring rainfall, it put forth red juvenile leaves. The colour is presumably from anthocyanin, which protects new cells from high incident light, especially UV radiation. During the hot, dry December of 2003, it retained its red leaves, but began losing the green leaves and by the end of the year had lost all of the latter. During January the red leaves turned dark green and fell off. The plant is now dead (August 2004).

A hybrid *Hebe* cultivar about 1 m radius had an 'old-fashioned' rose growing through it with 'normal' leaves and flowers. When the rose was repeatedly pruned almost to ground level and a woody-weed killer applied to its stumps, it produced thin stems with few leaves, but when these shoots reached the 'surface' of the *Hebe*, they each produced >15 small flower heads.

The Christchurch drought continued through the first half of January 2004, with at least three days of 31°C and clear skies, but during the second half of the month, there was at least a week of overcast skies with north-east winds. Then, new buds with bright, light green leaves formed on all plants of a row of nine *Pittosporum eugenoides*. These were particularly numerous on Trees 2 and 6, which had been cut down to half their height in December 2002. On 28th, 30th and 31st of January 2004, rain fell, often heavily. On 2nd

February there was bright sunshine, especially in the afternoon. The buds opened, exposing the upper epidermis of the leaves, and the internodes of terminal stems on all branches bearing these new leaves extended. This is interpreted as "predicting the future" from the evidence contained in the plants' climatic history. The pattern of stem growth has produced the maximum amount of photosynthetic tissue, which in turn has allowed for maximum production of structural carbon.

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