A COMPENDIUM OF CURRENT WISDOM REGARDING
THE WADDI TREE (*Acacia peuce*)

2018

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Accommodation for Aboriginal people at Boulia in the 1970s was not luxurious!

Believe it or not, this image was taken in 1973

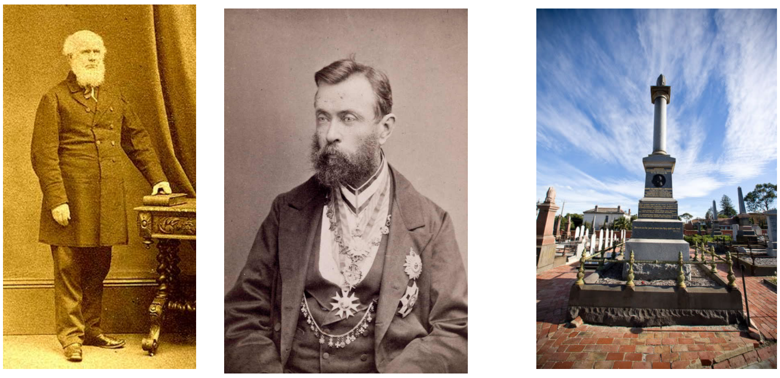
Introduction

I first saw the waddi tree, or *Acacia peuce* as botanists would have it, on a probably ill-advised trip from Adelaide to Townsville via the Birdsville Track and Boulia in the February 1988. Then, the road north from Birdsville was nothing like today's sealed highway and progress was slow, leaving plenty of time to contemplate the landscape. The appearance of tall trees silhouetted against the evening sky over a roasting hot gibber plain left a powerful impression but it was not until much later that the opportunity to get to know them better presented itself, courtesy of support from the Australian Flora Foundation, the Australia-Pacific Science Foundation and the Australian Institute of Nuclear Science and Engineering. This document is a summary of what we think we know about the waddi tree. It draws on early work by people like Crocker, Deveson and Chuk, more recent investigations by Tony Bowland and a series of projects carried out through JCU near Boulia. It is a living document and each version contains new material, most of which has yet to be published in the scientific literature. Consume the contents with caution.

We have chosen to use waddi tree in this tome, as opposed to alternative common names, for no good reason other than that it sounds and looks good. If you want to call *Acacia peuce* the Birdsville Wattle, Waddy Tree, Waddy Wood or just plain Waddy, so be it.

Discovery and botanical description

Acacia peuce is such a striking feature of the bleak landscapes it inhabits, that it is not surprising it was collected and described early. Formal description by Ferdinand von Mueller in 1863 was of material collected from a "Wills Creek", allegedly by Murray and Howitt in the course of their searches for the missing Burke and Wills expedition (Grandison 1980). Unfortunately, there is a scarcity of Wills Creeks in areas actually inhabited by waddi trees and Cleland (1968) advanced the idea that Howitt did not collect the specimens seen by von Mueller as his expedition did not travel north of Cooper Creek and would could not have seen the trees, let alone plucked specimens. Cleland preferred to think that the type specimen was collected by William Wills near Burke and Wills Camp 88 (close to present day Boulia) and made its way to von Mueller as a last gasp contribution to science, in much the same way as Robert Scott died with a sledge full of fossil plants from the Transantarctic Mountains, or Apsley Cherry-Garrard and Edward Wilson struggled to find Emperor Penguin eggs in the name of Science during mid-winter blizzards in Antarctica. Noble stuff that, but not especially sensible. Cleland's thesis seems to be an accurate reflection of events but misses out an important detail – Howitt conducted two journeys in search of Bourke and Wills, and on the second rescued King and found the graves of Bourke and Wills on the banks of the Cooper near what is now Innamincka.



Alfred William Howitt in old age (L) Baron Ferdinand von Mueller (Centre) and von Mueller's grave in the St Kilda cemetery in Melbourne

Though Burke and Wills probably saw *Acacia peuce* in 1861 during their return journey from the Gulf to Cooper Creek, not even they were silly enough to collect and retain specimens. On his second journey into the desert Howitt, this time accompanied by Murray, took time off from disinterring the gently festering Burke and Wills and rescuing King to conduct side trips, one of which took Howitt to the site of present day Birdsville. There he stood upon a rocky eminence and looked towards what is now called Mt Lewis, upon which grew " a new tree, which resembling a she-oak in appearance – but growing higher and looking disproportional at a distance, like trees through a mirage. It bears a flat pod containing several hard black seeds". Various specimens of *Acacia* collected by Murray were sent to von Mueller for his contemplation and a report by that distinguished gentleman to the Victorian Parliament in 1862-1863 contains reference to *Acacia peuce* (Grandison 1980). Thus does the waddi tree enter the annals of science. It is an intriguing thought that the tree which provided the type specimen is probably still alive somewhere on the flanks of Mount Lewis.

In 1939, Cecil Madigan led an expedition of science and exploration across the Simpson Desert. It took 25 days on foot and by camel to traverse the desert from Andado in the west (where stands the Mac Clarke (*Acacia peuce*) Conservation Reserve) to Birdsville (which is also infested with waddi trees) in the east. Along the way Madigan was one of the first proponents of "reality radio", sending regular live reports from the desert for broadcast by the ABC. *Acacia peuce* caught the attention of Robert Crocker, the expedition botanist, and was part of the trigger for his thinking about the origins of the desert and the effects that the desert had on vegetation. Many of the modern writings on the biogeography and ecology of the Australian desert have great, though often unacknowledged, similarity to the ideas promulgated by Crocker.

Bob Crocker in “collecting” mode on the Madigan Expedition to the Simpson Desert in 1939. The unfortunate bird is a bustard, no doubt destined for the pot. On the right, Crocker can be seen botanising among the waddi trees on Andado Station

Quaternary geology has made great strides in putting times and rates on processes identified by Crocker, however it is still possible to see unreconstructed Crockerism in the assumptions underpinning the work of some botanists (who shall remain nameless for the time being).

Two of the (many) adventures of Cecil Madigan – in Antarctica with Mawson in 1911-1912 and crossing the Simpson Desert in 1939

Indigenous knowledge

The waddi trees is such a striking tree that it would be astonishing if it did not feature in Aboriginal links to their country. Sadly not all that much is known of such matters, especially in Queensland. A number of names have been recorded (note that spelling of language groups will differ between authorities):

- “*Aratera*” – Aranda (NT)
- “*Arripar*” – Lower Arrente (NT)
- “*Kurriyapiri*” (Red Ochre Father) – Pitta Pitta (Boulia)
- “*Kungaryi*” – Midhaga (extinct language) (Qld)

An impressive example of a waddi tree can be seen in a compound behind the Boulia State School. This tree is said to mark a corroboree ground of significance to the Pitta Pitta people.

KOOREE-YUPPIREE
(RED OCHRE · FATHER)
THIS WADDI TREE IS HELD SACRED BY THE ABORIGINES OF THE BOULIA DISTRICT. IT MARKED A CORROBOREE GROUND FOR THE PEOPLE OF THE LOCAL PITTA-PITTA TRIBE AND THE ABORIGINES OF THE NEIGHBOURING DISTRICTS.

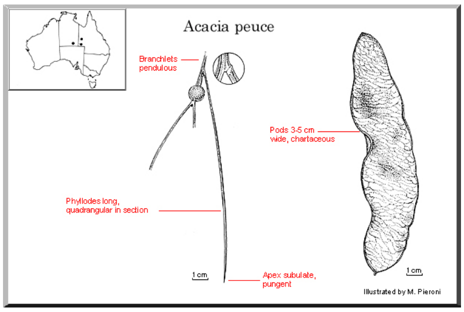
Waddi trees are also associated with a story place in the Mac Clarke Reserve and the presence of stone artefact scatters through the area is testimony to occupation, although the lack of permanent water suggests visits were episodic. In the country around Birdsville, a story explaining the absence of trees from the Simpson Desert focuses on the devastating effects of a fire gone wild in the course of a domestic dispute among ancestral beings. The sensitivity of the waddi tree to fire (see below) and its capacity to grow in a variety of arid settings raises the possibility that this species was one of those that the fire cleared out of the desert in the time since of Aboriginal management of the continent began, some 50,000 or more years ago. The hard, dense, wood was used for manufacture of clubs (hence the common name), though numerous desert trees have timber equally well suited to this ignoble purpose.

Relationships

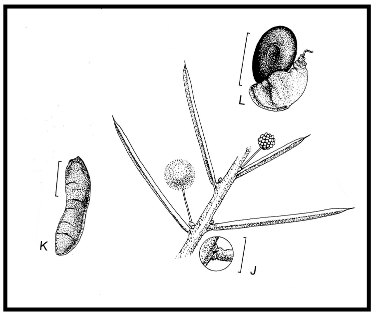
Acacia peuce appears to be one of those species which are sparing on information about where they fit into the genus *Acacia* (or, in the terminology of Pedley, *Racosperma*). In the *Flora of Australia*, it is considered closest to *Acacia crombiei*, differing mainly in the phyllodes (*A. crombiei* has typically narrow linear and flat ones with distinct marginal veins and mid-rib whereas *A. peuce* phyllodes are quadrangular with a yellowish nerve at the apex of each angle, to 40cm long and with a sharply pointed apex – the point is often broken off – *Flora of Australia* v. 11a, p 364).

Pungent pointed apices of mature phyllodes of Acacia peuce.

Phyllodes of *Acacia carneorum* (formerly *A. carnei*) are similar to those of *A. peuce* (though much shorter) but the pods and seeds are very different.



Acacia peuce

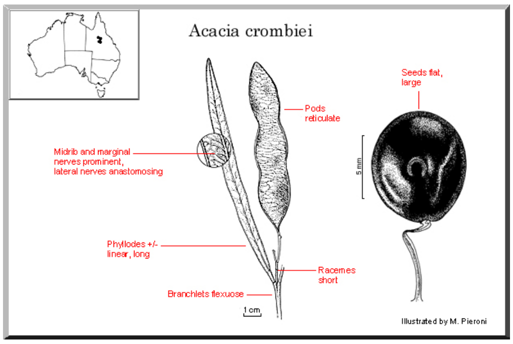


Acacia carneorum

Tindale and Roux (1974) draw a chemical connection between *A. peuce*, *A. crombiei* and *A. carneorum* based on the presence of peltogynoids in heartwood (the only three *Acacia* spp to have them; otherwise these chemicals are more likely to turn up the sub-Family Caesalpinoidea).

Just for the record, the *Flora of Australia* v. 11a provides the following information on *Acacia crombiei* and *A. carneorum*:

- ***Acacia crombiei*** – a tree to ~ 10m with habit reported to be similar to *Acacia cambagei* and ***Acacia cana*** (whatever that might be). It is an uncommon species occurring in patches from the vicinity of Muttaburra to Elmore Station north of Richmond. Phyllodes are flat and non-pungent.

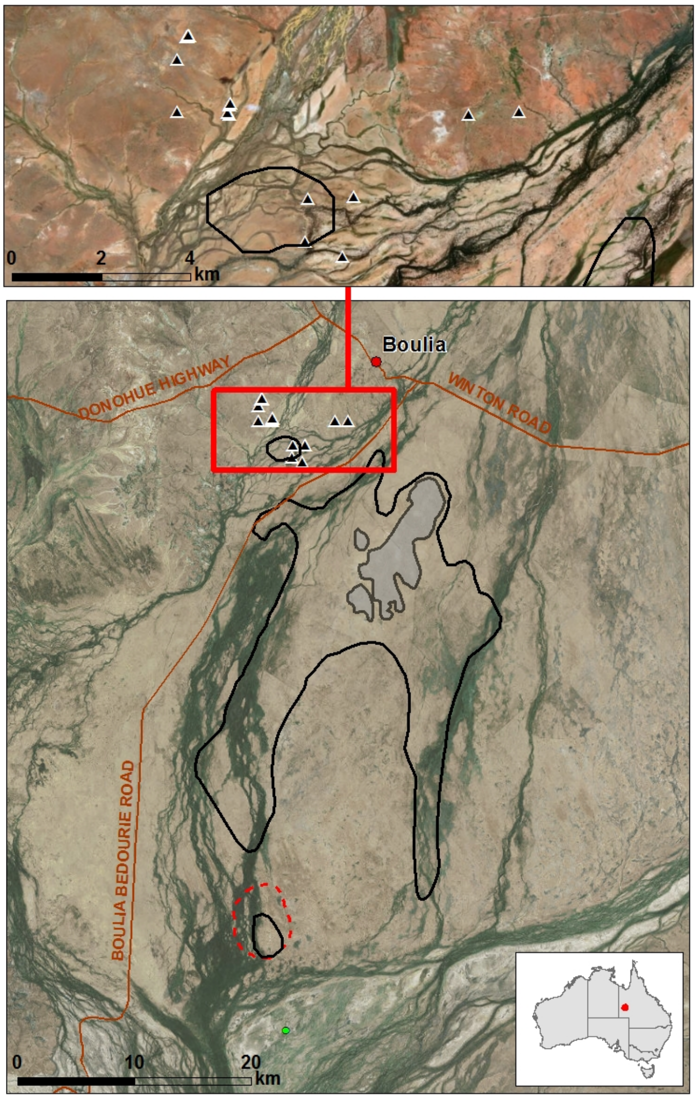


Details of Acacia crombiei

- ***Acacia carneorum*** – a straggling shrub or tree to ~ 5 m. with a habit similar to some *Hakea* species (see *H. leucoptera* in the Tirari Desert). It is not a choosy a plant, growing on sand hill country and sand plains (with mulga – *Acacia aneura*), with *Callitris glaucophylla* (primarily on sand plains) or with chenopodiaceous shrubs on alluvium along water courses. It is found from southwest of Lake Frome (South Australia) and Peterborough to Tibooburra and the Menindee Lakes in NSW.

Distribution

Acacia peuce has a very restricted distribution around the margins of the Simpson Desert. A large stand of trees is found on country occupied by Marion Downs Station, Mudgeacca Station and Montague Downs Stations. The species also straggles on to Goodwood Station and Clearview Station in the Boulia district.



Map of waddi tree distribution near Boulia. Black line delimits distribution mapped by Deveson (1980). The dashed black line surrounded by red dashes shows waddi trees on Marion Downs Station. Black triangles west of the Burke River are trees on Clearview Station. Map prepared by Stephanie Duce

A less populous stand occurs on Roseberth Station, about 10 km north of Birdsville. *A. peuce* is also on Adria Downs Station some 60 km north of Roseberth. This latter group I tend to refer to as the Bedourie Stand - if you search for *Acacia peuce* and Bedourie in a certain famous search engine, you are likely to encounter a photograph taken by Russell Cummings and uploaded to Flicker. It turns out that the location of the trees photographed is actually near Birdsville, not Bedourie (Russell Cummings, pers comm 2014.

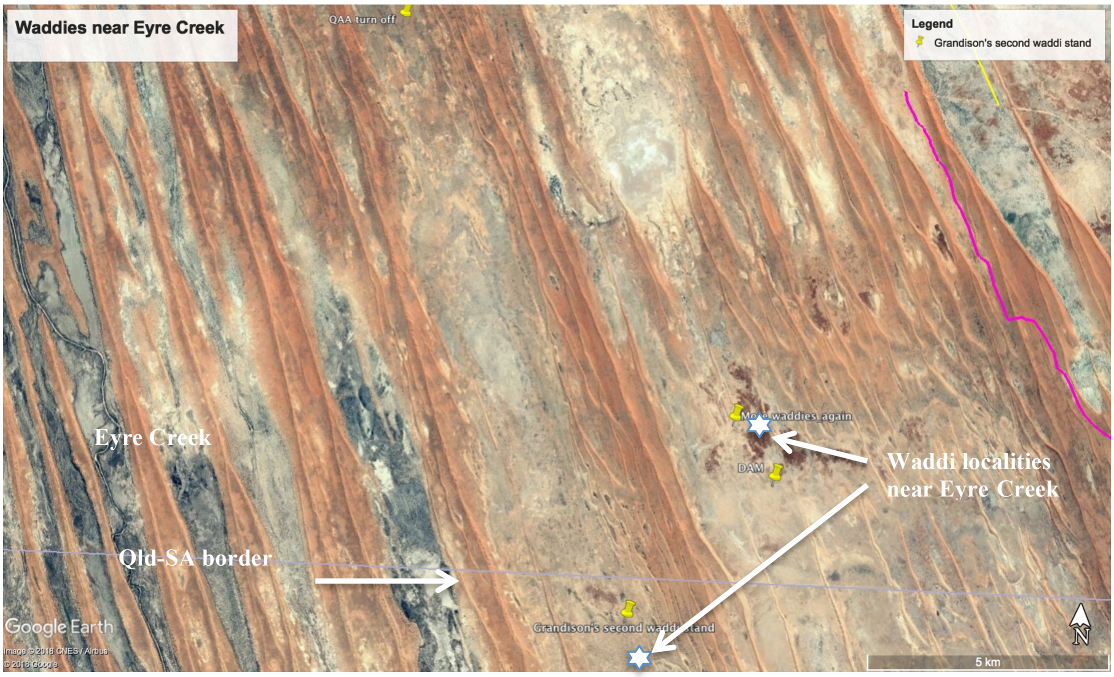
Outlines of the Bedourie stand of Acacia peuce. You can count about 90 trees from this google Earth image –(or you could if you had the original and a magnifying glass!)

I counted 122 trees in the Bedourie stand and, according to Deveson, a count of ~300 was made by Grandison in the late 1970s. There are few dead stems in evidence in the Adria Downs stand and I have no reason to suspect, until a better census is undertaken, that the population has declined markedly there.

The final formally recorded population is found across the Simpson Desert on Old Andado Station, about 230 km southeast of Alice Spring in the Northern Territory. A substantial portion of this latter stand is now included in the Mac Clarke (*Acacia peuce*) Conservation Reserve. As far as is known, *Acacia peuce* does not grow in the Simpson Desert proper. There are persistent local rumours that *Acacia peuce* is also found in South Africa. These are false.

Perusal of the Australian Virtual Herbarium suggests that there are waddi trees at a couple of other places, including Windorah and on the nearby Cuddapan Station, whilst Crocker records a small patch of trees east of the Mulligan River, near Muncooni waterhole. A search of the Cuddapan locality in July 2014 did not locate any waddi trees and it is likely that, if the record is not a geographical infelicity, the trees there were destroyed by fire, as there are indications of recurrent burning on the dunes and sand plain the herbarium record suggests hosted *Acacia peuce*. I have yet to search for the stand at Muncooni however Google Earth images show a stand of trees in dominantly open country in roughly the right location. I will look for these trees at some time in the future.

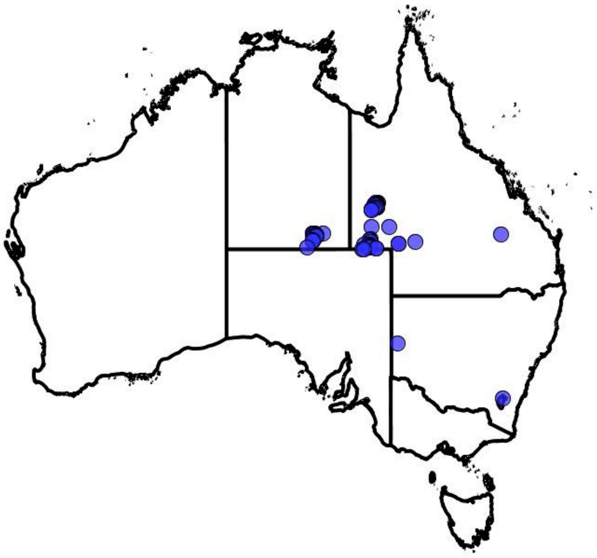
Further entries in the ALA by gentlemen named Henry (no idea what his first name might be) and Ralph Grandison suggest the presence of waddies just west of Eyre Creek near Birdsville. The position cited by Henry is patently inaccurate, placing sampled tree(s) in the middle of the flood plain of Eyre Creek and that is not at all consistent with what we think we know of waddi site prefereces. That recorded by Grandison (and Grandison has a track record of finding waddi trees in odd places) is at the same latitude, but a few kilometres east at 26° 00'S 139°00' E. Google Earth images show trees casting a shadow typical of *A. peuce* and I am reasonably certain that ground checking will confirm that identity. If so, the distribution of *A. peuce* extends into South Australia.



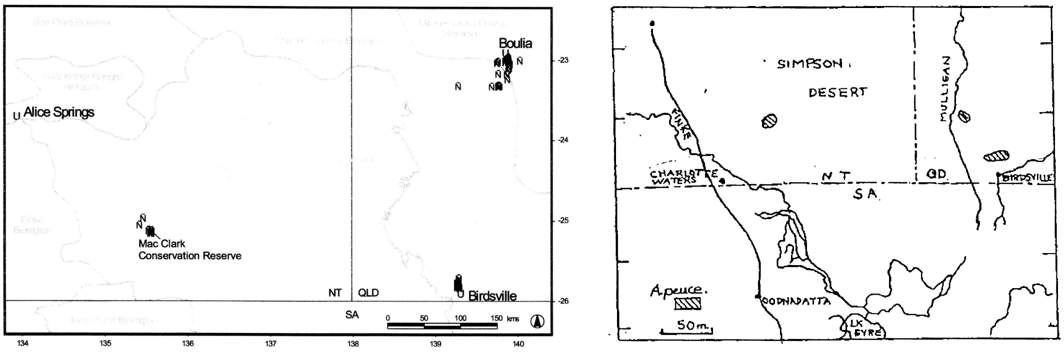
Regional setting of an apparent waddi tree stand near Eyre Creek. Note red linear dunes typical of the eastern Simpson Desert, the broad flood out trace associated with Eyre Creek and the presence of alleged waddi trees in South Australia- but only just!

Detail of the southernmost purported stand of waddies near Eyre Creek. Note the grey substrate derived from alluvium deposited between dunes by Eyre Creek, and the shape of the shadows cast by the "waddi" trees

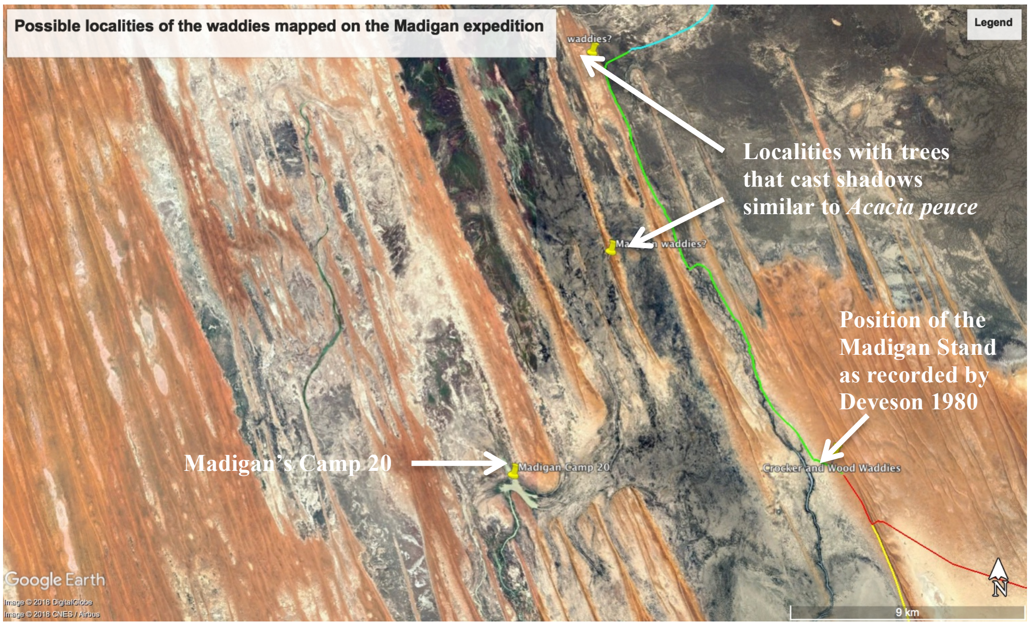
The map below represents the officially recognised distribution of *Acacia peuce* (it needs work as something like 40% of the records for *Acacia peuce* in the ALA are placed incorrectly) :



The distribution of Acacia peuce as recorded in the Atlas of Living Australia.Note that the occurrence in eastern Queensland and the occurrence on the SA NSW border are both products of incorrect latitude / longitude data. The occurrence in the ACT is a plant growing in the National Botanic Gardens



Map showing more detail of the known distribution Acacia peuce (L). The area in between Birdsville and the Mac Clarke Reserve is the Simpson Desert. The other of map from the Madigan expedition shows a patch of Acacia peuce east of Mulcoonie (Muncoonie) Waterhole on the Mulligan River. We do not know if this stand exists and I can find no mention of it in Madigan's book.



Possible localities of waddi trees that might be part of the stand mapped by the Madigan Expedition. Camp 20 is on Muncoonie Waterhole adjacent to the Mulligan River north of Birdsville. I am far from convinced that waddi trees are actually here, but will need to check.

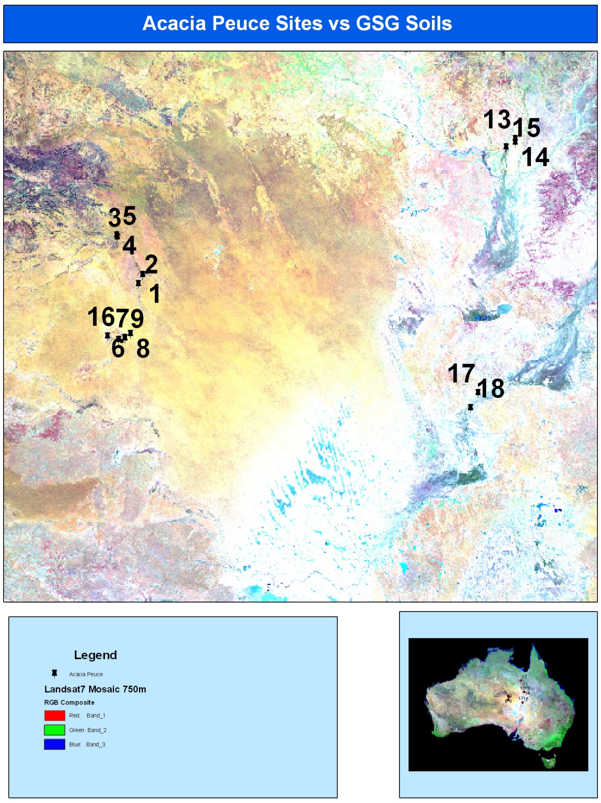
The analysis of factors underlying the distribution of organisms is far from straight forward and is particularly tricky for disjunct organisms such as *Acacia peuce*. Distribution is, at its most basic, determined by some of, or interaction between, factors such as:

- Physiological tolerance to climatic conditions
    - eg. restriction of wet tropical rainforest to coastal ranges in eastern Queensland;
- Capacity to obtain nutrients from substrate
    - eg. occurrence of *Eucalyptus regnans* and *E. delegatensis* on relatively high nutrient soils in southern tall open forest communities
- Competition with other organisms
    - eg. zonation of mangroves along salinity gradients;
- Historical factors
    - eg. persistence of climatic relicts such as *Eucalyptus recurva* in refugial sites near Braidwood;
- Influence of extrinsic factors such as fire or introduced predators
    - eg. survival of dry rainforests on fire protected sites such as the Toomba basalt near Charters towers.
- Serendipity!
    - eg. survival of a few individual *Acacia peuce* near Rieck's Dam following a fire in 1976

Application of bioclimatic or environmental models helps to refine our understanding of the major factors which influence the distribution of a particular plant (or animal). Bioclimatic modelling uses algorithms to identify the most important environmental variables that explain the distribution of species, species groups or ecosystems and to predict their potential distribution in the absence of things like competition and / or predation. They are, therefore, artificial in the extreme and have inherent subjectivity built in to them when variables to be used in an analysis are chosen, but have the virtue of allowing large volmes of data to be analysed in a relatively short time. There are numerous approaches to this endeavour but all programs, such as Bioclim, Climex and MaxEnt, gather vast data sets, interpolate values between data points and then fit surfaces linking the point data. The programs then train their algorithms by analysing data from the known distribution of the taxa in question and can then map the environmental envelope in which the taxon exists, or could potentially exist.

Models can be purely descriptive, identifying key environmental variables influencing distributions, but are now more likely to be used predictively to analyse the likely effect of changing climate on organisms, ecosystems and landscapes. In the example below, a Bioclim model predicts that Acacia pecue could potentially occupy landscapes between Boulia and Birdsville but that the Simpson Desert provides a barrier between the eastern and western limits to the distribution.

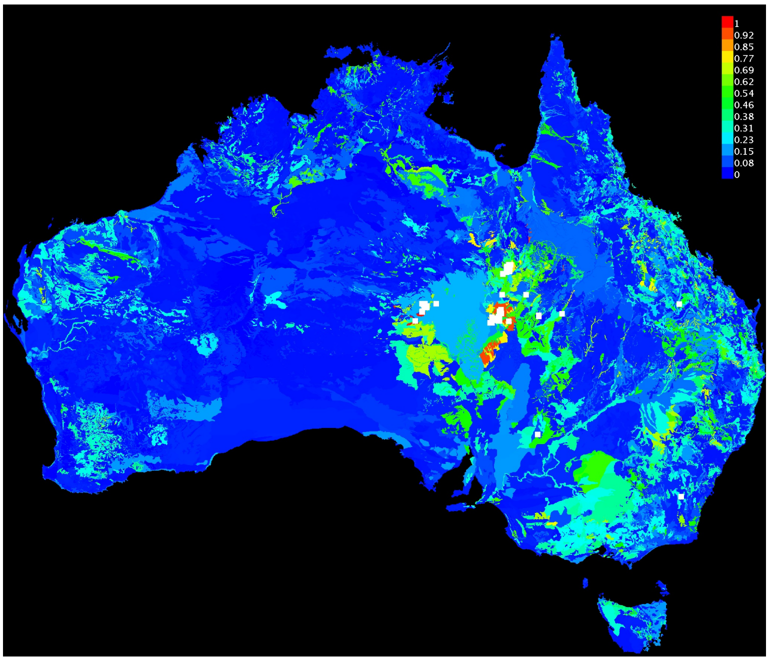
It is, of course, possible to produce quite different predictions using other variables. The map below shows *Acacia peuce* localities overlaid on a false colour Landsat image that emphasises soil type. There are striking differences in the specral character of soils supporting *Acacia peuce* on the eastern and western sides of the Simpson Desert. To the east, soil textures tend to be fine (high silt / clay content) whilst in the west, there is a marked similarity to the signature of sandy soils that dominate in the Simpson Desert. This is a bit over simplified, as *A. peuce* tends to occupy rocky micro-sites which are too small to be adequately portrayed on the image.



Acacia peuce localities overlaid on soil character

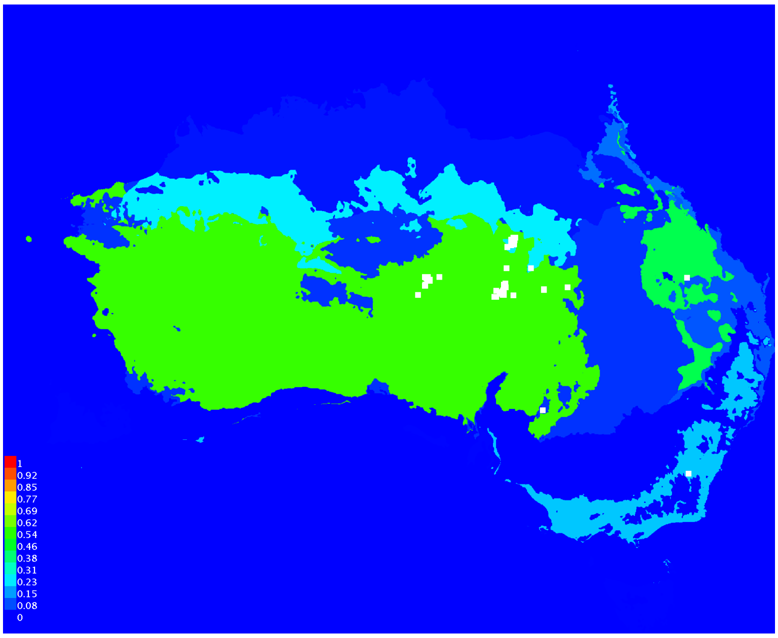
Nonetheless, this image suggests that:

- *A. peuce* occupies distinctly different soil landscapes on either side of the desert;
- The Simpson Desert seems to be a distinct barrier, even though trees in the west occupy substrates that appear to be functionally similar to those of the Simpson Desert, albeit without the dunefields. Note, however, the apparent presence of waddies between Simpson Desert dunes near Eyre Creek.
- Bioclimatic models that incorporate a soils layer will struggle to adequately describe the soil environment given the criteria upon which such layers are based.



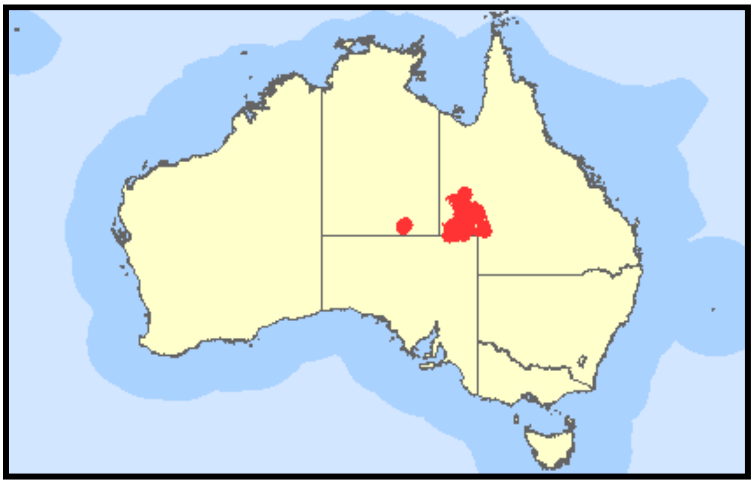
MaxEnt output mapping soil suitability for Acacia peuce. Variables are coarse soils and percent clay. Note the extent of highly suitable soil south of Birdsville and the scarcity of suitable soil at both Boulia and the Mac Clarke Reserve west of the Simpson Desert

From a purely climatic point of view, a MaxEnt model trained on the current distribution of *Acacia peuce* and portraying climate according to the Köppen classification, suggests that *A. peuce* could grow without drama over much of inland Australia, including throughout the Simpson Desert.



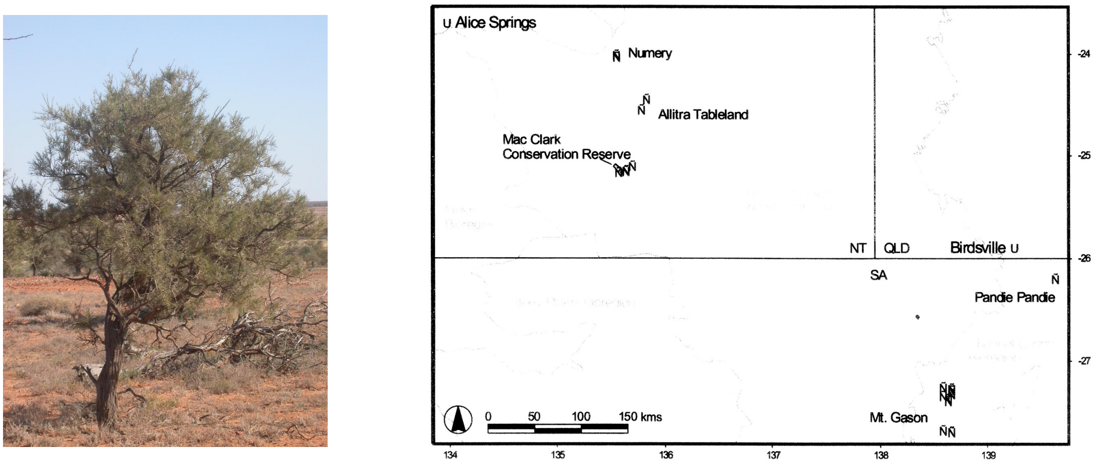
MaxEnt plot showing Köppen climate suitability for Acacia peuce at continental scale. The apparently suitable conditions in eastern Queensland reflect the influence of a geographically spurious record

An early Bioclim prediction of the potential distribution (figure below) also suggests a wider potential distribution than in real life however the Simpson Desert remains a significant barrier between eastern and western populations of the tree.



This map (taken from the Department of Environment and Heritage website) depicts an idealised distribution of Acacia peuce based on bioclimatic predictions generated by ANUClim 5.0. Note the apparently continuous extent of suitable habitat linking what are actually disjunct stands at Boulia and Birdsville.

Interestingly, several other *Acacia* species have distributions similarly disrupted by the Simpson Desert – see *Acacia pickardii* for example, which grows near Birdsville (and southwards down the Birdsville Track) but also on the heights of Hubbard Hill, overlooking the Mac Clarke Reserve.

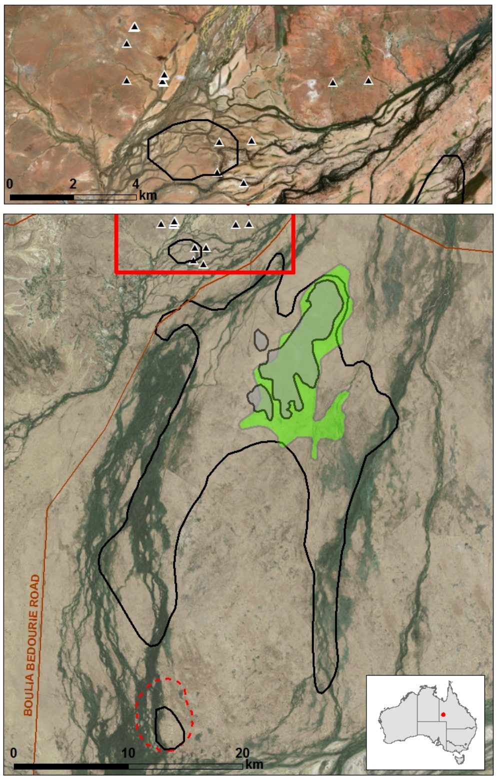


Distribution of Acacia pickardii. The stand at Pandie Pandie was only discovered in the last few years. Occurrences on the Allitra Tableland and on Numery Station are in very small number

Status

Acacia peuce appears to be a common tree in the small areas of habitat that it occupies. Something over 1000 individuals grow in the Mac Clark Reserve and substantially more grow near Boulia. Deveson (1980) estimated there may be ore than 100,000 individuals in the Boulia district and that 25,000-30,000 are found in the main stand on Mudgeacca Station, Montague Downs Station and Marion Downs Station. A remotely sensed estimate made by Arnaud Grancher in 2010 is consistent with Deveson's census. Grancher digitised trees from about two thirds of the main stand and was able to count 4890 adult trees and 46187 juvenile / sub-adults. A further 20,000 trees, more or less, in the stand were not digitised. Grancher noted that the waddi tree now grows on Goodwood Station, indicative of a slight northward extension of range since Deveson's time. This is not a major revelation as the waddi trees on Goodwood can be seen clearly from the Coorabulka Road.

An overlay of mapping carried out by Hugh McInally in 2007 (using a GPS unit on the dash of a light aircraft) and the maps prepared by Ed Deveson in 1980 (using map and compass) suggests that there has been relatively little expansion in the core areas of waddi occurrence near Boulia since the 1980s.



Map overlaying depictions of the core distribution of Acacia peuce in 1980 and 20xx. The green shading shows data generated by McInally, area enclosed by the black line shows distribution according to Deveson. Note that the McInally map shows and expansion of the core range to the south east and slightly to the north. Without a great deal more work it is difficult to determine the significance of the differences as the methodologies of mapping differ radically and there is no common definition of what constitutes the core range that was being mapped.Note that McInally missed the waddi trees on Marion Downs and both McInally and Deveson missed the trees on Clearview. Map prepared by Stephanie Duce

Acacia peuce is listed as Vulnerable unter the Environment Protection and Biodiversity Conservation Act 1992 (def.: (a) it is not critically endangered or endangered; and (b) it is facing a high risk of extinction in the wild in the medium-term future) at a national level, Vulnerable in Queensland, Vulnerable in the IUCN Plant Red Data Book (1978) and Endangered in the Northern Territory (def.: a. it is not critically endangered; and b. it is facing a very high risk of extinction in the wild in the near future) due to:

- Small area of occupancy <500 km^2
- Small extent of occurrence < 5000 km^2
- Reduction in population size over the last 10 years through a decline in area of occupancy and quality of habitat
- Severe fragmentation and decline of sub-populations
- Continuing decline of mature individuals.

Threats include senescence of old trees and failure of regeneration to replace them (reasons for failure are uncertain but Bowland and Heywood (2002) and Nano *et al.* (2012) consider that grazing by cattle is detrimental, mostly as a result of their effects on soil and mechanical damage to young trees). Risks are also posed by fire – more than 100 mature trees were killed by fire in the Mac Clarke Reserve in 1975 after record rainfall in the previous summer encouraged unprecedented grass growth – and lightning strike. Nano *et al* (2006) suggest that exclusion of cattle from the Mac Clarke Reserve may lead to an increased risk of fire in good years as grass that would have been eaten by stock cures into a potential fuel bed. Management of natural resources is always fraught with compromise. Nano *et al.* (2012) give a summary of the demographic attributes of *Acacia peuce* in the NT that place the tree at risk there. We will need to look at how their conclusions translate into conservation challenges in Queensland.

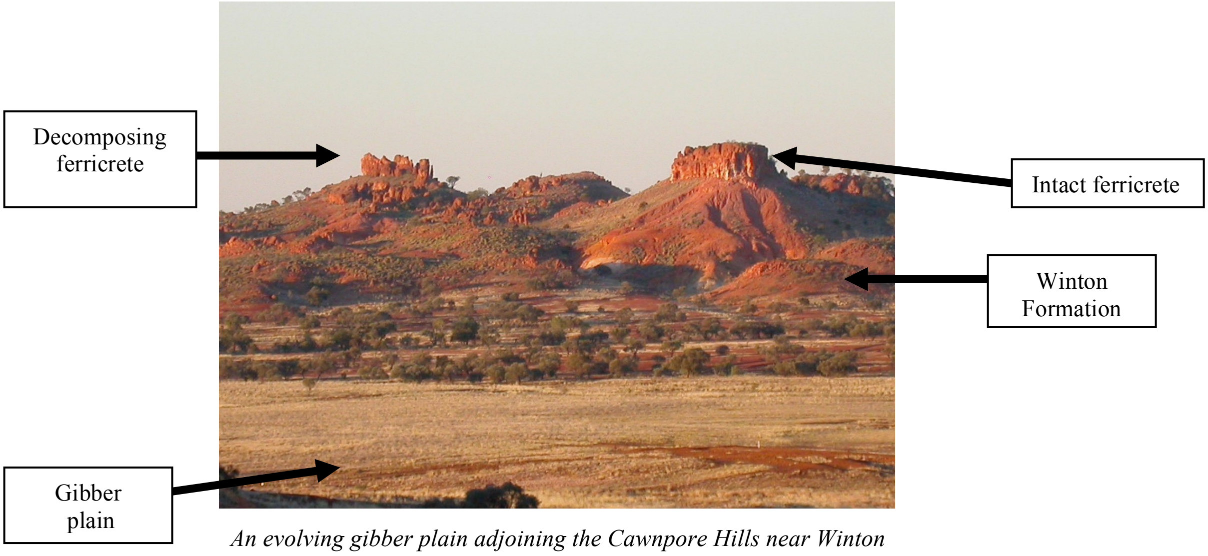
In earlier times *Acacia peuce* was extensively cut for fencing but this use appears to have been abandoned as steel fence posts became more widely available and economical. A resurgence of rabbit numbers consequent on developing immunity to rabbit calicivirus may well pose a significant threat to seedlings that emerge after future rainfall events. The Mac Clarke (*Acacia peuce*) Conservation Reserve is the only protected area in which the species grows. All Queensland occurrences are on pastoral properties.

Habitat preferences

Acacia peuce is normally associated with “stony downs” country, which is a shorthand description of a low relief landscape covered by small rocks known colloquially as gibbers. Gibbers are variously derived but are most often the remains of broken down duricrusts which settle on the land surface, have the interstitial fines winnowed away by wind and water and end up as an armouring mantle of stone overlying the local soil. Gibber landscapes are extremely hard going for plants which typically exploit micro-relief by congregating in almost imperceptible hollows or drainage lines across the plain.

Micro-relief that has been exploited by plants on a gibber plain
Cordillo Downs, South Australia

Gibbers may have little obvious relationship to the soil they mantle, as they are products of breakdown of surfaces which may have been significantly higher than the current gibber plain. As an example, consider the image below:

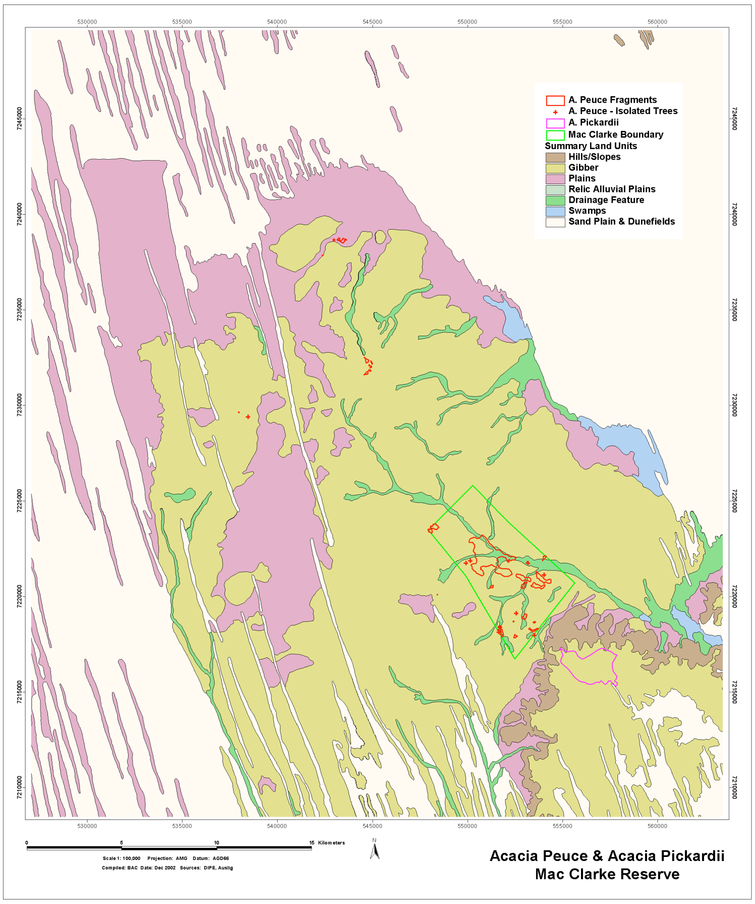


An evolving gibber plain adjoining the Cawnpore Hills near Winton

Here the crennelated cap on the hill on the left hand side of the image picks out an iron enriched duricrust (ferricrete) which is falling to pieces and releasing fragments which move down slope to the plain. An intact version of the ferricrete surface can be seen on the hill top to the right. Rocks below the ferricrete are Cretaceous age sediments of the Winton Formation. They are soft and are rapidly removed as erosion proceeds. This means that the gibbers end up sitting on older units of the Winton Formation in what a geologist might call an unconformity. For our purposes, it is worth noting that gibber surfaces occupied by *Acacia peuce* might have quite different sub-soil characteristics, depending on the local geology.

In the Mac Clarke Reserve, gibbers mantle a landscape formed on Rumbalara Shale, which weathers to highly expansible sodic clays. Profiles contain an abundance of kopi (an aeolian form of gypsum) had exhibit pH values between 7 (at the surface) to about 8.5. Halite (NaCl) is commonly found in the sub-soil – below about 50 cm (Deveson 1980).

Images from the Mac Clarke Conservation Reserve – note gibber surface (dominated by silcrete clasts) overlying an earthy profile containing an abundance of gypsum



Waddi habitat on Old Andado Station.
Note occurrences on gibber, alluvial plains and across drainage features

At Birdsville, the picture is more complex. Trees are found on a range of sites, from Mount Lewis – which is an oxymoron if ever I heard one - to standard old gibber plains and, just occasionally, on low dunes or on sand aprons piled up against the flanks of the "mountain".

View from the top of Mt Lewis
Note scattering of waddi trees on gibber plain

The substrate at Mount Lewis is sandstone capped by remnants of a ferruginised surface. The gibbers appear to be primarily mudstone clasts coated by desert varnish. In other areas, silcrete is the more common clast forming rock.

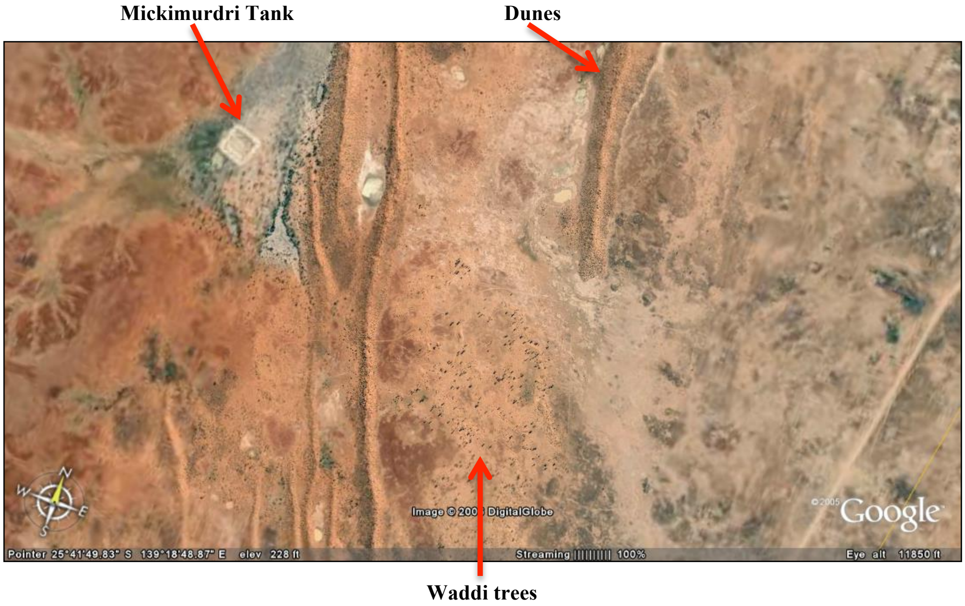
Images taken atop Mt Lewis. On the left is Atalaya hemiglauca growing on the remains of the ferruginised surface with waddi trees growing on gibber plains in the background. On the right are waddi trees growing on sandy mounds piled up on the slopes

Soil profiles are dominated by earthy textured materials overlying sandstone. Kopi is prominent below about 30 cm (see below). The pH in this pit (0cm, 25cm and 50cm) is uniformly between 9.5 and 10.

Soil pit below Mt Lewis near Birdsville. The bedrock here is sandstone overlain by a spectacular kopi unit which is in turn overlain by fine red sand.

Although waddi trees are not generally thought to cope well with sand dunes, near Birdsville this is not always the case. The waddi trees below are growing quite happily on a low dune typical of those found on the fringes of the Simpson Desert and the Tirari Desert (to the south of Birdsville between the Birdsville Track and Lake Eyre). The dune sand overlies gibber plain but it is quite stable and could not have engulfed trees already established on the site.

On the northern margins of the waddi tree stand at Birdsville, the trees are found in sandy inter-dunes, many of which have small, locally derived and highly intermittent stream channels. Further west an extensive area of gibber plains between the Birdsville-Bedourie Road is waddi tree free until another patch, again on sand plain, appears at Mickimurdri Tank 5 or 6 km away. The western boundary of waddi trees at Birdsville is abrupt - cross one sand dune and the trees vanish.



Google Earth image of the area around Mickimurdri Tank northwest of Birdsville

Around Boulia, waddi trees grow on alluvial plains associated with the Georgina and Burke Rivers. The surface materials appear to be sandy however clays are never far from the surface and dominate the root habitat of mature trees.

Typical waddi tree habitat on Montague Downs Station near Boulia.
Note the abundance of juvenile trees and the absence of gibbers.

Soils on the plains are dominantly strongly reddened duplexes with surficial pH around 6 (in shallow sandy A and A2 horizons) rapidly changing to pH 9-9.5 in medium clay of the B horizon. The B horizon is calcareous with carbonate segregations taking the form of earthy blebs a couple of millimetres across buried deep in the pit. Gypsum was found, in a deep hole dug on an alluvial flat. Gypsum was also noted in auger holes dug during 1980 by Deveson.

In some areas there are low dunes (~ 2m high) of medium, poorly sorted (indicating that the sand has not travelled far from its fluvial source) red sand which are most likely source bordering sand dunes. These dunes do not appear to suit waddi trees and their crests are characterised by grasslands with frequent *Grevillea striata* and occasional *Atalaya hemiglauca* or *Corymbia terminalis*. Hummocks of red sand are found overlying the duplex profiles. The sands are fine grained, well sorted materials which retain clear aeolian bedding structures. These are probably derived by aeolian re-working of the source bordering dunes, and unlike the large source bordering dunes, support waddi trees.

Aeolian cross bedding in fine, well sorted red sand.
The sand overlies a stripped duplex profile

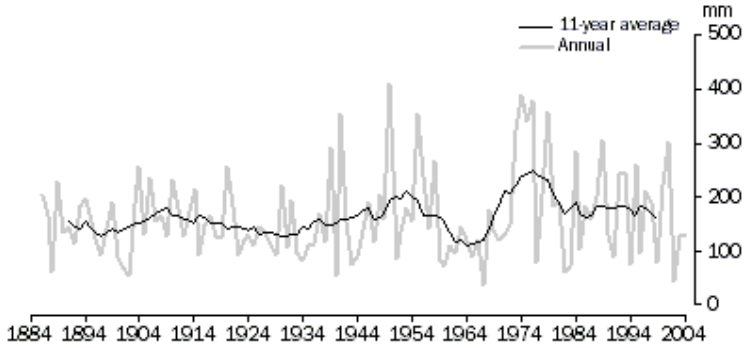
Small gravel particles of fluvial origin are found throughout the soil profiles. Gypsum crystals are also present in some. Where the soil profile has been stripped, as on the track to Mudgeacca Tank, the gravel forms a lag, which has the appearance of a gibber plain but lacks desert varnish and is dominated by water-worn quartz pebbles.

According to the Queensland government, *Acacia peuce* is a defining feature of Regional Ecosystems:

- R.E. 5.7.8; *Acacia peuce* low open woodland between dunes (at Birdsville)
- R. E. 4.3.21; *Acacia peuce* low open woodland on alluvium (at Boulia)

As might be expected from where the waddi tree grows, rainfall is low, variable and unpredictable, summer temperatures high and winter temperatures regularly below freezing. At the Mac Clarke Reserve, rain fall averages (for what that particular statistic is worth in a desert) about 150 mm per annum; mean daily summer maxima are about 39^{o}C in January and 20.5^{o}C in July. For Birdsville the figures are Jan daily max = 38.8^{o}C; July daily min = 7.4^{o}C; mean annual rainfall 167mm and at Boulia, Jan daily max – 38.5^{o}C; July daily min = 22.8^{o}C and mean annual rainfall about 265 mm per annum. Note that the mean figures for rainfall are poor descriptors of conditions as the variance in rainfall receipt is enormous:

S2 ANNUAL AND 11-YEAR AVERAGED ANNUAL RAINFALL , Marree (South Australia)



Source: Australian Bureau of Meteorology.

In this diagram, the rainfall received in Marree on the southern end of the Birdsville track fluctuates over a range of nearly 200 mm, which, given that the mean annual figure is around 155mm, is an impressive illustration of how simple statistics can be misleading. Mean annual evaporation far exceeds mean rainfall in all seasons – the waddi tree lives in a dry part of the country.

If there are lessons to be learned from the above, it must be that the waddi tree is a pretty tough customer. It grows in very dry areas on a variety of soils which exhibit bit a propensity to physiological drought (as a result of the inverse soil texture effect and the presence of evaporitic minerals in soil profiles), are potentially highly erodible, prone to shrinking and swelling with a neutral to highly alkaline pH range, and on sands as well. Such soil settings are widespread in the region and you might exercise your imagination to contemplate why the waddi tree is not ubiquitous, rather than restricted.

Growth habit

Acacia peuce grows as a tall erect tree, in stark contrast to the straggly affairs typically found in arid environments. It can reach 17m in height and while often single stemmed, forked or multi stemmed individuals are not unusual. Close examination of gnarled specimens often shows that they are recovering from mechanical damage, either natural as a result of wind throw or as a result of cutting of fence posts, strainers and so on.

Waddy trees – Left is single stemmed individual with typically pendulous adult foliage. Note the broken riser on the top left of this tree. On the right is a double stemmed tree resulting form removal of the original trunk, probably for fence building.

The ability to recover from mechanical damage is important as winds are strong and persistent in the region and often cause the loss of large branches, even on mature trees. Some trees even seem to be suckers, such are these (dead) examples in the Mac Clarke Reserve, leading to some interesting reflections on the reproductive status of the species and the strategies which need to be adopted when sampling for genetic analyses. Similar stems linked below ground occur near Mudgeacca Bore and on Clearview Station close to Boulia.

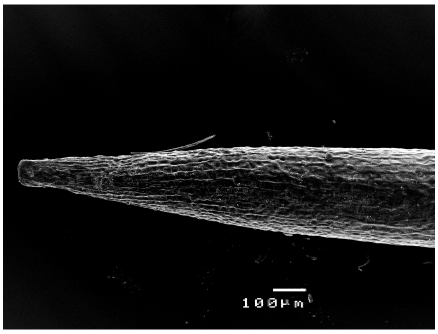
Below ground connection between adjoining waddi stems in the Mac Clarke Reserve. The trees were killed by fire in 1976 and erosion of topsoil has exposed the upper part of their root systems.

Waddy trees appear to have several distinct growth phases. Seedlings have the standard cotyledons, followed by production of a pair of pinnate true leaves, which are then replaced by soft, flat phyllodes which apparently "smell strongly of urine" and "may induce headache" (Johnson 2006). How the phyllodes produce headaches is a mystery to me.

Seedlings of Acacia peuce clearly showing cotyledons, pinnate leaves and soft, strap-like early phyllodes

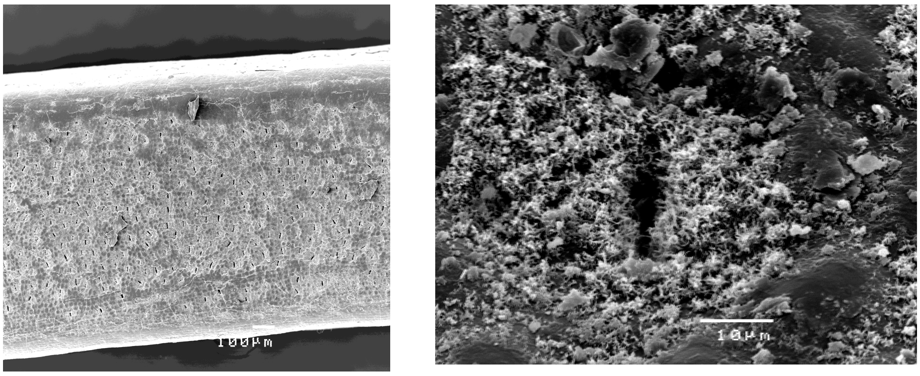
Seedlings at 6 months (L) and 2 years of age (R). Note the development of typical pungently pointed phyllodes and close packing of phyllodes in the older plant. (Source of images lost in mists of time)

When viewed under the scanning electron microscope, young waddi phyllodes are almost featureless, courtesy of a thick coating of wax that masks the underlying structure.



SEM images of waddi phyllodes. Note the coating of wax over the surface of the phyllode on the left. The enlarged image on the right shows a series of appendages merging from the apex of the phyllode. These may be vestiges of the true leaves which, in common with all phyllodinous Acacia species are visible as the first leaves to emerge after the cotyledon stage but are then replaced by phyllodes, which are expanded photosynthetic petioles.

Where the wax coating is less complete, phyllodes exhibit a high stomatal density though each stoma is protected by encrustations of wax which presumably slow the loss of water from the stoma while it is open, and contribute to reflection of excess solar radiation, thereby keeping the phyllode as cool as can be reasonably expected and reducing the risk of photo-damage to photosynthetic apparatus.

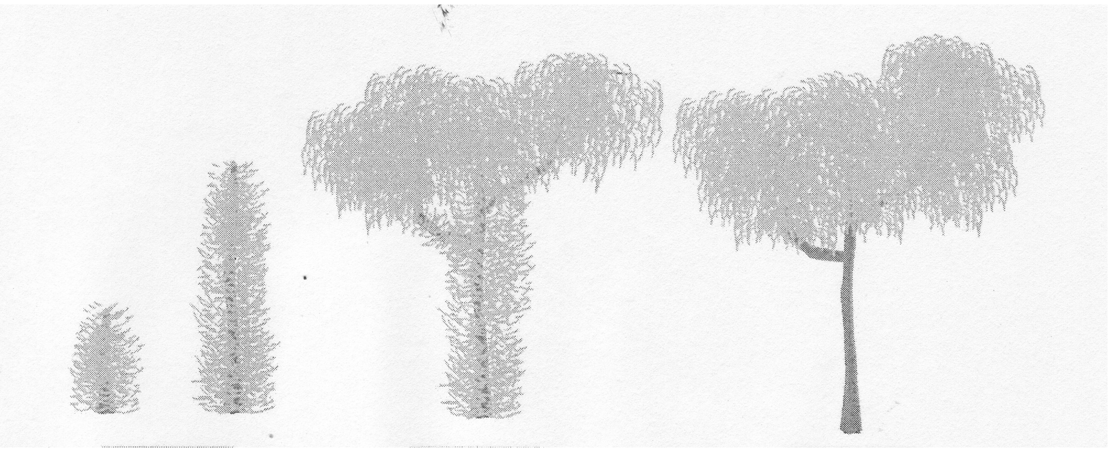


Section of phyllode showing dense scatter of wax encrusted stomata. On the right, an individual stoma can just be seen through the wax coating on the phyllode surface and around the stomatal aperture

Young trees develop a spiky armature of pungent phyllodes arranged in a tangled mass along branches. This arrangement gives every appearance of being an ant-herbivore defence strategy, especially as the spiny appearance is retained until the tree reaches a height more or less out of reach of major browsers (past and present). Trees to over 8 m height may have a two phase appearance, with a spiny mass of "juvenile" phyllodes down low and the typically pendulous, less fiercely spiny adult foliage high up. The transition between the foliage types often occurs at about 2-3m above the ground, leading to a suspicion that it reflects defence against depredations by the now extinct Australian megafauna, many of which were browsers.

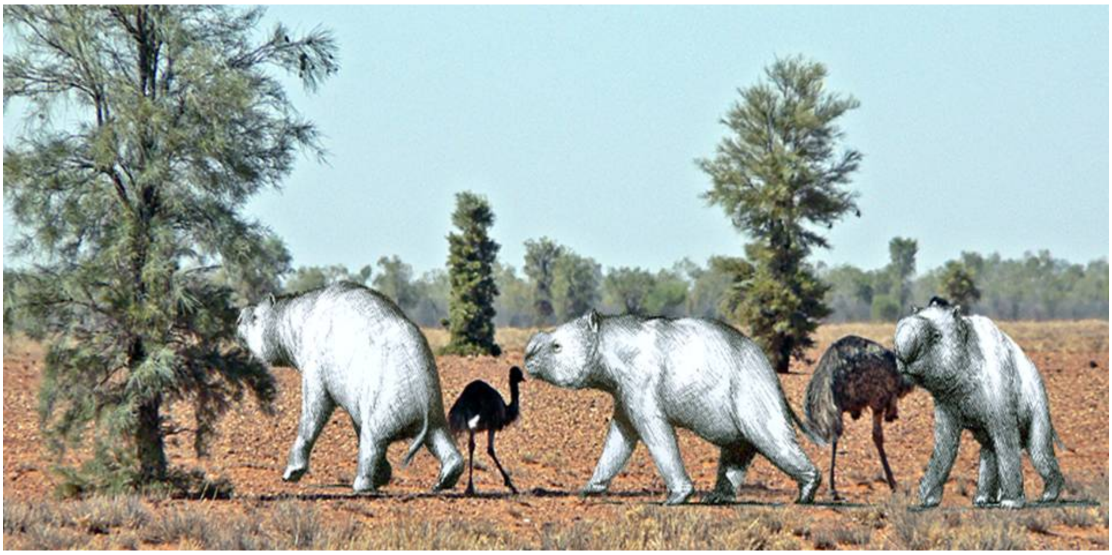
Growth forms in Acacia peuce – the adult tree on the left has typically pendulous foliage. The tree in the centre shows a clear transition between the spiny defensive form down low to the pendulous form above, while the juvenile on the right is in full browser deterrence mode.

We have decided that for descriptive purposes, the waddi tree takes the forms illustrated below:



Growth form 1   *Growth form 2*   *Growth form 3*   *Growth form 4*

The two forms on the left are considered to be "juvenile", the centre tree is "transitional or mixed adult" and the one on the right is "adult." It is arguable that the "bonsai" form should also be included, however these individuals may be showing the effects of severe browsing rather than a distinctive aspect of their ontogeny.

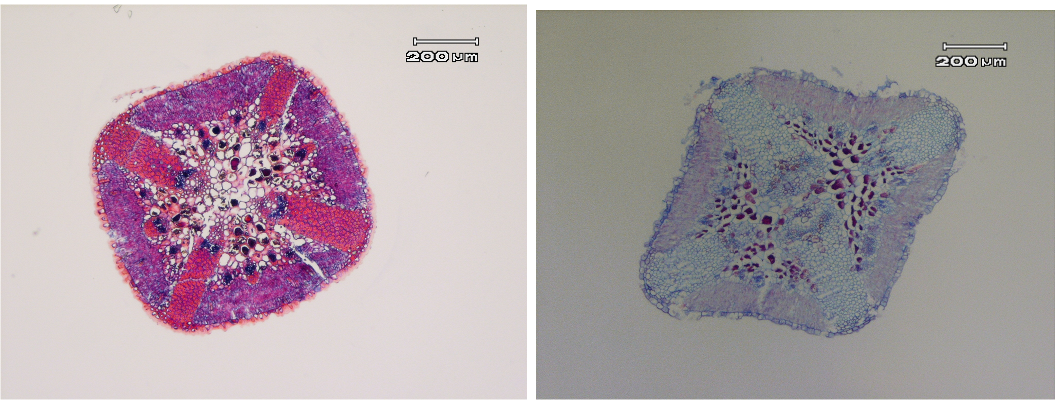


Boulia at 50ka? The mammals are Diprotodon optatum*. The bird on the left is and emu (*Dromaius novaehollandiae*), that on the right is probably* Genyornis newtoni*, a huge extinct bird reconstructed here as a ratite but which was in reality a giant cursorial goose*

The youngest fresh growth seems to be soft and potentially delectable for itinerant browsers. These fresh phyllodes are produced by adult trees and the means by which they become rigid and spiny are unclear. The younger rigid foliage is distinctly glaucous.

Foliage forms in the waddi tree – soft and green, softish and red, stiff and glaucous

When viewed under the microscope, the anatomy of pungent and pendulous phyllodes differs radically. Pungent phyllodes are reinforced by bundles of fibres that extend into the core of the phyllode from its vertices. The fibres presumably lend some mechanical support and rigidity to the phyllode but would also reduce its palatability to browsers. Mature pendulous phyllodes lack the concentrations of fibres.



Light micrographs of pungent rigid phyllode (on left) showing strongly developed fibre bundles at vertices of the phyllode and cross section of a pendulous adult phyllode which lacks the fibres.

Phyllodes are heavily browsed by invertebrates of different sorts. Lots of caterpillars were noted on a visit to Boulia in 2007. The butterfly caught in the act of ovipositing on fresh young foliage (below)

was identified by Peter Valentine as *Theclinesthes miskini* (sometimes called Miskin's Blue or Wattle Blue), a common species which uses a number of *Acacia* species, including *A. victoriae, A. tetragonophylla* and *A. salicina* as larval food plants. It is now known to have *Acacia peuce* on the menu as well.

Chewed waddi tree phyllodes at Boulia in April 2007. All damage appears to be from the activity of invertebrates. The caterpillars in the image on the right hatched in transit from Boulia and industriously chewed their way through the green pods on which the eggs had been laid. Peter Valentine believes them to be either T. miskini or Jalmenus icilius.

While considering this pattern of browser defence as a legacy of the depredations of megafauna, it is as well to consider whether stock animals might have similar effects. Waddi trees are poor fodder and camels and cattle do not seem keen to eat them with entusiasm (though camel, cattle and even kangaroo scats collected at Boulia contain remains of waddi tree phyllodes, suggesting that they'll eat them when necessary). It is also worth noting the tendency of juvenile trees in the vicinity of water points to be heavily browsed). Sheep were run near Boulia until the 1980s and their tastes may be less discriminating than those of cattle. It is distinctly possible that what look to be juvenile plants are in reality quite old – perhaps up to 50 years in some cases (Tony Bowland pers com.) – and are effectively bonsai courtesy of the gnashing teeth of woolly ground lice.

Bonsai waddi trees inside the yards at Mudgeacca Bore

How might you decide which model of heterogeneous growth form (megafauna vs sheep) has the best explanatory power?

Despite the hard and uninviting wood, *Acacia peuce* is subjected to boring by insect larvae. The main culprits seem to be Jewell Beetles *Chrysobothris subsimilis* (Hawkeswood 2006) but longhorn beetles are also likely to be involved. It is not certain whether the borers affect tree health, but dead stems sometimes have impressive porosity from borer activity.

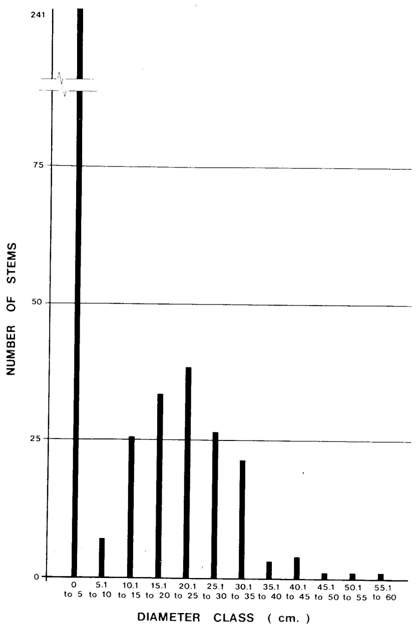
Bored stems of Acacia peuce

Population structure

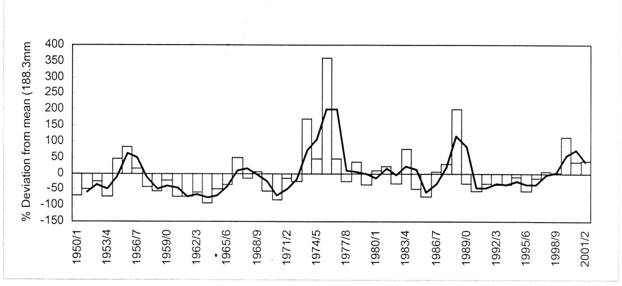
Waddi trees in the Mac Clarke Reserve are found in a number of discrete populations scattered over about 10km^2 within an overall area of about 300km^2 (Bowland n.d.). A stand to the north of Rieck's Dam was decimated by fire in 1976 and on a recent visit I found only 4 living trees out of the 100 or more originally growing there.

Waddi trees killed by the 1976 fire

A second group on and about the crest of North Hill is composed of mature trees with limited regeneration in the form of mid-sized juveniles present. There are a number of very large, very old trees in this population, many of which show signs of senescence and damage from wind or lightning strike. Chuk (1982) does not consider this population to be viable in the long term. Chuck indicates that there is a stem density of mature trees of about 100/ha in the main stand at the Mac Clarke Reserve. Stem size classes are indicative of episodic recruitment.



The majority of mature stems were between 20.1and 25.0 cm diameter over bark (d.o.b.) in 1982 but there were also heaps of small stems (0-5cm d.o.b.) whose presence was attributed to regeneration following the flood years of 1973-1974.



Rainfall plotted as percentage deviation from the mean – note the major spike in 1974

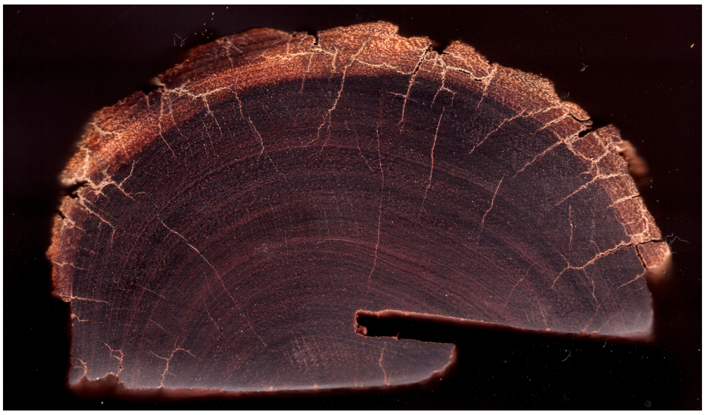
Bowland (n.d.) reports that stand density increased again between 1980 and 2001, again reflecting regeneration (with very moderate attrition) following rains in 1978-1981. This is a clear indication of the importance of rare recruitment events keyed to episodic heavy rain to a drought tolerating species living in habitat marginally viable for the tree growth form.

This neat story is complicated somewhat with data that indicate during the germination event of 1978-1981, seedling emergence was only weakly correlated with rainfall and mortality of seedlings increased with high rainfall while little or no mortality occurred in periods of low rainfall within that interval of time (Bowland n.d.). I suspect that seedling roots are susceptible to waterlogging of the soil or that high rainfall and accompanying erosion put paid to establishing plants (though Bowland presents no data against which these interpretations can be tested).

In his survey of waddi trees Deveson (1980) considered the Birdsville population to be near senescent, comprising mostly older trees with evidence of significant insect damage, sparsity of crown and limited evidence of regeneration, even after the extraordinary rain of 1973-1974. My impressions of this stand are similar. The Birdsville population of *A. peuce* comprises a number of discontinuous sub-stands spread over about 50km^2 of sand plain, gibber plain and occasionally sand dune. It is not clear how this pattern of occurrence came to be. An additional stand of *Acacia peuce* occurs on Adria Downs Station (about 60km north of the main Birdsville population) and goes some way to filling the gap between trees growing at Boulia and those at Birdsville (though there are still 300 km or so to account for! And much of the gap is characterised by soils and landscape that appear to be eminently suited to *Acacia peuce*). Deveson (1980) mentions that the Adria Downs trees were found by Grandison, and that there were some 300 individuals. When I re-visited the site in Juy 2014, I counted 122 trees. There were few dead stems and it is likely that others lurk in odd corners of the site. I suspect that the stand is still in more or less the same condition as when it was first sighted and that the count of 300 or so remains a reasonable estimate.

At Boulia there appears to be a healthy population that recruited effectively in 1973-1974 and again in the early 1990s (graziers report that prior to 1990 it was possible to see the lights of Mudgeacca from Montague Downs, a feat clearly impossible today because of the density of intervening waddis). This is by far the largest stand of waddi trees, covering about 900km^2, though again the stand is made up of a number of sub-populations, including a scungy little one just south of Boulia on the Bedourie Road. There has now been a fair bit of work done at Boulia and you might like to cast your mind towards the sorts of measurements that might be made to better interpret the character and trajectory of this most important place to the waddi tree.

Given the infrequency of successful recruitment events, it seems axiomatic that the waddi tree must be a long-lived species. Unfortunately it is easy to make a generalised prediction of this sort and quite another to be able to generate quantitative data to support it. Getting ages from trees is a complex business. In the temperate northern hemisphere, annual growth pulses are reflected in the laying down of distinct annual rings in the wood. Count the rings and, all other things being equal, you have the age of the tree (this can be VERY impressive – over 5000 years for bristle cone pines and similar for *Lagarostrobus franklinii* or Huon Pine from Tasmania). Things are not that simple in the tropics or in the desert. Waddi trees produce rings but there is no guarantee that they are annual – indeed it seems likely that they grow very little in the dry (for that read “normal’) years and rather more enthusiastically in wet years.



A polished section of a waddi tree branch. Note the very closely spaced rings (which would make Chuk's attempts to count them in the field with a magnifying glass and exercise in futility!) and beautiful purplish heartwood.

This means that rings are likely to be missing and the true age of the tree will be substantially greater than ring counts would suggest. In 2007, dendrochronologist Patrick Baker from Monash University and I investigated the possibility of using tree rings to determine the age of waddi trees and also to use ring widths as a guide to past rainfall patterns. This endeavour failed miserably as ring patterns on one part of the tree do not correspond to patterns on the other side, or in intervening segments, for that matter, making the whole enterprise unworkable. In addition, detailed analysis of the anatomy of the rings showed them not to be true rings at all in the sense that there was no distinct cellular break between one ring and the next, as occurs in "true" rings.

Chuk (1982) assumed that the rings in *Acacia peuce* from the Mac Clarke Reserve were in fact usable features and in a rough and ready dendrochronological investigation reports finding an average (based, I think, on counts of a number of radii on the same stem) of 230 rings in a stem of 24.2cm diameter, 196 rings in a stem of 20.2cm diameter and 142 rings in a stem of 16 cm diameter. Given the size of the largest tree in the Mac Clarke Reserve (~ 55cm diameter under bark), it can be expected to have undergone ~ 500 growth events in its lifetime. What this means in calendar years is another matter entirely. You might care to note the comment above about the reliability of the counts made by Chuk however growth increment data derived from dendrometer bands are consistent with the guesstimated age of 500 years for the largest trees. It is also worth noting that even though the age estimates are not especially firmly grounded, they have entered the scientific folklore almost as established fact.

The Boulia site is somewhat more mesic than either the Mac Clarke Reserve or Birdsville and as a consequence, trees may perform differently there. To test this possibility, Joe Holtum and I set up seven band dendrometers (such as the one illustrated below) on trees along the Coooraboolka Road and have been reading them regularly over the succeeding years.

Band dendrometer measuring girth increment of waddi tree on Montague Downs Station

As of 2014, the waddi trees bearing dendrometers have performed remarkably consistently. The average annual diameter increase has been 1.99 +/- 0.48 mm / year. The very dry years of 2012/2013, 2015/2016 resulted in a much lower than expected growth increment in all trees. The average diameter increment in the Mac Clarke Reserve, a drier site, is 1.06 mm / year.

In the Mac Clarke Reserve, trees are often close to drainage lines. This seems to be in part because drainage lines are reasonably well defined there. Under these circumstances you could raise an argument that successful germination and establishment is more likely where water concentrates but it is equally likely the stream traces (which are dry for 99.99 percent of the time anyway) provide traps for seed pods being blown across the gibbers by the wind. At Birdsville, trees seem less constrained by drainage. Who knows what the story is at Boulia?

Waddi trees in the Mac Clarke Reserve – note the way they are growing along the fold in the land in the mid-foreground. There are plenty of others on the gibber surface behind the photo point though and it would be unwise to get too keen on the importance of drainage to waddi establishment just yet.

On the longevity of *Acacia peuce*

As noted above, there has been much speculation about just how long *Acacia peuce* and other desert trees might live. Estimates based on girth increments and gut feelings have lead to estimates that some of the larger waddi trees might be as much as 500 years of age, whilst the susrvival, in good health, of a large example of *Grevillea striata* blazed by the Sturt expedition to central Australia to at least the year 2000 suggests that this species too can be quite venerable. Over the summer period in 2006-2007 I collected a number of stumps for dating by accelerator mass spectroscopy (AMS) radiocarbon dating. This method uses a mass spectrometer to measure the mass of individual carbon atoms fired along a curved path in a particle accelerator. The different atomic weights of ^{12}C, ^{13}C and ^{14}C mean they travel slightly different trajectories in the accelerator and atoms of each isotope can be counted separately. At its simplest, the ratio of ^{14}C to ^{12}C provides a measure of the elapse of time between fixation of C by photosynthesis and the time of death of the plant. By convention year zero for radiocarbon dates is 1950 A. D., so all radiocarbon ages are effectively referred back to that year.

A number of corrections that must be made before the radiocarbon age (yrs BP) can be converted into calendar years. The precision with which this calibration can be made differs through time and the ages recorded for *Acacia peuce* in this suite of samples happens to be one where calibration is very imprecise and calendar ages are, therefore somewhat less precise that at other times in the past. Radiocarbon calibration is needed to account for the minor fluctuations in ^{14}C formed in the atmosphere at different times. Calibration data sets are built up from independently datable carbon sources, usually tree rings, which can provide an estimate of the starting ^{14C} signal with reference to activity in the dated sample. Note that radiocarbon ages are quoted with an error term of 1 standard deviation (eg 205 +/- 29 BP), which reflects the precision of measurement of radiocarbon abundance in the sample. Effectively it means that there is a 66 percent chance that the true age lies between the bounds of the error. To improve the probability to 95 percent you need to use two standard deviations, and to get 99 percent, three standard deviations in the error term are required.

Most samples submitted for dating came from the centre of the biggest available tree stumps and therefore reflect the age of the tree reasonably closely. Stumps cut by chainsaws were used in order to avoid spurious results from trees that died years before and have lain quietly festering on the ground for some indeterminate number of decades – or perhaps, centuries (see observation below). At Birdsville, trees were cut in the 1970s. At Boulia, most were apparently cut in about 1955 (Dick Suter pers comm.) whilst the trees from Rieck's Dam were killed in 1976.

Samples 1 to 5 came from trees growing on Roseberth Station near Birdsville; the others come from the Mac Clarke (*Acacia peuce*) Conservation Reserve about 300 km south of Alice Springs, on the western side of the Simpson Desert.

Roseberth No 1 (WK 20778) is a spectacularly large individual (dbh 44cm) felled in 1973 to use as a strainer post. To allow for the radiocarbon year zero being set at 1950 A. D., we need to add 23 years to the radiocarbon age. If the median age for this tree is used to calculate its age, it would have been about 170 years old when cut. It was in excellent nick despite being on the ground for 33 years prior to sampling and provided splendid material for a date.

Roseberth No 1 ready for sampling

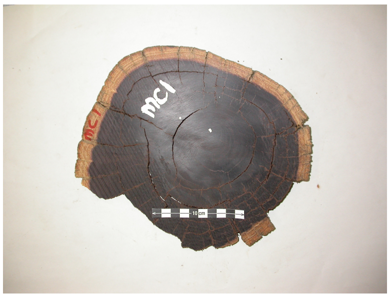
Roseberth No.2 is a gnarled and venerable specimen that appears to have been cut many years ago and has defeated the best efforts of generations of axe wielding tourists before falling to the mighty Husqvarna. It too has impressive girth and is comparable to the larger individuals in the Birdsville stand.

Roseberth No 2 in its natural habitat

Roseberth No. 2 was probably cut around 1970, so 20 years need to be added to the calibrated age to gauge its venerability. It would likely have been about 214 years of age before it was killed

Mac Clarke No. 1 is one of more than 100 trees killed by a lightning started fire in 1976 and so you need to add about 26 years from the apparent radiocarbon age to get an idea of the age of the tree. This would suggest the tree to be about 150 years old when it was killed.

Waddi trees (apparently) killed in the1976 fire



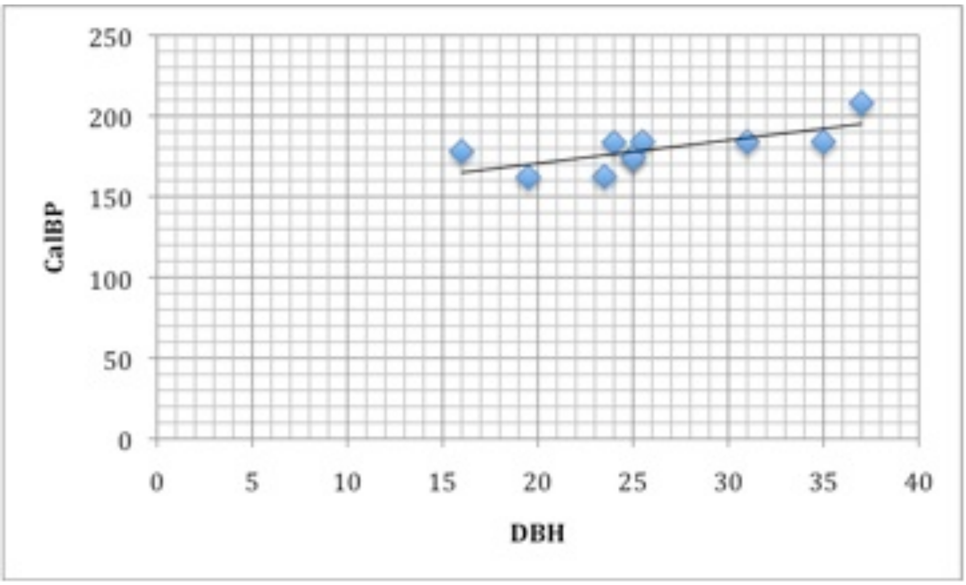
Mac Clarke No 1 cross section ready for sampling

And at Boulia, where trees were (mostly cut in about 1955) Montague 6 was also about 150 years of age at death.

Table 1 AMS Radiocarbon Results (calibration curve shcal13.14c)

Sample	Locality	Stem diameter (cm)	Lab code	Sample size (g)	% Modern carbon	^{14}C yrs BP	Calibrated age range BP (2 σ error)
Montague 1	Montague Downs Station, Boulia, Qld	26	WK 24295		98.7 +/- 0.2	109 +/-30	12-147
Montague 3	Montague Downs Station, Boulia, Qld	25.5	WK 24296		98.4 +/- 0.2	133 +/- 30	146-222
Montague 6	Montague Downs Station, Boulia, Qld	31	WK 24297		98.3 +/- 0.2	134 +/- 30	146-222
Roseberth 1	Roseberth Station, Birdsville,Qld	35	WK 20778	0.32	98.3 +/- 0.4	136 +/- 29	146-222
Roseberth 2	Roseberth Station, Birdsville, Qld	44	WK 20779	0.28	97.7 +/- 0.4	185 +/- 29	133-283
Roseberth 3	Roseberth Station Birdsville, Qld	25	WK 20780	0.26	97.6 +/- 0.4	197 +/- 29	116-233
Roseberth 4	Roseberth Station, Birdsville, Qld	25	WK 20781	0.63	97.5 +/- 0.4	205 +/- 29	137-231
Roseberth 5	Roseberth Station, Birdsville, Qld	24	WK 20782	0.30	98.2 +/- 0.4	145 +/- 30	148-219
Mac Clarke 4	Rieck's Dam Andado Station, NT	16	WK 20783	0.23	97.5 +/- 0.4	206 +/- 30	137-219
Mac Clarke 1 (sapwood)	Rieck's Dam, Andado Station, NT	23.5	OZJ 710	0.31	121.26 +/- 0.51	Modern	No calibration possible
Mac Clarke 1b (trunk centre)	Rieck's Dam, Andado Station, NT		OZJ 711	0.32	98.17 +/- 0.5	150 +/- 45	154-171
Mac Clarke 2 (trunk centre)	Rieck's Dam, Andado Station, NT	19.5	OZJ 712	0.5	98.17 +/- 0.48	150 +/- 40	153-171
Mac Clarke 2b (sapwood)	Rieck's Dam, Andado Station, NT		OZJ 713	0.3	98.91 +/- 0.45	90 +/- 40	12-147
Mac Clarke 3 (sapwood)	Rieck's Dam, Andado Station, NT	23	OZJ 714	0.27	97.59 +/- 0.47	195 +/- 40	294-
Mac Clarke 3b (trunk centre)	Rieck's Dam, Andado Station, NT		OZJ 715	0.29	94.82 +/- 0.48	425 +/- 45	423-508

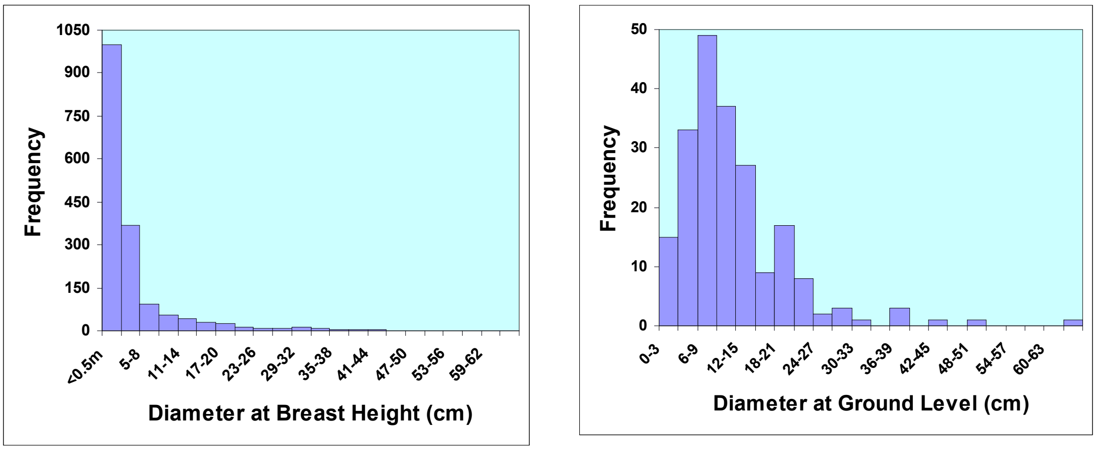
Plotting the median age of calibrated radiocarbon dates against stem dbh of the sampled trees yields an amazingly consistent increase in age with diameter.



Extrapolation of the growth curve derived from measured stems to 56cm, diameter of the largest known tree in the Boulia area yields an expected age of about 220 years. Extrapolating the curve back to the Y-axis suggests that even a very narrow stem is about 100 years old. The solution to this seeming paradox lies in the pattern of growth adopted by trees – early growth is vertical, yielding a long spindly stem. Secondary growth expands the stem. It seems from morphological data that secondary growth in *Acacia peuce* really sets in at a dbh of between 15 and 16 cm, at which time the stem expands laterally and the side branches and foliage begin to be shed, gradually producing the clean trunk characteristic of mature trees. Hence I would expect the age vs dbh curve to differ quite markedly were smaller stems sampled for dating.

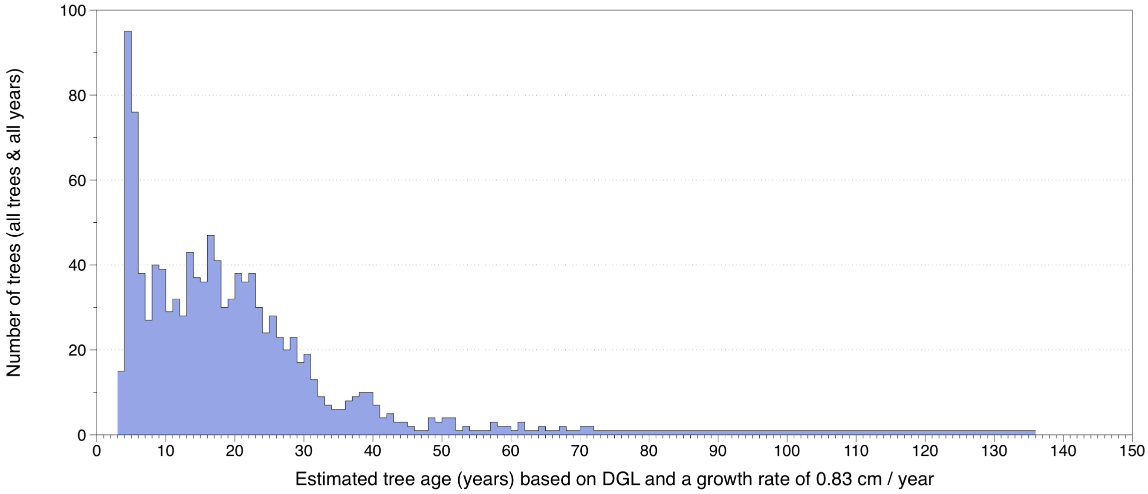
On the face of it, the dates suggest that even the larger waddi trees are significantly younger than anticipated. As the trees sampled were killed rather than died, they do not, in and of themselves, say how long a waddi may live but as their sizes are comparable to the biggest living trees and the few trees that are larger are almost always looking pretty crook the hypothesis that waddis compensate for sporadic reproduction by extraordinarily long lives looks somewhat wobbly.

When considering tree age you can also use growth rates to approximate size vs age relationships. In 1980, Ed Deveson examined stand structure at all three sites where waddi trees grow. The majority of mature stems were between 20.1and 25.0 cm diameter over bark (d.o.b.) in 1980 but there were also heaps of small stems (0-5cm d.o.b.) whose presence was attributed to regeneration following the flood years of 1973-1974. More recent data collected by JCU 3rd year Botany students shows a persistence of a large number of smaller trees.



Stem size frequencies at Boulia in 2007. Compare with frequencies obtained from the same stand by Ed Deveson in 1980

Repeated measurement of trees in quadrats at Boulia suggest the diameter at ground level increases at about 0.83 cm per years so the diameter of a tree can give an estimate of its age. When converted into an age – frequency diagram, it's pretty clear that in the plots we have investigated, and assuming the growth increment is an appropriate reflection of long term trends, the vast majority of trees are less than 30 years old and that the oldest we have located was only about 135 years of age. How much weight you would put on ages estimated by stem increment is open to debate.



Histogram of tree age versus frequency for all quadrats investigated on Coorabooka Road

To put these statements into a slightly different perspective, we have recourse to a rather attenuated set of growth increment data from dendrometers applied during 2007. There are only 7 trees encumbered with these devices, each of them chosen for their regularity in outline (which means that the dendrometers fit neatly on the trunks). Their starting dimaters range between 62 cm and 9.5cm. In the four years the dendrometers have been recording increase in tree circumference, the average increment has been a remarkbly uniform 1.99mm/yr.

If we take the extraordinarily dubious step of assuming this rate of increment has held true through time, the dendrometer bearing trees are estimated to be between 247 years and 54 years. The estimate of 247 years comes from a tree with dbh of aroound 42 cm. By contrast, Roseberth 1 (dbh 35cm) is estimated from radiocarbon measurements, to have been about 170 years old when it was cut, would yied a diameter-based age of about 205 years. This is not too bad an agreement, though if I had to put money on it, I'd prefer to flutter on the radiocarbon measurements, the more so in the light of the normal patterns of tree growth which see rapid increases in height, followed by secondary expansion of the stem that is rapid in the early stages but which slows over time as photosynthate is distributed over ever increasing areas of tissue.

It is worth noting that in 1980 Ed Deveson attempted to obtain conventional radiocarbon dates from a 40 cm dbh tree from Boulia and found a radiocarbon age of 110+/- 20 BP which, when calibrated for atmospheric variations in ^{14}C came in at about 140 +/- BP, not a million miles (or their metric equivalent) from the apparent age of Roseberth No 1. Ages estimated from ring counts from the tree Deveson dated ranged between 127 and 165 "years". Deveson noted, though, that the radiocarbon age from pure cellulose was significantly younger than that from whole wood and was (rightly) concerned that there may have been contamination of the cellulose extract and that the whole wood age is the best estimate. Deveson also suggests that there may be radial transport of carbon compounds into the trunk and that wood storage of carbohydrate to fuel growth may lead to anomalously young ages from stem materials. This seems extremely unlikely to me, given the wood density and thinness of sapwood in the sections we examined.

A curious sideline emerged from examination of the radiocarbon dates from the Mac Clarke Reserve. Two of the trees selected for dating looked odd – both had been burned at the base of the trunk.

Trunks of waddi trees that died well before the 1976 fire in the Mac Clarke Reserve.
The tree on the left died some ~90 ^{14}C years ago, the one on the right, ~195 ^{14}C years ago

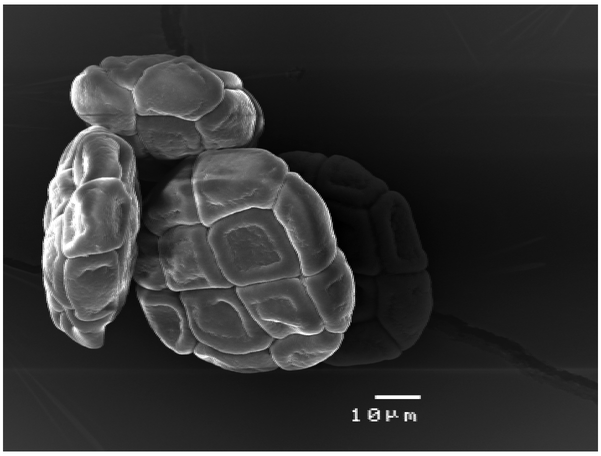
Although it is possible that they had been burned through and fallen in 1976, it seemed equally likely that they were already dead and on the ground when the fire passed through. To test this, I collected samples from the centre of the trunk, as per the rest of the trees but also took wood from the outermost part of the sap wood. One of the trees died about 90 ^{14}C years ago and the other 195 ^{14}C years ago. The wood of both trees is in remarkable condition and it is clear that waddi tree carcases can remain in the landscape storing carbon and providing habitat for a very long time. This is one of the very few instances where the length of time that coarse woody debris can survive has been measured and is clearly a minimum figure as logs in all stages of decomposition occur through waddi tree stands.

Phenology

As the regeneration of *Acacia peuce* seems dependent on rare episodes of extreme rainfall, it would be reasonable to assume that the phenology of the species would key in to environmental variables. Flowering tends to be more common in the period between October to March when rain is less unlikely than in other seasons however small numbers of seed pods are found on threes throughout the year, suggesting that this is a far from fixed phenomenon. Flowers are sparse, pale yellow solitary balls.

Waddi tree bud and flower. Acacia peuce is unlikely to appeal to the tulip growing set. But note the number of images of flowers that feature ants …

Pollination is likely to be insect mediated as the flowers and buds attract flies and other flying creatures and, in keeping with all *Acacia* species, the pollen are shed as polyads which are too heavy and compact to blow far in the wind. See notes below for a more detaild discussion of pollen, pollination and pollen quality. We will set up some pollen traps to investigate pollen flux within and around the waddi stands near Boulia.

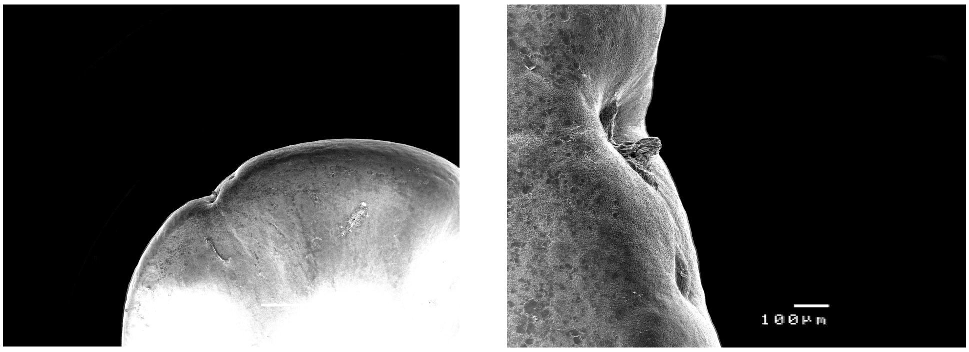


Scanning electron micrograph of Acacia peuce polyads. There are 16 monads per polyad.Note the rectangular pseudo-colpus clearly visible on the central grains f the polyad. This structure probably allows the grain to expand as it hydrates in preparation for emergence of the pollen tube.

Seed pods are remarkable structures. They are flattened indehiscent, chartaceous pods reaching 20cm x 5cm. The seeds they contain are flat circular affairs lacking the aril or eliasome that many *Acacia* species use as a bait to attract the attention of seed dispersers such as birds or ants. The seed pods are readily carried by the wind and at present this seems the most likely means of dispersing seeds away from the parent tree.

Waddi tree pods in the Mac Clarke Reserve

In the Mac Clarke Reserve, one isolated tree is growing about 6 km away from the rest, testimony to the capacity of winds to occasionally shift seeds substantial distances (the tree is too small for the alternative hypothesis, i.e. disjunction through death of other trees in the area to stand up to scrutiny). Seed production between trees is quite variable – some produce many seeds in pods, others produce few. In general though, the number of viable seeds in pods is low (you might care to put some numbers to this claim). Seeds germinate easily with or without hot water treatment (and just about any other of the hard seed treatments you might care to attempt) but nobody has had a look at the effect of smoke on germination. This would be interesting in the light of the apparent sensitivity of adult trees to fire. The high rate of viability of seed might be taken to argue against any proposition that low seed production reflects inbreeding and reduced genetic fitness in a declining species.



SEM image of a waddi seed. Note the smooth surface. The dimple in the margin is the micropyle through which the first roots emerge.

In considering the oddity of waddi tree seed pods, Bowland (n. d.) raises the possibility that one of the reasons for its restricted distribution is that larger vertebrate seed dispersers have vanished from the scene. Megafauna are implicated in the dispersal of a whole range of seeds in modern and vanished ecosystems and Bowland considers *Acacia peuce* pods to fit the bill for what is expected of a megafaunally dispersed plant, viz Howe (1986):

- Large, tough indehiscent fruit
- Fibrous pulp (not the case for *A. peuce*)
- Dull colour
- Resistant seed (not especially so in *A. peuce*)

The regular production of large, variably filled seed pods may be indicative that, as other species of *Acacia* overseas still are, *A. peuce* was once part of a mutualistic relationship with a megafaunal partner now extinct. Scrutiny of papers dealing with this subject in Australia and elsewhere are not especially supportive of Howe (1986) and though *Acacia peuce* has almost certainly had a predator-prey relationship with megaherbiveores, I tend not to think seed dispersal is part of the relationship.

Graziers near Boulia suggest that *Acacia peuce s*eeds can be dispersed along drainage lines and this is a proposition worth considering. It is at least possible that some of the trees at Birdsville were derived – in the distant past - from the Boulia stand by seed washed down rivers during flood times. The fate of intervening populations, and the mechanisms by which colonisers spread (up-wind) from the channels to the current sites occupied by waddi trees, remain a mystery to me. There is no chance at al, inm y judgement at least, that he trees in the Mac Clarke Reserve owe their occurrence to fluvial processes, except at the smallest of within stand scales, as there is no co-ordinated drainage in the vicinity, and the nearest river system, the Finke, drains a wadi-free catchment.

At present the only vertebrate seed predators known to affect the waddi tree are galahs and cockatiels.

Cockatiels appear fond of waddi tree seed and will set about extracting it from pods by chewing around the margins of the swelling which shows where the seed lies in the leathery legume, leaving the distinctive lesions visible on the image to the right.

It would, however, be most surprising if the native rats (at Mac Clarke Reserve these include *Pseudomys australis, P. hermannsburgensis* and *Notomys alexis*), which live in waddi tree communities, did not take advantage of seed and pods which fall to earth within their reach. About 3 months after major rain events, populations of the silky rat (*Rattus villossissimus*) surge and they too may set their fangs to nibbling the odd waddi seed. We found a dead silky rat on the Cooraboolka Road in 2011, so they are around our sites. I have tried feeding waddi seeds to the *Melomys* which insist on invading our house but have yet to see any interest being taken. It remains to be seen if other rodents will eat them, not withstanding the prediction made above.

Waddi tree seeds lying loose on the soil surface at Boulia in November 2007

This silky rat won't be eating any more waddi seeds – but what about his mates?

Bowland (n.d.) found no soil seed store and inferred that regeneration depends on seeds held on the tree or, possibly growth of suckers. Based on some very boring and dreary hours spent digging soil pits and sieving the soil removed there from, we are also sure that at Boulia lacks a soil seed store. Bowland argues that seed viability seems to decline faster for arid *Acacia* species than others, reinforcing the need for a capacity to produce seeds in readiness for the next rain. Cattle eat the pods, and reduce seed availability to some unquantified extent by so doing. Bowland argues that invertebrate predation on seeds not yet released from pods is very low and has negligible impact on recruitment but the images of waddi pod eating caterpillars presented above suggest that some losses are experienced.

In a review of pollen-pistil interactions, Kenrick (2003) notes that *Acacia* in general has a tendency to produce few fruit per flower and posits four potential explanations, (while recognising that many species of *Acacia* do very nicely in spite of it!). The explanations involve:

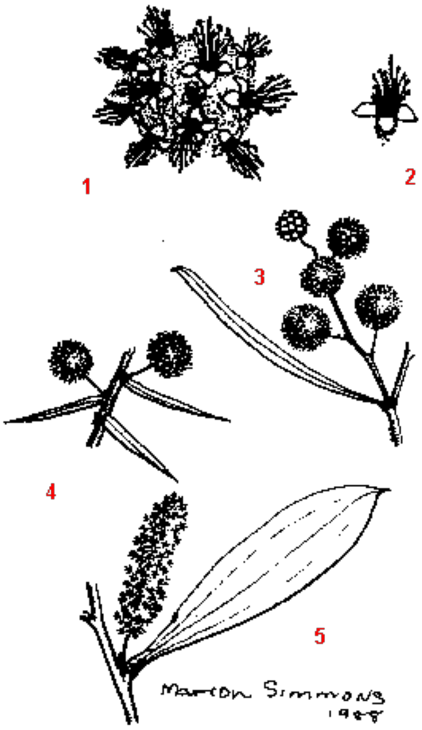
1. There are too few pollen vectors to ensure pollination of all ovules available
2. *Acacia* is self-incompatible and a substantial proportion of pollen arriving at a stigma is too closely related to the recipient plant to be viable
3. Polyads have too few viable pollen to fertilise all available ovules
4. Environmental conditions influence the balance between mal and female parts of flowers in the inflorescence.

***Acacia* Flowers**

Acacia flowers are compound structures that form as racemes, spikes or single heads. The individual flowers are usually small and pretty much indistinguishable unless you look carefully. The flower heads are axillary (they originate from the angle between the leaf or phyllode and the branchlet. There are four types of flower heads:

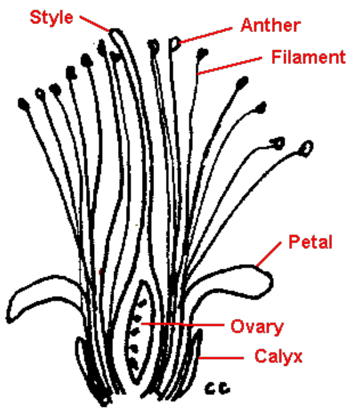
- Cylindrical spikes (5 below)
- Pairs of single globose (spherical) flower heads on separate stems.
- Pairs of single globose flower heads, each on a pedicel arising from a single common axillary shoot.
- Five globose flower heads, each on a single stem coming from an extended axillary stem.

The illustration from Simmons 1988 (below) gives a visual impression of *Acacia* flower arrangements. *Acacia peuce* flowers, needless to say are single axillary balls, pretty much the same as in illustration 4.



Acacia flowers are actinomorphic, ie. the whorls of flower parts sepals, petals and stamens are radially symmetrical so that the flower can be bisected symmetrically in several planes. Flowers are generally 5-merous - there are 5 parts in each floral whorl, eg. whorl of petals (only visible under a hand lens or microscope), calyx, sepals etc.

Stamens are the most conspicuous part of the flower (see below). They are usually very numerous (more than 10) but vary markedly in number. Filaments (elongated structures that support the anthers) are free, long and slender and crowned by small bilocular anthers which open by longitudinal slits to discharge pollen contained within. The stile and stigma, which together form the pistil, are terminal. The ovary is superior - floral whorls are inserted below the ovary. The carpel or female unit of the flower is solitary, the placenta marginal and the ovules usually numerous attached to the upper suture of the fruit.



SECTIONAL VIEW OF AN ACACIA FLOWER

Fruit and Seeds

Fruit, derived from one carpel, is a pod or bean-like structure (a legume) containing many seeds attached near the upper suture. It is dehiscent, ie. seeds are liberated by splitting along sutures in holding the pod together. Seeds have a leathery test or coating. Endosperm within the seed, is generally absent or sparsely developed. This does not seem to be the case with *Acacia peuce*.

Pollen

Acacia pollen, like that in other members of the Mimosaceae, is arranged in a biconvex disc comprising multiple conjoined pollen grains. This structure is known as a polyad. Polyads of Australian species of *Acacia* typically contain 8, 12 or 16 individual pollen grains arranged two grains deep in the central part of the disc but only a single grain deep along the margins. *Acacia peuce* has 16 pollen grains in each of its polyads.

There's a correspondence between the number of grains in the polyad and the maximum number of seeds that develop in each pod. This, in effect, means that a single polyad can fertilise all the ovules in the pistil; it is perhaps no surprise that there tends to be only one polyad deposited in the receptive are a of the stigma, a phenomenon that seems to be facilitated by secretion of stigmatic fluids post-pollination. These fluids seem to push the polyad into an appropriate position and may (or may not) prevent the successful acceptance of additional polyads. Ovule numbers differ between species (Kenrick 2003 suggests the range for Australian species is 5-15) generally being less than, or slightly greater than, the number of grains in the polyad. You might expect that a single pollination event could, in principle, result in a full pod of seeds. In the case of *Acacia peuce*, this would mean that the maximum seed number per pod should be ~ 15-16.

The numbers of anthers dictate the number of polyads produced as there is a strict 8 pollen-forming loculi / anther. The number of anthers per flower is fairly uniform but ratio of male to hermaphrodite / flower heads can affect the numbers of pollen per pistil. This ratio can change between years, suggesting that there is some degree of variability possible in pollen production and in potential seed yield.

Pollen quality

Pollen quality is an expression of the likely effectiveness of pollen in its task of delivering gametes to ovules. The study of pollen quality is a lively one in circles devoted to archiving plant biodiversity and there is disagreement as to the best ways of measuring and describing pollen vitality. According to purists, pollen viability can only be measured with reference to pollen tube germination and growth in vivo as stains may point to viability of pollen that are patently dead. Study of *in vivo* (and *in vitro*, for that matter) germination of pollen is not easy and it is more practicable for most purposes to use stains as a way of assessing pollen quality. For discussions of this matter, look to Sedgely & Harbard (1993), Heslop-Harrison (1992) and Kenrick & Knox (1985).

However you measure it, pollen quality in *Acacia* is important as, in most cases (between 82% and 100% of the time, in fact), a single polyad occupies the receptive surface on each stigma (see Knox and Kenrick 1983; and others). That polyad can be shown by isozyme analyses to be the progenitor of the seeds that develop in the resultant pod (Muona *et al.* 1991).

Pod production and pollination

Low yield of pods / flower head are the norm for *Acacia.* For example, Moncur et al. (1991) found that in *A. mearnsii* 6242 flowering heads resulted in a princely 64 pods (containing 327 mature seeds. By my admittedly dodgy mathematics, that comes out to 5.1 seeds per pod or 1 seed for every 19 or so flowers). The finding that hand pollination raised pod yield per flower head from 1.3% of flowers producing pods to 21% of them doing so suggest that pollination is a limiting factor on potential seed production and recruitment. In the species of *Acacia* where this has been examined, self-incompatibility is high, limiting the capacity for self-pollination that could improve seed yield. A corollary of this is that pollen dispersal is a critical step in reproduction in *Acacia*. *Acacia* polyads do not travel far in the wind (they are always significantly under-represented in studies of pollen rain) and that the occurrence of sufficient insect vectors (a wide range of insects, none of them as effective as the imported European honeybee, has been suggested to fill the role of pollinator) is essential to yield a fully crop of seeds.

To return to Kenrick (2003), we can evaluate the factors underlying low seed set in *Acacia*, and *A. peuce* in particular as follows:

1. Too few vectors – this may relate to the tendency of ants to frequent *Acacia* plants to sample extra floral nectaries, where provided, or tend scale insects. The ant may provide services by defending the plant against herbivores but they are also powerful deterrents to visitation by potential pollinators and, in some cases, may damage the flowers themselves. *Acacia peuce* certainly supports a splendid array of scale insects, which are tended by large, aggressive ants. We should be alive to the possibility that this may influence pollination success. This was obviously in the mind of Gilpin *et al.* (2014) when they attempted to explain the lack of seed set in *Acacia carneorum* (which, you may remember, is one of the close relatives of *A. peuce*). Their conclusion was that although *A. carneorum* attracts a diversity of native insects, they callyy little pollen and do not move around the plant much. The authors conclude that the ineffectiveness of native insevt visitors lies behind the low seed set in *A. carneorum* and that, by contrast, the relative success in *A. ligulata* owes much to the efforts of the introduced honey bee (*Apis mellifera*). We need to know more about the pollinators of *A. peuce* – maybe next year?
2. Pollen is too closely related to recipient plant – The tendency to self-incompatibility displayed by *Acacia* (Kenrick 2003, Kenrick and Knox 1989, Gilpin *et al.* 2014) means that pollen need to be carried between trees to be effective. A scarcity of vectors and unsuitedness to anemophily of pollen arranged in polyads would mean that self-incompatibility may be a significant additional barrier to seed production. In fragmented habitats, pollination success has been shown to be markedly reduced, probably as a result of the incapacity of the habitat fragments to support the diversity of insects involved in pollination of *Acacia* (Cunningham 2000). Whilst the habitat of *Acacia peuce* is fragmented, the size of the fragments is such that it would be folly to blame the low observed seed set on this process, though the need for sufficient pollinators to be present in the environment can't be emphasised enough.
3. Polyads have insufficient viable grains to fertilise full set of ovules – The observation that a single polyad is involved in the fertilisation of all ovules in an individual pistil, and that potential seed numbers in a pod reflect the numbers of pollen making up a polyad, points to pollen quality being an important variable in seed set. We have observed that polyads of *Acacia peuce* frequently appear to be completely inactive, or contain significant numbers of inactive pollen grains, raising to possibility that this is a significant factor behind the poor seed set measured. I have been unable to locate any systematic studies of pollen quality in Australian *Acacia in vivo* and cannot but wonder whay Gilpin et al. (2014) did not consider

this matter in their study of *A. carneorum*. The ever diligent, if turgid, Kenrick notes that pollen quality differs between plants and that quality deteriorates rapidly once the pollen are released from anthers and flowing maturation of the flower but offers scant information about the quality of pollen liberated from particular flowers. Our data hint that pollen quality is important in explaining the poor seeding performance in *A. peuce* but we need more, much more, data.

4. Environmental factors affecting balance of male and female flowers – This is a phenomenon identified in *Acacia mearnsii* (Moncur *et al.* 1991). In this species, it appears that the proportion ofmale flowers is low in years when flowering is light (52% male flowers) but much more pronounced in heavy flowerings (93%). Kenrick (2003) considers the proportion of male flowers to be a plastic character that allows individual plant responses to environmental conditions or resource availability, permitting pollen production to remain more or less constant whilst minimising commitment to female structures in disadvantageous conditions. How this gels with the behavioue of *A. mearnsii* is a little unclear to me.

Fire and the waddi tree

To this point, several references have been made to the sensitivity of waddi trees to fire. Now it is time to justify these statements. The death of hundreds of waddi trees after a fire in the Mac Clarke Reserve in 1976 was attributed to passage of a relatively high intensity fire burning grassy fuels, which grew during a splendidly wet summer the previous year and cured in subsequent months. Fire intensity is a measure of heat release during the life of a fire. It is measured in kiloWatts / metre (kW/m^{-1}) of fire front and can be estimated by solving the equation $I = 500.w.r$ where I = fire intensity in kW/m of fire front, w is the fuel load in t/ha and r is the rate of spread of the fire in kph. The rate of spread of the fire is strongly influenced by wind speed and topography – within certain limits, the higher the wind velocity the faster the fire will spread, whilst fires burn rapidly up slope and more slowly down slope. The desert landscape is pretty flat so wind is the major determinant of how fast a fire can spread.

The other major variable, fuel load, is strongly linked to rainfall, and in the desert, the main fuel is grass. It is important to distinguish between the perennial hummock grasses (*Triodia*) and the tussock grasses which tend to respond strongly to seasonal rainfall. *Triodia* is not found on any of the waddi tree sites so discussion here assumes we a re dealing with tussock grasses like *Aristida, Astrebla or Isielma*. Grass grows rapidly, decomposes rapidly and reaches relatively modest peak loads, even in the wettest of years. Grass is also eaten by herbivores so cattle, sheep, rabbits, macropods and insects have important roles in consuming biomass, thereby modifying the fire environment, and one of the concerns in conserving waddi trees in the NT is the increase in fuel build up which accompanied exclusion of stock from the Mac Clarke Reserve.

Most plants survive fire reasonably well courtesy of all sorts of adaptations, many of them structural. These include epicormic buds, lignotubers and sundry other bits and pieces. A key role is performed by the bark, which insulates the heat sensitive cambial tissue and protects it from damage. The thicker the bark, the better the insulation (see Vines, 1968). The effectiveness of bark as an insulator interacts with the residence time of the fire in the vicinity of the tree. This is called the burn out time and dictates the time over which the heat pulse from the fire builds, passes into the bark and dissipates as the fire passes. With grassy fuels, the burnout time is short so that even if the fire is intense, temperature builds and declines rapidly. Unless there is an accumulation of fuel, such as leaf litter or whatever, around the base of the tree the fire passes and life returns to normal in a few minutes.

In 1976 lightning ignited a fire which killed about a hundred waddi trees near Rieks Dam. There are no data that allow detailed reconstruction of the fire but a few observations are pertinent. First, the fuel load is unlikely to have been more than about 3 tonnes/ha^{-1}. Under more or less average conditions (relative humidity 10%, air temperature 35^{o}C, wind 20 kph and fuel fully cured) a rate of spread of ~5kph might be expected. This would generate fire intensities of ~6750kW/m^{-1}. This sounds impressive but under normal circumstances, woody plants subjected to such a fire would not fare too badly. There is rarely much litter accumulation under waddi trees so it would be reasonable to infer that the fire passed quickly. Waddi tree bark is thick (~ 2 cm or so according to measurements made by Joe Holtum) and persistent; I expect it is a splendid insulator (we will return to this later), and yet the trees still died.

To look at this in more depth, your colleagues in 2013 and 2012 undertook to model the probable fire intensities expected with fuel loads generated in a wet year (2012) ands in an extremely dry year (2013). They assumed that weather conditions – temperature, wind speed and relative humidity - were average for the fire season, or were at the extreme end of the spectrum. They then calculated expected fire intensities and also the height to which those fires would char or scorch trees and compared those figures to the height distribution of trees measured in the Boulia stand. The results were instructive. Under all modelled conditions, a fire burning through the waddi trees would totally scorch up to 95 percent of the individual trees. This very likely to result in death of the tree. Char heights (which approximate flame height) were relatively modest however they would impinge on the foliage skirt sported by juvenile trees.

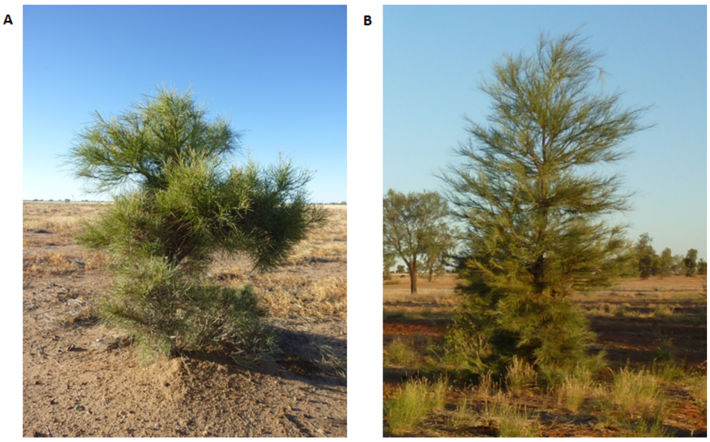
Stems killed in the Rieks Dam fire average 13.1 cm d.b.h. (compared with average of 24.9 cm for trees on the un-burned Mac Clarke Reserve hill site). These are relatively small trees and many of similar size still sport the dense fringe of spiny foliage we have previously claimed to be a deterrent to the ministrations of now extinct vertebrate browsers (see graphs below).

The juvenile growth form of the waddi tree produces plenty of flammable fuel (left and centre), unlike the mature form seen on the right

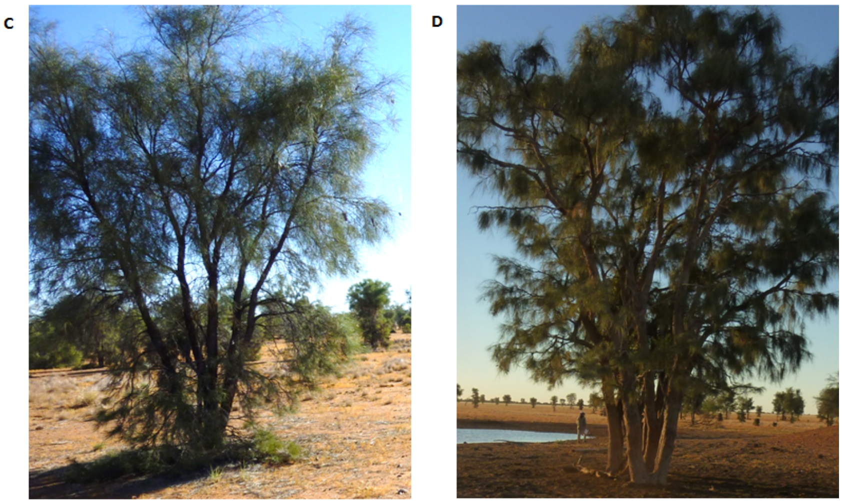
A cheap and nasty experiment carried out in 2007 shows that this foliage, which includes live tissue and a mass of dead grey stuff, is very flammable and would burn for a great deal longer than a bit of grass. If burning it would pose a fair challenge to the survivability of the tree. The skirt, if indeed it existed on the Rieks Dam trees in 1976, would also act as ladder fuel, carrying fire into the tops of the tree where bark is thinner, apical buds are exposed and the whole protective thing is less well developed.

Young foliage is flammable – it would do a tree no good at all if it caught alight

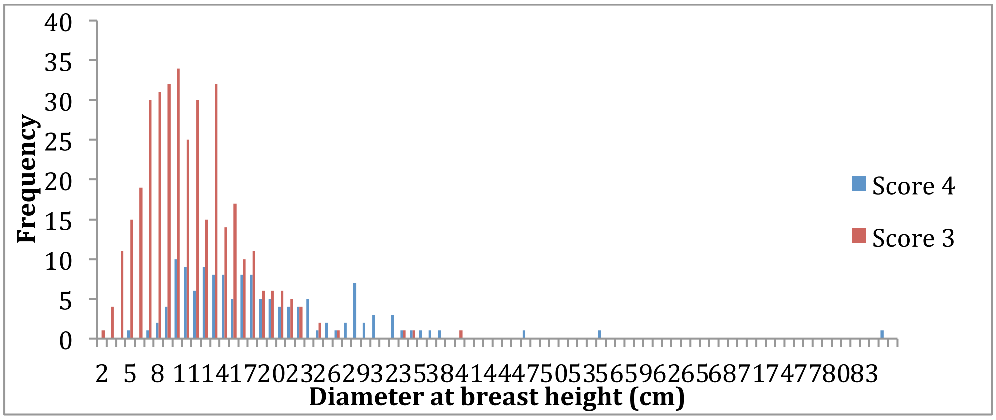
In 2014, Ruginia Duffy considered the question of how old a waddi tree is when it changes from the skirted to unskirted form. To do this, she measured stem diameter at breast height and at ground level, scored each measured stem as growth form 3 or 4 (see section on tree architecture above) and graphed the results (see below). Her stratified sample consisted of trees considered to be large for growth for 3 and small for growth form 4 so as to avoid measuring the vast number of stems in growth forms 1 and 2, which would inevitably die in any fire that could carry through the stand (see figure below for illustrations of growth forms.



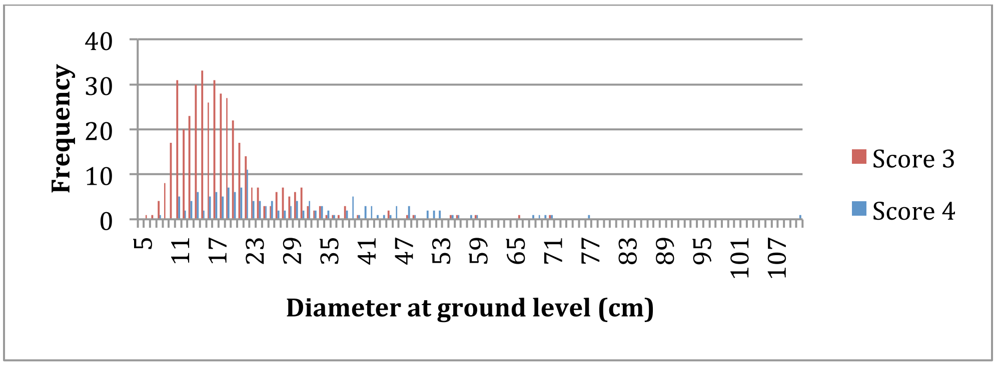
*Growth forms of A. peuce - **A** score 1 tree, **B** score 2 tree*



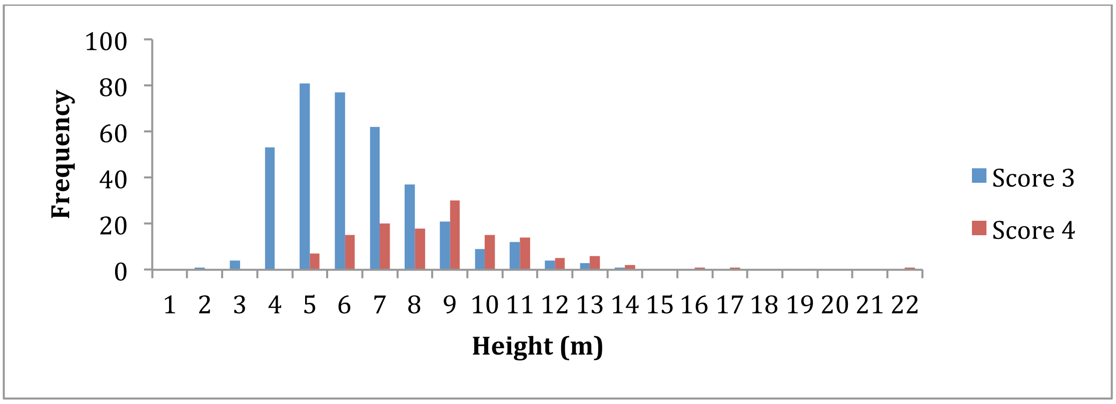
*Growth forms of A. peuce, **C** score 3 tree, **D** score 4 tree.*



Frequency of score 3 and score 4 stems plotted against dbh (N=499). Note the large number of score 3 stems and the marked overlap of dbh measurements. Stems below 8cm dbh are almost certain to be score 3 whilst stems above 24cm dbh will most likely be score 4



Frequency of score 3 and score 4 stems plotted against diameter at ground level (N=499). Again there is marked overlap in diameter between stem scores.



Stem score vs height (m) also shows overlab however there are no score 4 trees below 5m heightand very few score 3 tree above 10 m. N=107

The upshot of this investigation is that there is a very considerable (at dbh, dgl and tree height) overlap between stems of skirted and unskirted trees. This suggests that there is no neat phenogical cue that triggers self-pruning and that trees of substantial size may posess the skirt that we believe pre-disposes them to damage in fires.

Based on the dbh graph, it seems that skirted trees dominate the population up to a dbh of ~17cm. Between 17cm dbh and 23cm, the proportion of skirted and non-skirted trees is about equal and for trees greater than 23cm dbh, score 4 forms predominate.

Based on girth increment measurements (dbh), I estimate that the skirted trees dominate any new cohort of individuals for at least 80 years (dbh of 15-17cm). The cohort of trees between 17cm and 23 cm, in which skirtedness is more or less evenly distributed are about 80-120 years of age, whilst score 4 dominance occurs in trees greater than 120 years of age. This suggests that even very minor fires can potentially kill most individuals less than about 80 years old by canopy ignition, and may kill trees up about 120 years of age. At Boulia this, in turn, means that we'd need to wait another 40-60 years before trees that germinated as a result of the 2014 wet season would be in transition to the purportedly less likely to ignite growth form 4. It would be a magnificently impractical experiment to set a few waddi trees alight and see what happens but the above speculation more or less fits the known facts and until we have a fortuitous fire under controlled conditions with observers and instruments on hand, that'll do for the moment.

As noted earlier, trees can be killed in fires by destruction of foliage and buds. They can also die as a result of heating of the vascular cambium in stems to a lethal temperature. This is usually considered to be about 60°C and the job of the bark (among many other things) is to keep cambial temperatures below lethal levels in the event of fire. There has been a fair amount of experimental investigation of the insulating properties of bark (see Vines 1968, Lawes et al. 2011a and Bowman *et al*. 2014 for some Australian examples) and in 2015 and 2016, we carried out our own experiments to see how the bark of *A. peuce* performs as an insulator as compared with the bark of a selection of tree species that do not appear to be so fire sensitive.

We chose to follow the method described by Lawes *et al.* (2011a), in which a kerosene soaked wick is ignited to apply heat to the bark whilst temeratures at the bark surface, at the cambium under the bark and the ambient temperature are measured by type K thermocouples and recorded on a data logger.

Experimental burn on Eucalyptus coolabah. Note flaming wick, thermocouples, data logger and stunned expression on the faces of the student pyromaniacs.

This method is said to approximate the heating experienced by a tree bole in a natural fire, but yields much more variable data than heating applied by a blowtorch or similarly more predictable instrument. For the full gruesome story, please refer to the separate document on fire and the waddi tree – what follows is a summary of what we did and what we found.

Firstly, theory has it that bark thickness generally increases in proportion to stem diameter. This means in effect that small trees have thinner bark, and are more susceptible to stem damage by heating than are larger trees. We had a small data set, and some of the data recorded were, to put it as politely as possible, ambiguous, however the smaller waddies showed little indication of a positive bark thickness-stem diameter relationship (see table below). This would suggest that even the smaller trees (provided they survived to become large enough for us to sample) had bark more or less as thick as that on larger stems. It follows that waddi trees should be reasonably resistant to cambial damage by heating from an early stage – possible as early as about 20 years, if dendrometer-derived diameter increments dicussed above are to be believed.

Bark thickness on the fibrous part of the trunk of *Eucalyptus coolabah* was about twice that of the waddies, immediately suggesting that *E. coolabah* is likely to be a better thermal perfomer than *A.*

peuce. We also tested the thermal properties of the bark of *Corymbia dallachyana*, a good example of a gum-barked eucalypt, but for some reason no bark thicknesses were recorded for that species. I will need to repeat the measurements.

Tree	**D_{60} (cm)**	**Bark Type**	**Bark Thickness cm.**	**Basic density g/cm^3**
A. peuce Herbert	93	Not recorded	0.7	
A. peuce Larry	65	Not recorded	2	0.6
A. peuce Steve	56	Not recorded	0.97	0.7
A. peuce Jeffery	61	Not recorded	0.8	0.8
A. peuce Lucas	75	Not recorded	0.9	0.6
A. peuce tree 3 16/6/16	24.7	flaky	1.0	Not measured
A. peuce Tree 4 16/4/16	20.5	flaky	1.0	Not measured
A. peuce Tree 5; 16/6/16	37.5	fine	1	Not measured
A. peuce Tree 4	12.7	flaky	0.6	Not measured
A.peuce Tree 7 17/6/16	14.6	fine	0.9	Not measured
A. peuce tree 6 17/6/16	16.7	flaky	1.1	Not measured
E. coolabah Julia	14.0	Box	2.3	Not measured
E. coolabah Pauline	9.5	Box	2.25	0.9

Bark thicknesses and bark basic density measured in Acacia peuce and Eucalyptus coolabah*. No data were recorded for* C. dallachyana*. D_{60} is diameter of trunk at 60cm; bark type refers to appearance or type of bark (in the case of* A. peuce *there are coarsely flaky and finely fibrous barks, each of which has potentially different thermal properties. Basic density is calculated using wet weight and volume of sample after drying*

Bark insulating capacity is inversely proportional to basic density (see Bauer *et al.* 2010), a reflection of the role of air spaces in the bark as barriers to conducted heat. Measured basic density of *A. peuce* (N=4) ranges from 0.6 to 0.8 g/cm^3, that of *C. dallachyana* (N=3) is a uniform 0.6 g/cm^3 whilst *E. coolabah* bark comes in at 0.9 g/cm^3 (though N=1). From this you'd expect the waddi bark to work better as an insulator than coolabah, though this, of course, needs to be traded off against the thicker bark possessed by the eucalypt.

The table below offers up the thermal performance of bark of the various trees subject to our experiments. Beware of the small sample sizes and variabity of numbers; what is on offer here is what I believe to be the implications of our work, not the final and definitive truth! Again, I urge you to examine the document that explores the interaction between *A. peuce* and fire mentioned above for the full story.

Tree	Max T at cambium ^{o}C	Max $T_{max(surfac)}$ ^{o}C	Measured rate TΔ ^{o}C/min	Measured T to $Tc_{(60)}$ mins	Estimated T $Tc_{(60)}$ mins
A. peuce Herbert	56	280.5	2.35	N/A	1.4
A. peuce Larry	43	246	4.25	N/A	11.6
A. peuce Steve	84	485	10.5	3	4.9
A. peuce Jeffery	46.3	417	2.5		1.9
A. peuce Lucas	85	501	5.6	5	2.3
A. peuce tree 3 16/6/16	45	293	2.2		2.9
A. peuce Tree 4 16/4/16	53	225	15.2		2.9
A. peuce Tree 5; 16/6/16	54.5	225	25.4		2.9
A. peuce Tree 4	64.5	166.5	6.25		2.9
A.peuce Tree 7 17/6/16	77.5	346	35	0.5	
A. peuce tree 6 17/6/16	50.5	181	11.25		3.5
E. coolabah Julia	38	747	0.88		15.3
E. coolabah Pauline	40	233	0.18		14.7
C. dallachyana 1	66.5	253	34	0.3	
C. dallachyana 3	44.5	87.5	3.5	N/A	
C. dallachyana 3a	60	450	21.3	1.0	

Tabulation of thermal performance of bark of study species. Tc is temperature in ^{o}*C measured at the cambium. Tmax* $_{(surface)}$ *is the highest temperature measured at the bark surface (below the wick, in other words) TΔ*^{o}*C/min is the time required to reach a cambial temperature of 60*^{o}*C as measured in the field and the estimated time to* $Tc_{(60)}$ *is the predicted time required to reach a cambial temperature of 60*^{o}*C based on the equation* $\tau c_{(60^{o}C)} = 2.9x^2$ *where x = bark thickness in cm (Lawes et al. 2011a)*

If these data are to be believed, *Acacia peuce* would require a fire to remain near the bole of the tree for bwtween 2.9 and 11 minutes befor the cambium would become hot enough to begin to die. As residence time (ie the time that a fire takes to pass a point) of grass fires is measured in seconds rather than minutes (Cheney and Sullivan 2008), it would be surprising if trees were to suffer serious trunk damage from the sorts of fire likely to occur in landscapes around Boulia.

Root architecture and function

Roots are, self evidently, a vital part of the suite of features that allow plants to grow and prosper. Roots are also notoriously difficult to study, especially in trees which grow in remote localities on very hard soil. Until recently we had not really thought much about waddi tree roots. There was an unspoken assumption that the trees have deep roots that tap into deep soil water and provide for the transpirational needs of the tree. Although it is extremely difficult to be precise on this topic, Canadell *et al.* (1996) report that some African trees (notably *Acacia erioloba* and *Boscia albitrunca*) send down roots at least 50 metres to reach water (*Boscia* is recorded as reaching 68m). In Australia, *Eucalyptus* *marginata* hits 40 m (see Dell *et al.* 1983) and there are claims from the practitioners of phytoexploration for metals such as gold, zinc, metal sulphides and such that spinifex (*Triodia* spp) gets somewhere near the 50 m below ground surface (Reid *et al.* 2008). This is a bit suss, if you ask me.

Aroon Edgar grew waddi seed in pvc pipes to see how the roots developed. The root system produced is illustrated below. The experimental plant has a dense cluster of phyllodes surmounting a 6 cm woody stem. Total height above the ground surface is 13cm. There is a vertical tap root that is quite robust for about 12cm, below which it thins significantly and descends vertically for a further 18cm. Then there is a bifurcation and development of a mass of fine, vertically oriented roots that look like a bit of a tangled mat. Most of these roots are close to vertical, though there are some that diverge at an angle of around 30^{o} from the main root axis. The central root is lost from sight, if it still exists, in this mass of roots. In the upper 12cm of roots, starting at about the soils surface, there are relatively robust horizontal to sub-horizontal roots running off the tap root to provide a distinctive spiky look to the system. The roots in the lower 2 cm of this tract are more vertical than those at the top. This upper root net looks very similar to the roots excavated by water pressure at Boulia in 2012. The total length of the root extracted from the pipe was 93cm, not bad for a seedling that was 13cm tall overall, with a 6cm stem.

A slightly out of focus image of roots excavated at the base of Acacia peuce at Boulia. Note horizontality of the surface roots.

Root system of a seedling waddi grown in a pvc tube filled with coarse river sand. Note the strong vertical development and the intervals of fine fibrous roots near the soil surface and at the bottom of the system

In the field, a similar pattern seems to occur. Excavation of the roots system of a doomed seedling (~10 cm tall) found on the very edge of the Cooraboolka Road revealed a vertical tap root that was more than 70 cm long and a lateral root taking off from the main root axis about 10cm below the surface.

Waddi seedling on the edge of the Cooraboolka Road.Note well developed tap root and lateral heading to the right from the tap root axis

In 2014 Claudia Pandolfo Paz spent hours excavating a fine root originating from a juvenile tree. The root ran just below the soil surface for over a metre. The root seemed to terminate in what appears to be a fuzz of fungal hyphae that looks very like what would be expected from an ectomycorrhizal Hartig net. This is the site of interface between roots and the fungi with which they form a mutually beneficial association. We have found hints of mycorrhizae previously, but this is the clearest indication yet that *A. peuce* is a mycorrhizal species. Fungi are not all that obvious in desert environments but at Boulia the Basiodiomycete *Podaxis pistillaris* is seen regularly. This is a species found in deserts world wide though little is known of its ecological role or whether it participates in mycorrhizal associations. More work is needed to both confirm the presence of mycorrhizae on *A. peuce,* whether any associations are permanent or transient and to demonstrate that the fungal party is *Podaxis* but in the absence of any hint of Rhizobial infection, using fungi to carry some of the nutritional load would not be unreasonable.

Apparently mycorrhizal rootlets excavated by Claudia Pandolfo Paz (L). The fungus on the right is Podaxis pistillaris. This fungus goes brown and falls apart whilst shedding its spores. Earlier in its life cycle the fruiting body is a dirty white. Latz (1995) notes that this fungus is used for decorative purposes by Aboriginal people throughout central Australia. Children also use it as a drawing implement and to imitate ritual leg-slashing associated with mortuary practices. The northern Warlpiri apparently use the spores as a fly repellent.

It is most likely that rapid downward growth allows roots to follow the wetting front after major rainfall events and develop the root net required to impart resilience to the inevitable dry times that follow. Hence germination in any particular year triggers a race between desiccation and access to deeper soil moisture reserves. Subsequent formation of mycorrhizal associations would aid nutrient uptake in what is certainly a nutrient poor soil environment.

Armed with the above examples from experiments and observations from the field here and overseas, the waddi tree can be expected to have a very tap deep root capable of getting access to water protected from evaporation by depth of burial. In a bore east of Mudgeacca Station, we found water at 16m below ground surface, seemingly well within reach of the roots of such a large tree with a demonstrated propensity to exhibiting a strong tap root. In July 2014 I collected water from the bore to tests its salinity. I did this by evaporating a known volume water and weighing the salt precipitated from it. Total salts in the water sample came in at 2.85 g/litre of which 0.188 g/litre is CaCO3 (determined by acid treatment of the gross residue) and 0.97g/l of other salts – mostly NaCl, I believe. Although the groundwater is salty to taste, the human taste threshold for NaCl is only about 0.2-0.3 g/l so we can taste the salt even though salinity is much lower than seawater (~35g/l NaCl). It would be a little surprising if the measured salinity at Mudgeacca was toxic to a tree able to send its roots into kopi, so the probability is that large waddi trees can support themselves by tapping into groundwater.

Extracting water from "No Name Bore" near Mudgeacca Station. In April 2010 the water table here was at about 21m below ground level. According to Philip Prince, owner of Mudgeacca, the bore was drilled to about 23m and was abandoned due to the saltiness of the water. It terminated in limestone.

Measurements of water use (see below) suggest, however, that at the end of the dry season waddi trees become water stressed (and more so than species such as *Grevillea striata*) to an extent that calls into question their use of deep soil water. There is, as yet, no obvious explanation for this phenomenon and possibilities might lie in root architecture, a greater sensitivity to water quality than we have assumed or local scale differences in the distribution and accessibility of deep water.

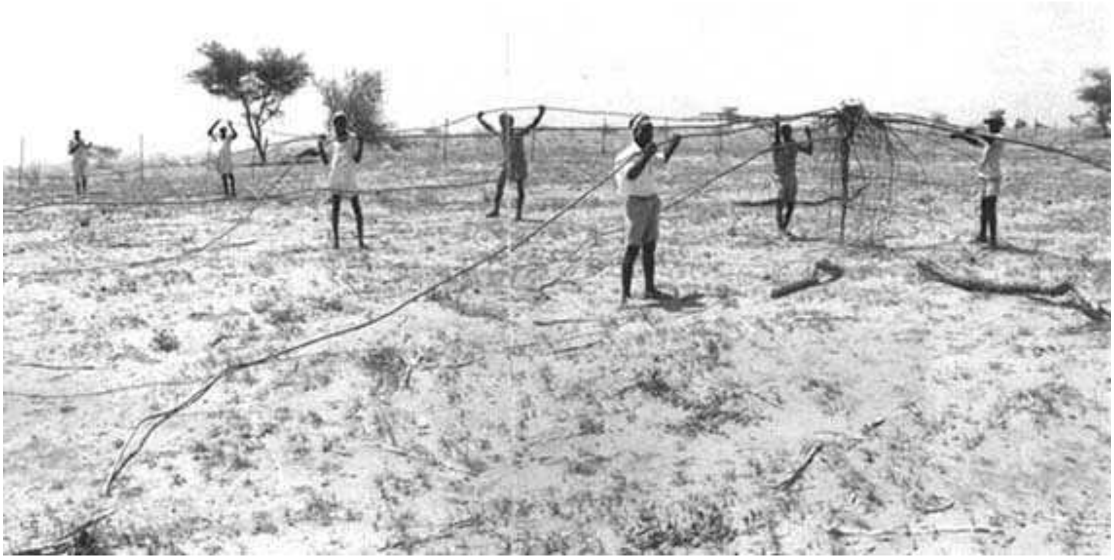
A second interesting facet of the root structure of waddi trees is the occurrence of extensive lateral roots which seem to grow along the interface between the light textured A horizon and heavy textured B horizon of duplex soils. The images below illustrate salient aspects of these roots.

Images Kor-Jent van Dijk

The roots seem to arise at the base of the tree and run reasonably straight just below the soil surface. In the images above a root is being exposed prior to being cut for examination. The root producing tree on the left is a small specimen but the root is well developed and extended at least 3 m from the base of the tree without appreciable reduction in diameter. The root on the right comes from a larger tree and the cut end clearly shows an internal structure comprising an extremely thin bark layer (virtually invisible on the hand specimen), a wide, pale and extremely porous layer and in the centre, a dark core with colour reminiscent of stem heart wood.

Images by Kor-Jent van Dijk

The porosity of these roots is amazing – you can blow air through almost a metre of root without popping a valve, or, as "Fidel" Holtum demonstrates (above right) suck air as well. I would not, however, recommend these roots as a snorkel because the rate of air-flow is modest. We do not know if air flows through the dark central portion of the root, nor have we yet worked out a density for the roots. Similar roots have been described from seven species of *Grevillea* growing in the Kwongan of Western Australia (Dodd *et al*. 1984). The descriptions of these odd *Grevillea* roots are uncannily similar to our own – even to the extent of remarking how easy it is to blow air through them and admitting that they had no idea what function the roots served. Extensive shallow roots are known from other species of *Acacia* – the examples below are from Senegal and are probably produced by *Acacia tortilis*. The function of these roots, beyond the obvious, is also a mystery. Note also the prominent tap root.



The lightness and abundance of air spaces in the root is reminiscent of aerenchyma, a tissue typically thought to function as an aeration mechanism for roots subject to periodic inundation or exposure to otherwise anaerobic conditions. Aerenchyma is not known to occur in *Acacia* (Les Pedley – Mr *Acacia*, or more accurately, Mr *Racosperma* - pers. comm.) and a more thorough anatomical description of these roots is required to set them into a morphological context. The role of aerenchyma is primarily aeration of roots or stems. This is normally needed in wet environments and the waddi tree is not famous for living in swamps. It does, however, grow on a flood plain and survival of trees during extended flooding may be one role the porous roots perform. Given the infrequency of flooding it does not seem likely to be their main role.

The roots may store starch (none has been detected but we have yet to look systematically) or water. If water storage is the primary function it is not likely to be as a seasonal reserve (the volume in the roots is not yet known but given trees transpire ~50 litres a day there would not be many days worth of water contained within them) but is more likely to be a daily reserve that allows the tree to transpire for longer in the day than soil water potentials should allow. If this is the case, I would expect the roots to gradually fill with water during the night and be drained by transpiration as the day progresses. If, as suggested by Dodd *et al.* (1984), the role of root structure capable of storing water is to help maintain cell turgor in the dry upper layers of the soil, the cyclical change in water content might be expected to be muted, if present at all.

To test this we'd need to measure water movement into and out of the roots, water volumes in the roots and, for preference, locate where the water in the roots originates. This latter task may be achieved by examining isotopic ratios in root water and comparing those ratios with ratios measured form ground water, surface water and meteoric water, with appropriate allowance made for fractionation within the tree. We should also have a firm grasp on other physiological measures of physiological activity such as stem flow, photosynthesis and stomatal conductance.

Storage of water in roots is characteristic of some mallee eucalypts, to the extent that they were used to supply drinking water by Aboriginal people. *Eucalyptus coolibah*, too, is alleged to provide water from its roots too (Russel Fairfax *pers. comm*.). At some times of year, the paperbarks *Melaleuca leucadendra* and *M. cajputi* were also used to supply water in the Northern Territory, but in this case the water was tapped from the trunk rather than roots. The spongy tissues of *Adansonia* and *Brachychiton*, which rely on stem water to maintain turgor and rigidity in their otherwise extremely feeble trunks, also contains a heap of water and the anatomy of the stems of these species is, at a superficial level, very similar to that of the surface roots of *Acacia peuce*. You'd probably find the same in *Gyrocarpus americanus* but I have not knocked a hole in that species to have a look (yet …). There is a basic need to thoroughly describe the anatomy of the spongy waddi roots so we can discuss their form and function a little more sensibly. There is also a need to look a bit more comprehensively at water storage in roots more generally and this will be done in time for the 2019 edition of the waddi guidebook.

These gentlemen are draining water from the roots of a mallee (most likely Eucalyptus dumosa*) at Yatala SA, probably in the 1970s.The roots do not look at all spongy to me. Source: Museum of Victoria*

In the mean time, a possible role for the roots is in the water related, but counter-intuitive phenomenon of hydraulic lifting (Mooney et al 1980). Hydraulic lifting refers to the notion that water can be abstracted from deep sources, such as ground water, drawn up the root and then at least a portion of it is leaked out into the soil at a shallower depth where the water is then available for transpiration the following day. This mechanism, as envisaged, is a passive process relying on the changes in soil water potential that derive from the cessation of transpiration as stomata shut down in the evening and over night. Hydraulic lifting is often mentioned in the context of horizontal roots, some of which distribute the water raised from below and some of which are dense root mats which re-absorb the water when needed to support transpiration. It is possible that concentrated fluids found in some horizontal roots may act as an osmotic pump, in much the same way as vacuoles operate at an intra-cellular level.

An important common element in discussions of hydraulic lifting is the recognition that roots can only store a relatively small proportion of the water transpired each day by most trees. This is certainly true of *Acacia peuce*, which requires about 50 l of water per day but the root systems, imperfectly known as they are, are likely to have capacity for a small fraction of that. By moistening soil, a vastly increased volume of water storage can be achieved but at the cost of increased loss to evaporation and losses to other plants which purloin the water brought into the reach of their roots by trees. This addition of water to shallow rooted plants is considered to be a potentially significant ecosystem process in dire need of further investigation.

The reality of hydraulic lifting as a phenomenon is being increasingly recognised and we should be alive to the possibility that the horizontal root systems and root mats seen in *Acacia peuce* may have a role in the process. When you stand in the dust next to your first waddi tree it would be worth thinking about whether hydraulic lifting is occurring and whether you might be able to measure the differences in soil water potential produced in the dry, hard and desiccated soils waddi trees grow in.

Another role played by roots of *Acacia peuce* is as a source of suckers. We have already seen that some stems connect below ground, suggesting that some trees reproduce asexually. It is also common to see haloes of "seedlings" in the vicinity of mature trees and it will be intriguing to see the extent to which the "seedlings" are actually suckers.

The waddi halo effect is well illustrated by this image taken on the Cooraboolka Road. Subsequent excavations could show no subterranean link between these individuals – the little ones appear to be seedlings.

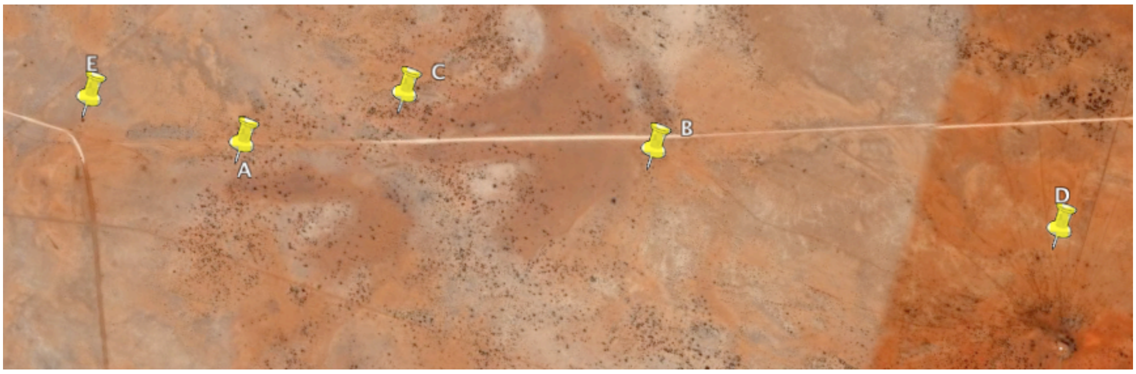
Genetic analyses are being conducted of this matter but until more money is found, molecular work has ground to a halt. Fortunately for us, erosion of top soil can expose shallow roots and provides some clues. Shallow roots leading from large trees near Mudgeacca Bore have been exposed by erosion around a tank excavated next to the bore. In addition to nearby stems joined below ground, one root runs for at least 10m in the direction of a medium sized tree and whilst it would be surprising if the two phenomena are unrelated, excavation suggests they are not. A second shallow root runs towards the tank and dives vertically into the ground, at which point a sucker arises. It is not clear what sort of root produces the sucker but it is clear that *Acacia peuce* can reproduce asexually and it is at least possible that a substantial number of plants in any given stand are clones of one sort or another. It will be important to explore this aspect of population structure more fully and a better appreciation of root involvement is a high priority research goal.

Sucker arising from a shallow root originating form a large tree about 10 m away

The shallow porous roots are a potential weak point in the waddi tree response to trampling by stock. For more information on the piosphere concept, see the document on the subject web site – here it's sufficient to note that grazing and trampling pressure increases exponentially as you approach a water point or other focal point in the pastoral environment. Browsing is a self evident pressure. Trampling is a bit more complex as the nature of the soil, vegetation and the like may respond by becoming compacted (measured by bulk density) or dispersed under hoof impact. The major impact of trampling is in the upper levels of the soil, pretty much where the shallow roots of the waddi tree can be found. Some of the roots are exposed in areas of high trampling (and where surface water flows erode the soil) but we have no idea what, if any, effects trampling has on roots that avoid exposure. This too is a matter which needs some research attention.

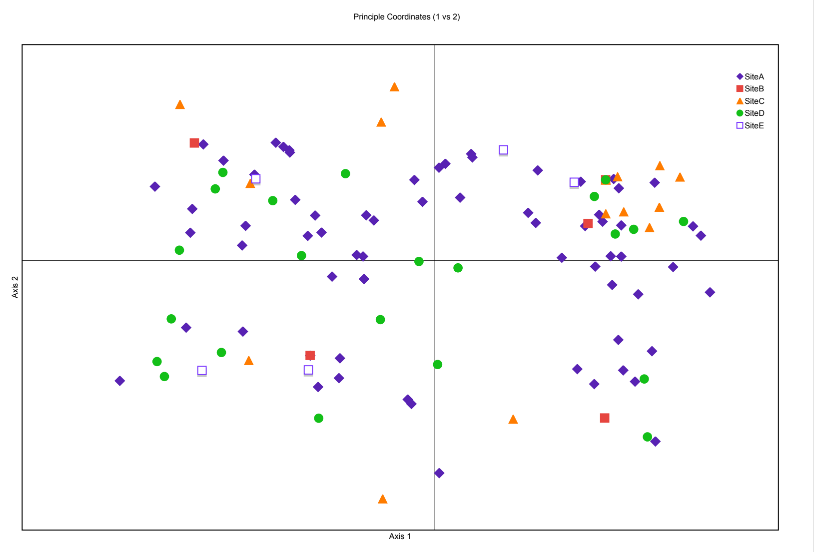
Genetic diversity of *Acacia peuce* at Boulia

In 2007 a study of the genetic diversity using DNA fingerprinting was carried out by students form JCU. The results were very revealing. Using DNA fingerprints, we can assess how similar or different age classes or localities are related to each other. We took samples from five locations up to 4 km apart along the Cooraboolka Road.



Site locations collected in 2007 mapped onto Google Earth satellite image of the Cooraboolka Road

DNA fingerprints revealed a high level of genetic diversity among the more than 100 trees analysed.



Genetic analysis showing relationships among all samples analysed and visualised using Principle Coordinates Analysis plot. Samples closer to each other are more closely related to each other.

There was some evidence of site-specific genetic diversity (purple bars on graph below) but this is within the range expected for the scale of sampling undertaken. The results suggest more common recruitment and interbreeding is occurring in these stands that may have been expected. This calls further into question the longevity and recruitment events of this *Acacia*. Ongoing research into the genetic structure of *Acacia peuce* is underway.

Physiology

The information provided above has been heavily influenced by observational approaches to understanding the nature of *Acacia peuce*. This even applies to what we know of the genetic characteristics of the species, though much of the "observation" is carried out hunched over an electrophoresis tank. Getting to grips with the nitty gritty of how the tree survives is the province of plant ecophysiology and Joe Holtum has made a start in unravelling tow of the fundamental aspects of its physiology – photosynthesis and water use. The following sections are even more of a work in progress than some of the material above but they are an important start both in understanding the waddi tree and are the first systematic physiological measurements on any Australian arid zone trees, let alone mistletoes. Take it away Joe …..

Measurement of Sap flow by *Acacia peuce*

What follows is an explanation of how we measured sapflow in *Acacia peuce*, what the data look like, and what we can interpret at the moment. This will demonstrate what we know about water-use by the plant and what we don't know or cannot be confident about.

We attempted to measure sap-flow in *Acacia peuce*. Using 6 sap flow sensors, we monitored 5 trees for 48 h (tree # 5 had two trunks). We tried to pick trees of differing size. The information on the trees tested is shown in table 1.

Installing a sap flow meter on the trunk of a waddi tree on Mudgeacca Station near Boulia. Note the three probes inserted into the xylem

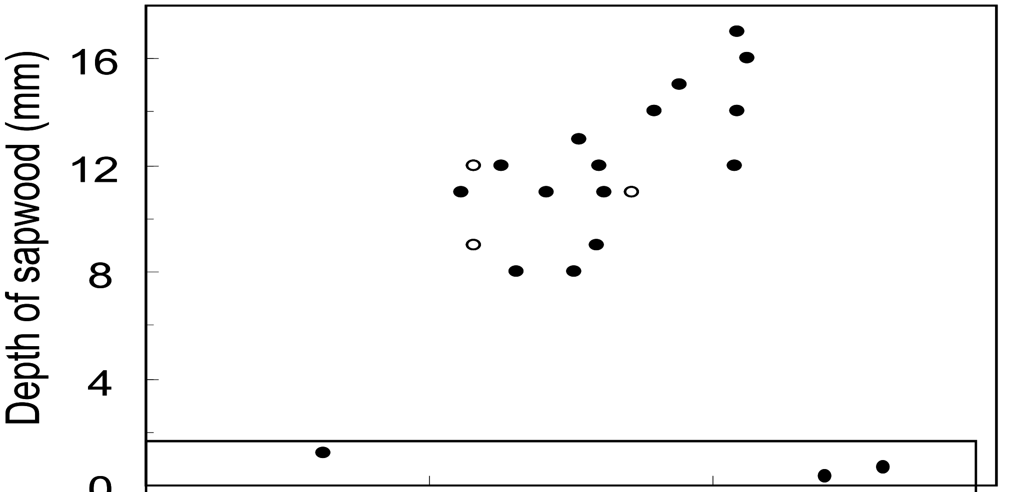
Table 1 Characteristics of *A. peuce* trees at Boulia for which we measured sap-flow

Stem	**1**	**2**	**3**	**4**	**5a**	**5b**
Height (m)	4.29	3.48	5.12	10.76	10.67	10.67
Diam at 1.3m (cm)	7.6	4.8	9.9	24.2	20.3	17.8
Area at 1.3m (cm^2)	45.4	18.1	77.0	460	323.7	248.8
Diam at 0.3m	10.3	6.3	12.4	28.7	29.5	29.5
Area at 0.3m (cm^2)	83.3	31.2	120.8	646.9	683.5	683.5

Each sap-flow sensor contains two measuring thermocouples at different depths. Because the sapwood of *A. peuce* is narrow, only one of the thermocouples in each sensor was actually in the xylem so we obtained one set of data per sensor.

Calculating sap-flow requires knowing the area of the sapwood. To know this, for each tree we have to know the diameter of the tree (DBH) and the thickness of the bark, the sapwood and the heartwood. It is difficult and time-consuming to measure this for each tree. I measured the thicknesses for a number of trees (e.g. Figure 1 and Box 1). I then calculated the areas and fitted equations to them that allow me to estimate the relationships between DBH and area of bark, sapwood and heartwood (Figure 2). The fit is good but we need more measurements to establish a better fit and to have more confidence in the variation.

Figure 1 *The relationship between DBH and depth of sapwood. Solid circles represent single-stemmed trees, open circles represent multiple-stemmed trees.*



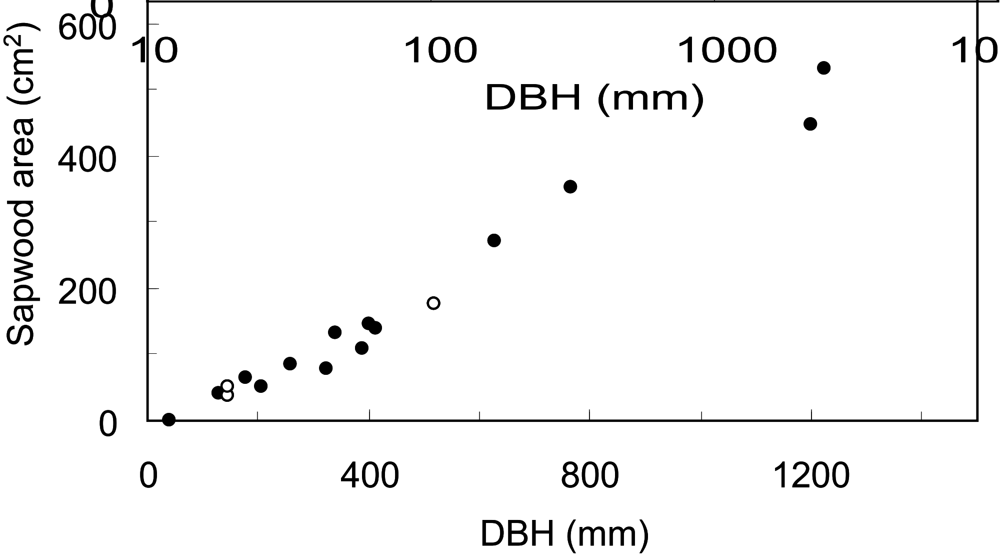


Figure 2 *Relationship between sapwood area and DBH. The equation* $y^{0.5}=a+bx^{0.5}\ln x$*, fits this data, where y = sapwood area that we want to know, x = dbh, a = 0.718541542 and b = 0.093084308. The fit is quite good, DF adjusted* $r^2 = 0.961$*, F value = 420.43.*

BOX 1

How I measured the thickness of the bark, sapwood and heartwood in trees

I measured DBH then, using an adze, I chipped away a small amount of bark at breast height to expose the vascular cambium. I measured the thickness of the bark. I drilled into the wood with a 1 mm sap-flow bit coated in white-out. I stopped drilling when there was an appreciable increase in resistance. I assumed that this increase in resistance occurred at the interface between the sapwood and the heartwood. I reversed the drill, withdrew the bit and measured the distance from the tip of the bit to the point at which there was no visible damage to the white-out

The estimation of sap-flow also requires knowledge of how heat is transferred through the wood, a process that is affected by wood density (mass of wood per unit volume of the wood). We measured wood density for a branch from tree # 5 (Box 2), but we really need data from more than one tree (Table 2). The heartwood density of 1.21 is slightly less than the only literature value I know, 1.425, which was for wood from a thick stem kiln-dried to 12 % moisture (Cause et al., 1989).

BOX 2

How I calculated wood density

We cut off a branch and measured diameter, bark depth, sapwood depth and heartwood depth. I then removed the bark with a chisel. I carefully pared off the sapwood from the heartwood and weighed both (fresh weight). I then put the sapwood into a measuring cylinder of water and measured the displacement, repeating the process with the heartwood. The sap- and heart-wood were then dried for two weeks at 55^{o}C and reweighed (dry weight).

Table 2 Estimation of specific density of sapwood and heartwood from *Acacia peuce*

Wood type	**Heartwood**	**Sapwood**
area cm^2	10.2	1.4

area %	72.8	10.0
sample weight g	20.19	10.11
volume displaced mL	14.1	7.9
wet wood density g mL^{-1}	1.43	1.28
dry weight g	16.997	7.095
dry wood density	1.21	0.90
H_2O in wood %	15.80	29.82

The raw sapflow data from the sensors is shown in Figures 3 and 4. It is ‘raw’ data in that it has not been adjusted to take into account the area of sapwood of each tree and has not been corrected for a number of variables that affect how temperature pulses move through a tree. The corrections required are a thermal diffusivity correction (which depends upon wood density), a wound correction factor (wounding around the sensors affects heat transfer), baseline error and offset (which occur when the probes are not exactly above each other or when xylem is not vertically oriented), probe spacing (not much of a problem as the drill jig ensures that probe-spacing is exactly 0.5 mm).

The manufacturers of the sap-flow gear, ICT International, supply a spreadsheet that assists the researcher to make the calculations required for these corrections. Unfortunately, I am having a few problems with the spreadsheet and have not yet been able to make the calculations, so although I have the raw data, I have not been able to convert it to sap-flows are per tree or sap-flow per cm^2 of xylem. Sorry.

Box 3

Are the raw sap-flow data good data?

In Figures 3 and 4, the raw data for trees 2, 3 and 4 show nice day-night separations of flow and noise levels are low. My guess is that the sensors are well-placed in the xylem of these trees. The data for trees 1, 5A and 5B show less abrupt day-night separations and more noise. I suspect that the sensors may be closer to the edge of the xylem in these trees.

I make these judgements having used the equipment once. This needs to be repeated with more than one sensor in each tree to test the variation.

Although I cannot yet state the water-use per tree, I can investigate the relationships between the raw sap-flow data and tree height, sapwood area, DBH and diameter at ground level (DGH). To do this I need to have an idea of relative sap flow per day for each tree i.e. I need to calculate the area under the curves in Figures 3 and 4. I printed the graphs and cut out the curves (just like in kindy!), after estimating the baseline, and weighed the paper.

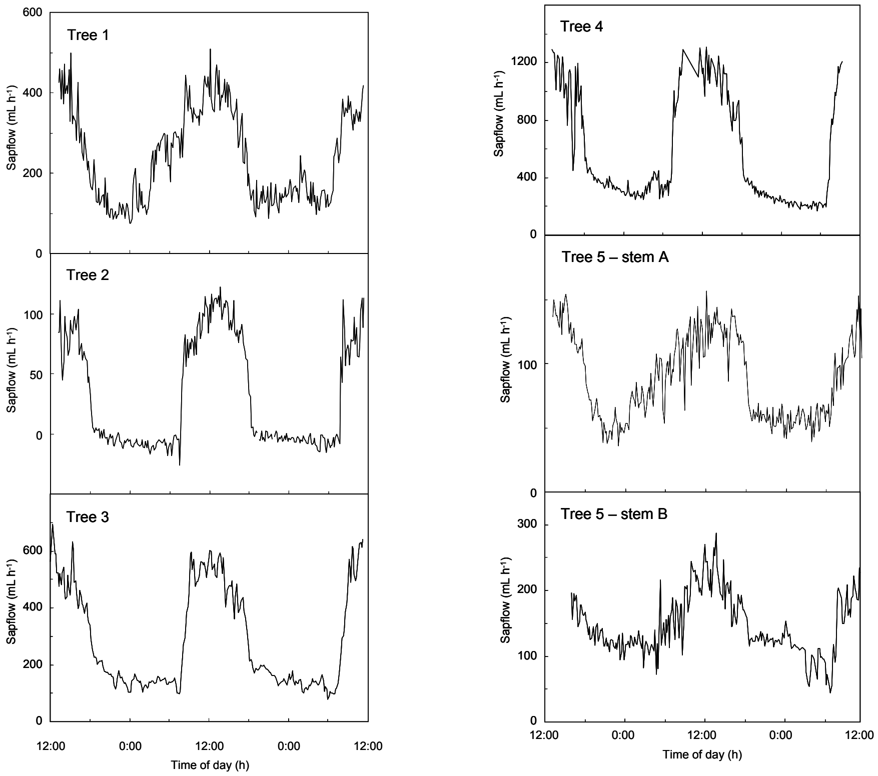


Figure 3 *Raw sap-flow data for* <u>*A. peuce*</u> *trees 1 to 5 described in Table 1. These figures have not been corrected for wood-density, thermal diffusivity, wound correction factor, baseline error or for sapwood area.*

The weights of the paper enabled me to estimate the relative sap-flow per tree (Figure 5). The units are arbitrary, but the values are relative to each other i.e. if the units for one tree are twice another that tree will have exhibited twice the sap-flow of the second.

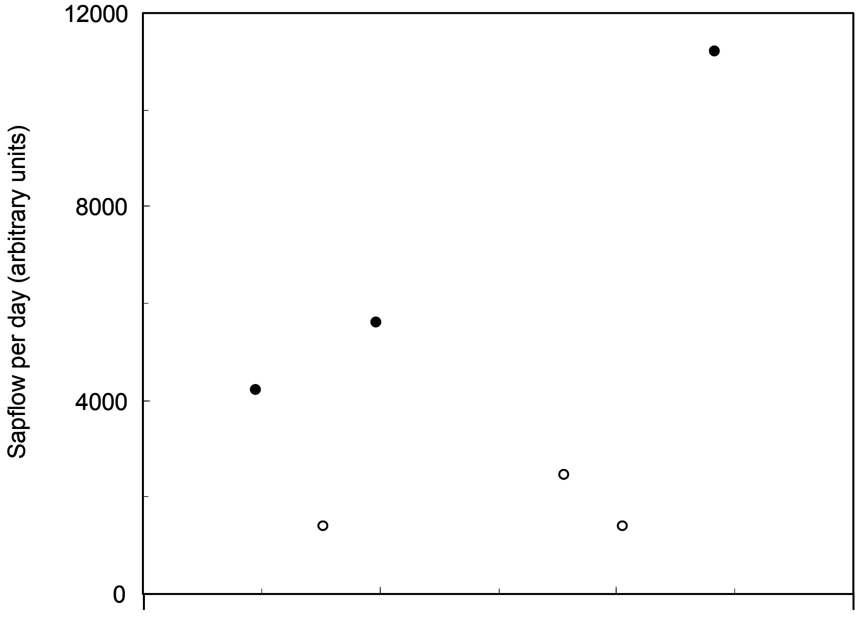


Figure 5 *Sap flow per day as a function of diameter at breast height (DBH) expressed as (A) non-corrected relative arbitrary units, and (B) relative arbitrary units multiplied by the sapwood area (cm^2) for each tree. Closed circles represent trees for which the raw sap flow data looked 'good' (see Box 3); open circles represent trees for which the sap flow data looked 'noisy'.*

Since we know the sapwood area, we can re-plot the relative data on the basis of sap-flow per cm^2 of sapwood (Figure 6).

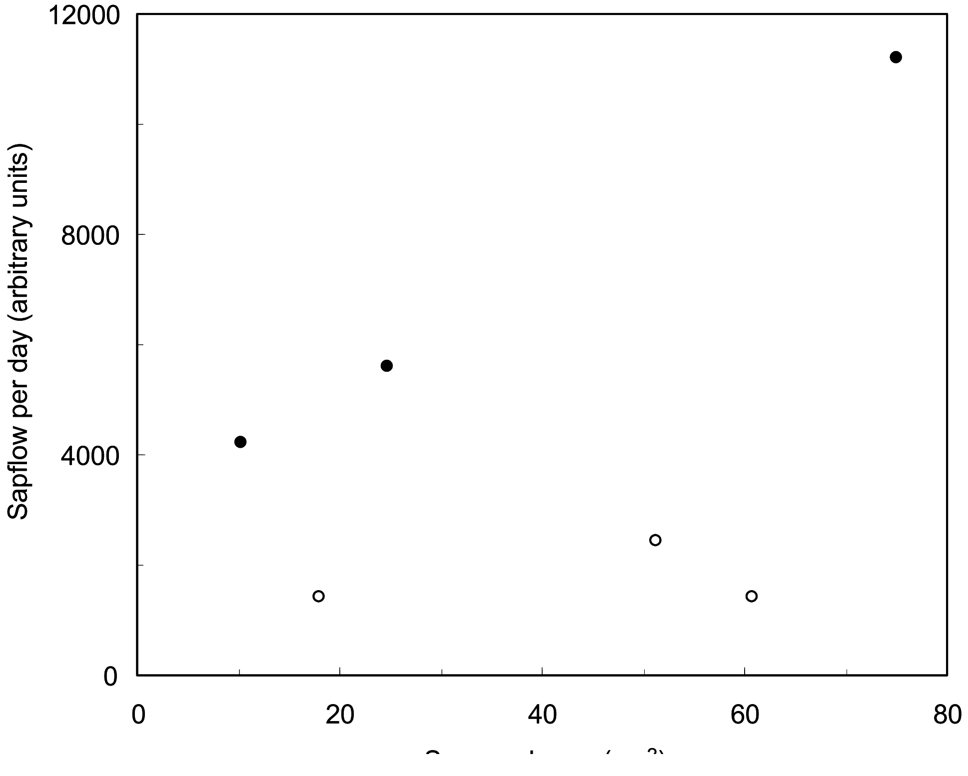


Figure 6 *Sapflow per day as a function of sapwood area. Closed circles represent trees for which the raw sapflow data looked 'good' (see Box 3); open circles represent trees for which the sapflow data looked 'noisy'.*

I have included photos of the waddi branch that was used for the measurements of wood density and a cross-section through a branch of a eucalyptus tree growing at the campsite (Figure 7), note the differences in xylem thickness.

***Figure** 7 Cross-section through (left panel) a branch of A. peuce and (right panel) a eucalypt growing at the Boulia Caravan park. Sap wood is white. Photographs by A. Calladine.*

Synopsis – what we have and the gaps

We have the first sapflow measurements ever made for *Acacia peuce*! Of the 6 measurements we have, three appear robust and three that appear less so. We have not yet been able to assign to the sap-flows the water-flow units that we need to calculate the water-use per plant.

The sap-flow values tell us first, that despite the drought, the plants are photosynthesizing and transferring water from the soil to the air, second that larger trees are pumping more water than smaller trees, third that the amount of water being pumped is approximately relative to tree DBH. The sap-flow technique is working for *A. peuce* and it appears that, with enough measurements of sap-flow coupled with good estimations of population structure and size, we will be able to calculate the amount of water being used by the population.

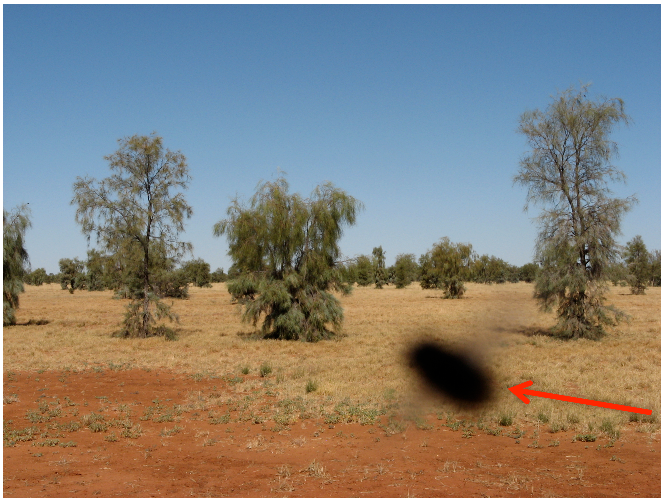
Clearly, we need to

(i) perform many more measurements on plants of different sizes in order to determine the relationship between water-use and tree size,

(ii) measure water-use during drought-wetting cycles,

(iii) correlate water-use with leaf water-potentials and number, or area, of phyllodes, and

(iv) validate the sap-flow method for *A. peuce*. To do this, one puts a sensor in a branch and then cuts off the branch and puts it in a bucket of water, having previously weighed the water (or measured its volume). The bucket is sealed and one tests whether sap-flow measured by the sensor equals water-loss from the bucket.



This is a fly ….

Waddis and bush fly, 2007

* * *

Comparing water-potentials of *Acacia peuce* (Fabaceae), *Grevillea striata* (Proteaceae) and *Lythiana spatulata* (Loranthaceae) growing near Boulia in western Queensland

Ancient History

In May, 2007, our initial foray into the world of *Acacia peuce* at Boulia, I stuffed up the water potential experiment when I packed the incorrect gas bottle connectors! *Mea culpa*! We have had subsequent success, having measured phyllode and leaf water potentials ($\Psi_{phyllode}$, Ψ_{leaf}) of the trees *A. peuce* (waddi tree) and *Grevillea striata* (beefwood) and the mistletoe* *Lythiana spatulata* in September and

November, 2007, and in May, 2008. In the following, I summarise our observations and attempt contextual explanation.

* Mistletoes are parasites, tapping into xylem of the host plant and drawing water and minerals for their own benefit

Experimental protocol

We typically measured five phyllodes or leaves per tree or parasite. For pre-dawn measurements entire leaves or phyllodes, usually 7 per plant (more in the case of *L. spatulata*), were collected between 1 h before dawn and dawn, and were stored in resealable zip-lock bags each containing a piece of moistened sponge (1 cm^3, Wettex). The sealed bags were stored in a dark, preferably cool, container until measurement of $\Psi_{phyllode}$ or Ψ_{leaf} using a pressure bomb (Soil Moisture Inc, OR). For afternoon measurements, tissue was usually collected between 12:30 and 13:00.

Measuring Ψ_{leaf} or $\Psi_{phyllode}$ of *A. peuce* and *G. striata* is relatively straightforward, but measuring Ψ_{leaf} of *L. spatulata* is difficult as the leaves have a tendency to rupture at the base of the petioles when pressures exceed ~ 2.0 MPa. The phenomenon, which occurs before sap is expressed from the xylem i.e. before measurements can be made, is consistent with gas under pressure in airspaces in the succulent blades expanding near the petiole where pressures are lower. Experimentally, we have attempted to circumvent this problem by (i) selecting leaves that are elongate, not broad, and have long petioles, (ii) constraining the top of the leaf and the base of the petiole within or below the rubber grommet that seals the leaf into the pressure bomb, (iii) adjusting gas flow such that the pressure gradient down the petiole is minimized, and (iv) collecting extra leaves of *L. spatulata* in expectation that a proportion will rupture.

Results

Acacia peuce

In September, 2007, the pre-dawn phyllode water potentials (Ψ_{pd}) of *Acacia peuce* exhibited considerable variation, ranging between -1.2 and -5 MPa (Figure 1). Values for individuals varied by up to 1 MPa from day-to-day. Ψ_{pd} of young, juvenile and adult were similar between plants from within each site. Some differences in Ψ_{pd} were obvious: the Ψ_{pd} of plants from site B (redesignated as site F in May, 2008), which is 1 km from site A, were about 1 MPa less negative than plants at site A, and at site A, one juvenile consistently exhibited Ψ_{pd} more negative than -4 MPa throughout a 3-day measuring sequence.

Surprisingly, afternoon phyllode water potentials (Ψ_{aft}) were not always more negative than Ψ_{pd} (Figure 2). They were so for all plants measured at site B (site F) but only for 10 of 26 plants monitored at site A.

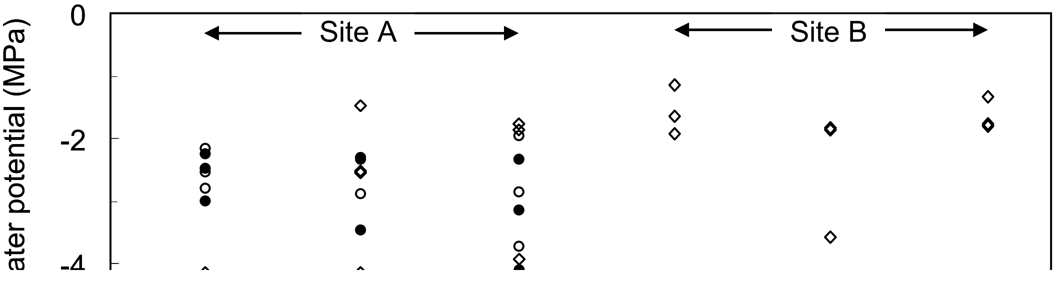


***Figure 1** Pre-dawn phyllode water potentials of lea Acacia peuce in September, 2007. Within each column, a plant is indicated by a symbol. If the same symbol occurs more than once in a column, the phyllode water potential of that plant was measured on more than one day. Note that site 'B' was redesignated as site F in May, 2008.*

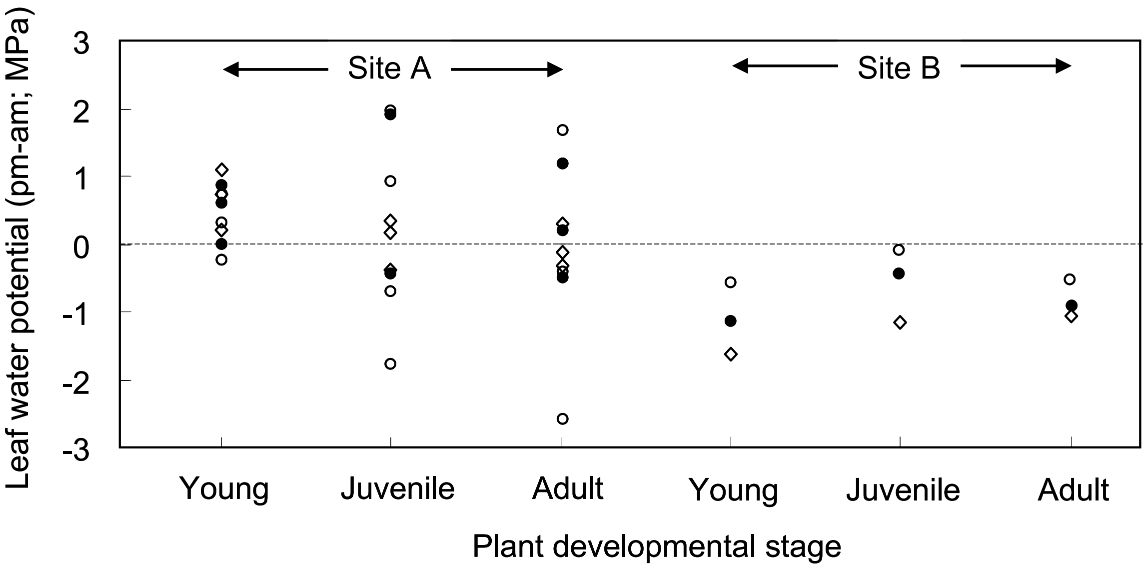


***Figure 2** The difference in phyllode water potentials between pre-dawn and early afternoon in Acacia peuce in September, 2007. Within each column, a plant is indicated by a symbol. If the same symbol occurs more than once in a column, the phyllode water potential of that plant was measured on more than one day. Note that site 'B' was redesignated as site F in May, 2008.*

Comparison of all measurements of Ψ_{pd} for *A. peuce* from site A indicates that Ψ_{pd} of adult, juvenile and young plants were similar between September 2007 and May 2008 (Figure 3). During this interval, on average the 'wettest part of the year, the nearby Boulia aerodrome site received 83.3 mm of rain, a value similar to the 121 year median of 88.99 mm (Figure 4).

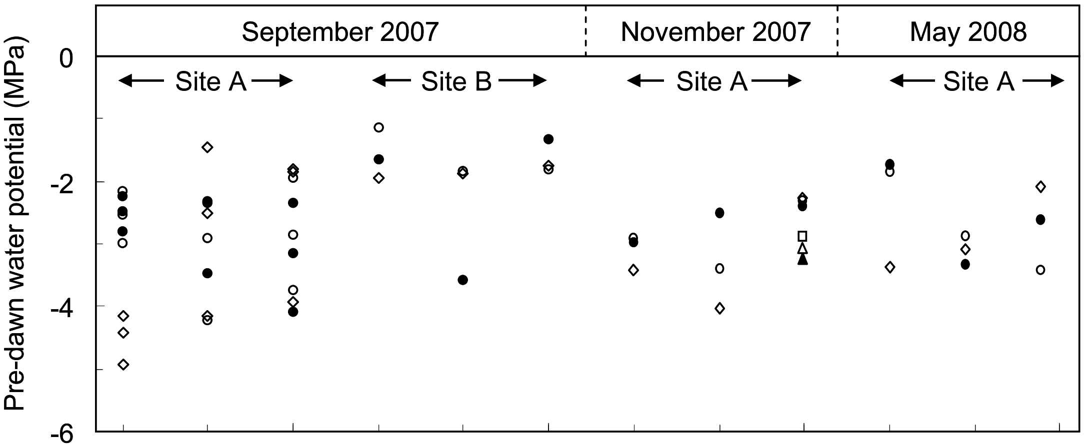


Figure 3 *Pre-dawn phyllode water potentials for Acacia peuce at two sites near Boulia between September 2007 and May 2008. Within each column, a plant is indicated by a symbol which is the average of measurements of 5 phyllodes. If the same symbol occurs more than once in a column, the leaf water potential of that plant was measured on more than one day. Note that site 'B' was redesignated as site F in May, 2008.*

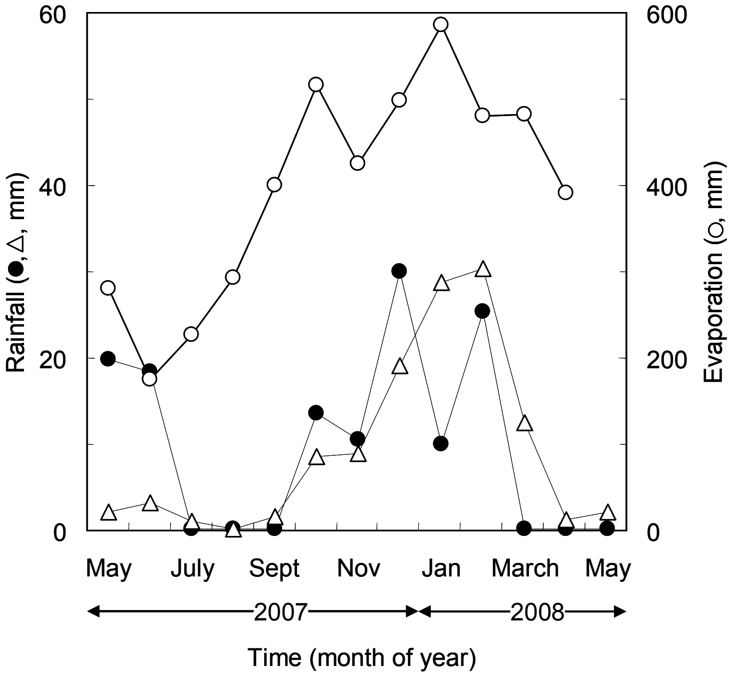


Figure 4 *Rainfall (●) and evaporation (○) between May, 2007, and May, 2008 and the 121 year median rainfall (△) at Boulia aerodrome (22.91°S, 139.90°E, 162 m). 121 year mean and median annual rainfall values are 121 and 120 mm respectively. Note the 10-fold expansion of the rainfall scale compared to evaporation.*

The majority of Ψ_{aft} measured subsequent to the September, 2007, field-trip have been more negative than Ψ_{pd}, generally less than 2 MPa more negative (Figure 5).

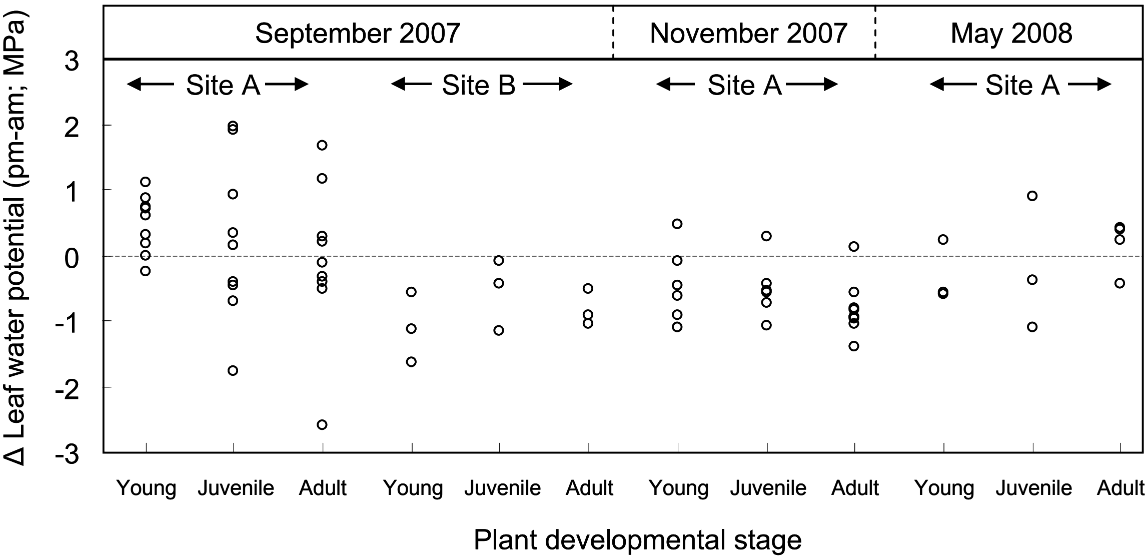


Figure 5 The difference in leaf water potential between pre-dawn and early afternoon in leaves from *Acacia peuce* at two sites near Boulia between September, 2007, and May, 2008. Each symbol indicates the average for measurements of 5 phyllodes of a plant.

Gevillea striata

In comparison to *A. peuce*, the Ψ of fewer trees of *G. striata* have been measured, all that have been were from site A. In general, the Ψ_{pd} of leaves of *G. striata* in September and November, 2007, and May, 2008, was similar and were less negative than phyllodes from *A. peuce* growing at the same site (Figures 4 and 6). For *G. striata*, the majority of Ψ_{aft} values were more negative than Ψ_{pd}, generally less than 2 MPa more negative.

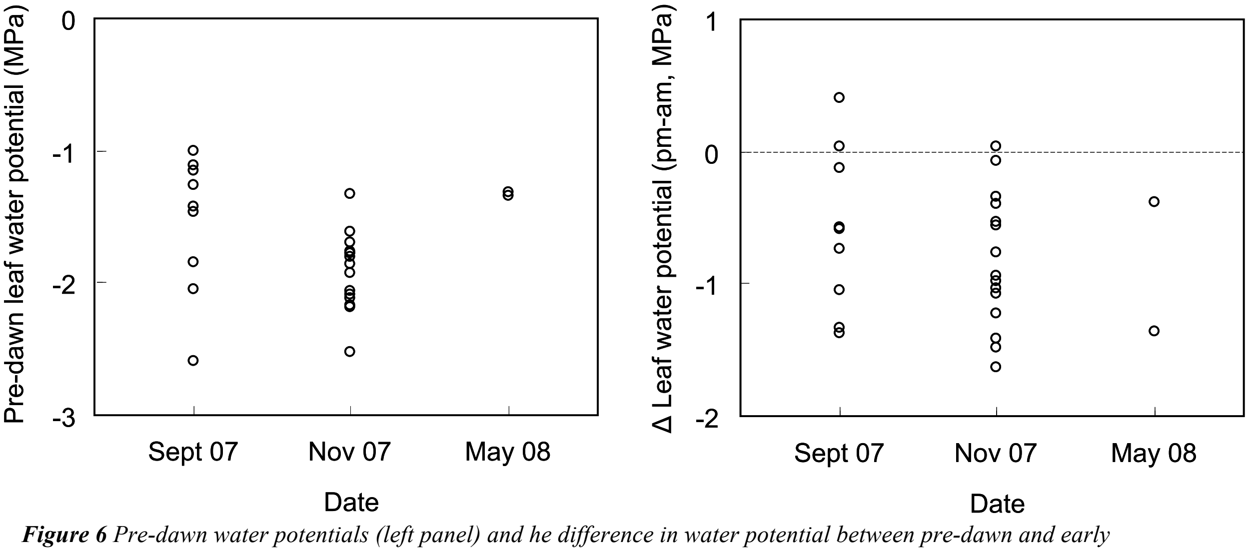


Figure 6 Pre-dawn water potentials (left panel) and he difference in water potential between pre-dawn and early afternoon (right panel) in leaves from Grevillea striata at site A near Boulia between September, 2007, and Ma, 2008. Each symbol represents the average of 5 measurements of a plant.

Lythiana spatulata

The Ψ_{pd} values of mistletoe *L. spatulata* reflected those of their hosts in September, 2007 (Figure 7), November, 2007 (Figures 8 and 9) and in May, 2008 (Figure 10). The Ψ_{pd} values of *A. peuce* were generally lower than those *of G. striata*, similarly the Ψ_{pd} values of *L. spatulata* of *A. peuce* were generally lower than those parasitizing *G. striata*. The differences between mistletoe and host tended to be greater in the afternoon than pre-dawn.

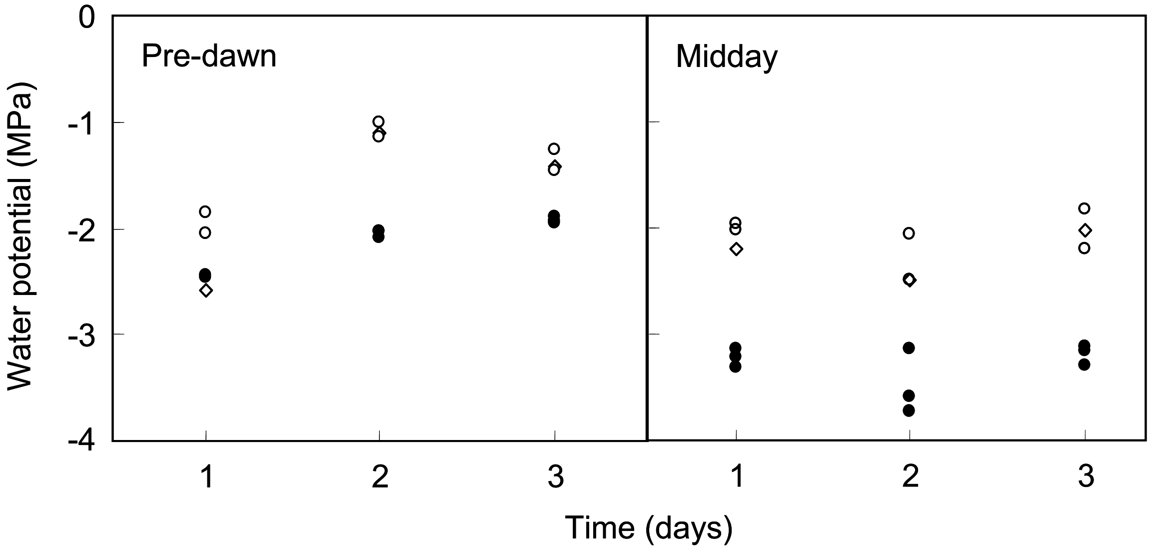


***Figure** 7 Pre-dawn (left panel) and early afternoon (right panel) leaf water potentials of* G. striata *trees (○),* Lythiana spatulata *parasitizing them (●), and near by non-parasitized* Grevillea striata *(◇) for three consecutive days in September, 2007. Each symbol represents a plant for which 5 leaves were measured.*

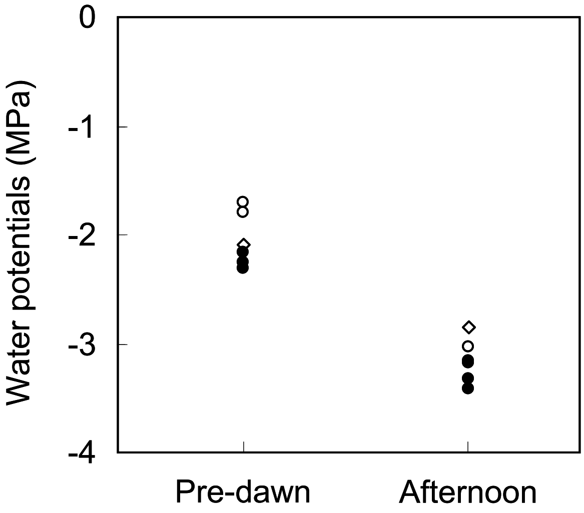


***Figure** 8 Pre-dawn (left panel) and early afternoon (right panel) leaf water potentials of G. striata trees (○), Lythiana spatulata parasitizing them (●), and nearbye non-parasitized Grevillea striata (◇) for three consecutive days in November, 2007. Each symbol represents a plant for which 5 leaves were measured.*

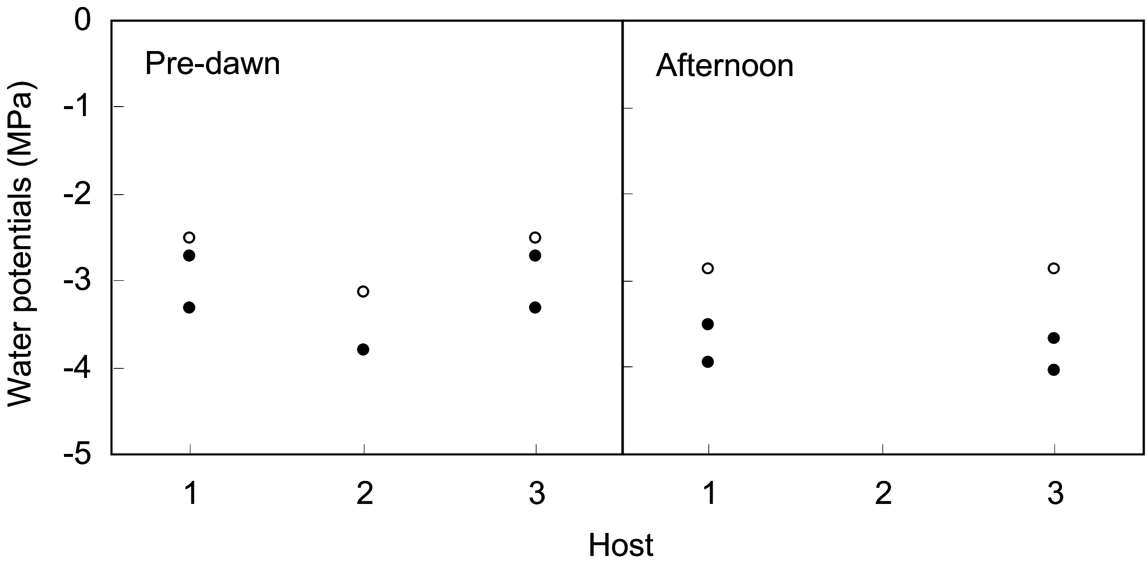


Figure 9 Pre-dawn (left panel) and early afternoon (right panel) leaf water potentials of *Lythiana spatulata* parasitizing 3 *A. peuce* trees (●) and its A. *peuce* hosts (○) in November, 2007. Each symbol represents a plant for which 5 leaves were measured.

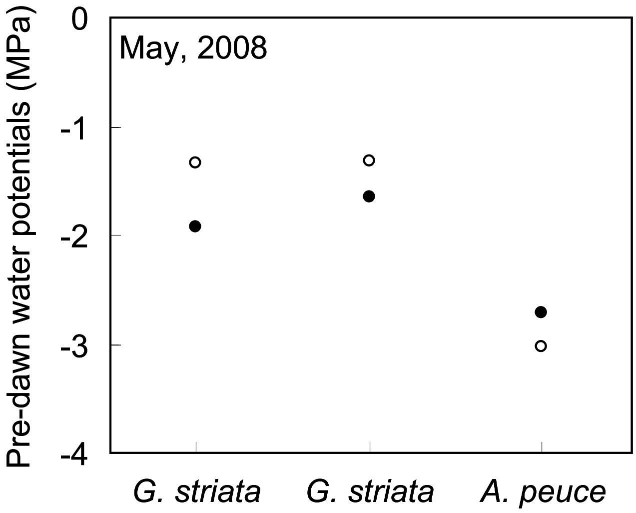


Figure 10 *Pre-dawn leaf water potentials of the mistletoe, Lythiana spatulata (●), and its hosts G. striata or A. peuce (○) in May, 2008. Each symbol represents a plant for which 5 leaves were measured.*

Discussion

Water relations of *Acacia peuce* and *Grevillea striata*

Within the sites we have studied, *A. peuce* and *G. striata* appear to operate at different $\Psi_{leaf/phyllode}$. The trees may be trapping different sources of ground water that are under different tension. Considering that the close juxtaposition of individuals of the species it is unlikely that they are tapping into surface soils with differing Ψ_{matrix}. Rather, it is more logical to propose that *G. striata* taps into ground water with less negative Ψ_{matrix} than that tapped by *A. peuce*. If so, the root system of *G. striata* should extend to greater depths than that of *A. peuce*. This proposition is testable.

If the species are not trapping into ground waters that differ in hydraulic status (I would be surprised if they were!) then the differences in $\Psi_{leaf/phyllode}$ may reflect differences in the way water is extracted by the two species. Different water extraction strategies should be reflected in hydraulic architecture of the roots, stems and the leaves, features about which our knowledge is rudimentary. Do xylem length and breadth, xylem area, Huber values etc differ between the species? To date we have measured $\Psi_{leaf/phyllode}$ in *G. striata* and *A. peuce* but not of any of the other trees at Boulia (e.g. *A. georginae, A. cambagei, A. victoriae, A. papuana, Owenia* sp, *E. camalduensis*) and thus do not know whether the $\Psi_{leaf/phyllode}$ values we have measured for *G. striata* and *A. peuce* are typical.

A. peuce appears to maintain a lower $\Psi_{phyllode}$ than *G. striata*, although we have no observations from plants growing under well-watered conditions. If this is a feature of *A. peuce*, rather than an indicator of stress at the site at which it grows, one might expect that *A. peuce* should lose less water per unit of stomatal aperture than *G. striata* (boundary layer and leaf temperature considerations aside). Perhaps also the low surface-volume ratio of the needle-like *A. peuce* phyllodes would also be conducive to reducing H_2O-loss per unit of surface area. BT3010 students in 2007 noted that *A. peuce* phyllodes contain many thick-walled sclerophyllous cells that would presumably reduce phyllode water conent and may reduce intra-phyllode membrane surface area. We know nothing about the relative leaf/phyllode temperatures or reflectance of either *G. striata* or *A peuce*.

Lythiana spatulata – a parasite of *A. peuce* and *G. striata*

If the Ψ_{pd} values of host trees are in equilibrium with Ψ_{soil}, then the observation that the Ψ_{pd} values of *L. spatulata* were lower than those of their hosts suggests that with Ψ in leaves of *L. spatulata* is maintained at a lower Ψ than Ψ_{soil}. This observation is consistent with the view that leaf cells of *L. spatulata* accumulate osmotically-active solutes. If this was not so, one would have to propose that the stomata of the mistletoes are open and transpiring during the dark, or at least more open than those of their hosts. This proposition is testable using gas-exchange techniques.

The increasing differences between mistletoe Ψ_{leaf} and host $\Psi_{leaf/phyllode}$ during the day and that the decreasing $\Psi_{leaf/phyllode}$ of the hosts and the mistletoe indicate that either the mistletoes lose more water during the day than their hosts or that they manufacture solutes. The first possibility can be tested using gas-exchange techniques and the latter possibility can be tested by measuring Ψ_{solute}.

In September and November, *L. spatulata* parasitizing *A. peuce* appeared stressed. Many leaves appeared to have abscised and those that remained had wrinkled surfaces indicative of reduced cell turgor. In contrast, the mistletoes we observed on *G. striata* generally had healthy canopies containing succulent leaves. We postulated, on the basis of leaf morphology and the Ψ_{leaf} values of ~ – 4 MPa, that the mistletoes on *A. peuce* were close to their minimum sustainable Ψ_{leaf}. However, the condition of *L. spatulata* may not just reflect the state of the host. During our visit to Boulia in May, 2008, although the Ψ_{leaf} *L. spatulata* were similar to those measured previously, the leaves of many plants parasitizing *A. peuce* were in excellent condition whereas many of the plants on *G. striata* appeared to be losing leaves and those that remained were in poor condition. Unravelling this paradox requires quantification of mistletoe seasonal growth cycles.

Historical interpretation

The disjunct distribution of *Acacia peuce* is often remarked upon by the botanically minded. As early as 1946, Crocker and then Crocker and Wood (1947) implicated the formation of the Simpson Desert in fragmentation of a previously wider distribution. Their interpretation remains the preferred option for contemporary botanists who further refer to the insidious northwards spread of sand across a clay dominated surface "comparatively recently". While there remains some currency in these interpretations, a number of modifications are required. We can now place the origin of aridity in Australia and the formation of the desert dunes into a better chronological framework.

The Simpson Desert

The Simpson Desert is one of the great sand deserts of the world. It covers about 170,000 km^2 and is centred on the down-basin reaches of the Great Artesian Basin, terminating against the eastern and northern margins of Lake Eyre and against the raised bedrock of the central ranges. Although, in the public eye, the landscape is defined by serried ranks of enormous red linear dunes, the desert landscape also features extensive clay pans and, in places, drainage lines that either flow into the Simpson and disappear or, like the Diamantina/ Mulligan, wend their way in a circuitous fashion to Lake Eyre. The rivers which reach the lake are found on the eastern side of the desert and are fed by rains originating in Queensland.

As stated earlier, the formation of Simpson Desert is key event in the history of *A. peuce*. Early workers (Crocker, Crocker and Wood) focused on role of desert in fragmenting a formerly contiguous distribution with plants growing on underlying substrate. That substrate was thought to be Cretaceous shales and siltstones of the Winton and Macunda Formations. The sand was thought to form a thin veneer over the Cretaceous - Wilson (1973) suggests sand would be ~1m thick across desert were the dunes to be flattened out. Later coring suggest sand cover is 10-35m thick; there is some intercalation with Tertiary gravel and lacustrine material, but the majority unconformably overlies Winton and Macunda Formations and is unlikely to originate by *in situ* weathering of those rocks. Pell *et al.* (2000) suggest that there are two sand provinces:

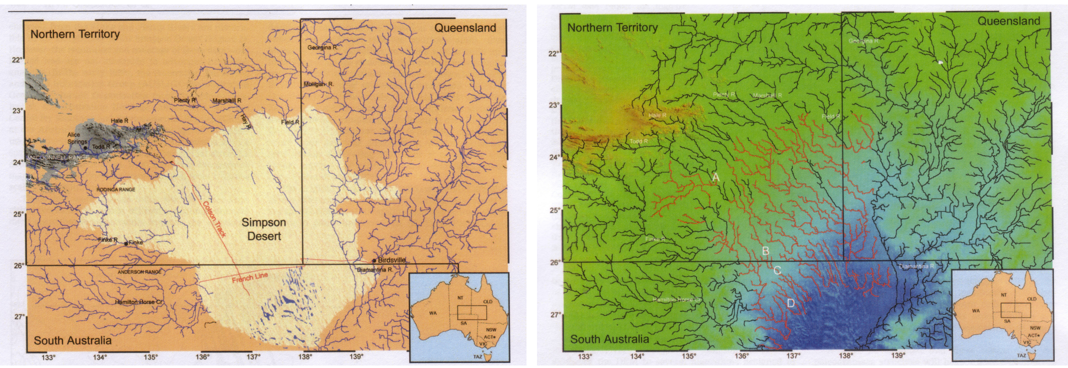
- The SE Simpson, Tirari and Strzelecki dunefields have pale yellowish sand with abundant zircon, garnet and ilmenite; there is minor Fe, as would be expected from the colour of the sand body. These sands are thought to have been derived by deflation of floodplains of major rivers and from the marginal duns around salt lakes.
- In the north and west, the sand is strongly reddened and there is abundant kaolin. These sands are considered to have been derived from underlying sediments after significant weathering and erosion.

Zircon ages suggest the sand bodies have arisen from multiple protoliths hundreds of km from basin and have been transported to the basin by rivers prior to deflation, and re-organisation by aeolian processes. The presence of channels bringing sand into the region would suggest that the pre-desert landscape would not be a million miles difference from the undeniably waddi-friendly setting we see at Boulia.

Recent work has pushed back the age of the Simpson Desert dunes quite significantly and in so doing, raised the probable age of disjunction of *Acacia peuce* should the formation of the desert be a key biogeographical determinant. Palaeomagnetic measurements from sand dunes in the Mallee districts of Victoria indicated that the denes there, which differ in form and, probably, mode of formation from those in the Simpson Desert are all palaeomagnetically normal, and thus post date 730ka BP. Thermoluminescence dating of dunes in the Simpson Desert was originally taken to suggest dune building started at about 100ka, however use of cosmogenic isotopes give a dune initiation age of ~1Ma, with the difference from TL resulting from bioturbation and re-working of the sands. This age is pretty much consistent with the first occurrence of gypsum in the Tirari Formation, which is also indicative of the evolution of groundwater and brine to sulphate saturation under an arid climate.

The mode of dune formation is debatable. Old views (such as those cited by Chuk and other biological personages, emphasise long distance transport of sand and extension of dunes from the south, with sand transported from an up-wind source and deposited in the lee of the dune snout. This process would account for the transgression of some dunes across gibber (which Fujioka *et al*. 2005 suggest date from between 2 and 4 Ma BP) or other non-sand supplying surfaces. The wind rift and vertical accumulation model argues that sand is derived from dune swales and dropped on dune crests, thereby increasing dune height. Long dunes would result from long sediment sources and the dues would remain pretty much in the same place. I do no like this model much. A more convincing model would be wind rift and extension. The sand comes from dune swales but moves along the dune and ends up at dune snout, allowing the dune to lengthen as long as a supply of sand is available. In the wind rift with extension model, the sand moves as a coherent body because of its lower coefficient of friction than that which prevails on a non-dune surface. In reality it is likely that a composite of all the models applies, with dominance of process differing at different times and in different places.

Although palaeodrainage features are subdued and hard to recognise, the branching pattern is well conserved under the desert dunes and can be traced with detailed topographic models and satellite imagery (Craddock et al 2010). Most of major rivers terminating in the desert were tributaries of much larger drainages and modern pans and playas in the desert tend to be located along the paths of the larger occluded streams. This can be clearly seen on the maps below – the map on the left shows the patter of disrupted modern drainage running into the Simpson Desert. That on the right shows the connections between these channels and the palaeodrainage buried beneath the dunes.



Drainage and palaeodrainage through the Simpson Desert (Craddock et al. 2010)

Unlike in the Sahara, these channels buried too deeply to be reflected in vegetation or regolith but they do provide an insight into the substrate on which *Acacia peuce* evolved and, presumably, prospered. And doesn’t it look a bit like Boulia?

The age of these palaeochannels is not known, however they appear to be graded to the 15-20m contour at the northern end of Lake Eyre, something like 40 m above the deepest part of the modern basin. If so, they probably reflect wetter conditions that prevailed during the Tertiary and during inter-glacial episodes throughout the Quaternary. The age of the dunes, and the general drying trend that seems to have taken hold as the Quaternary progressed would suggest that the drainages are older rather than younger. It would not be too hard to envisage them as systems that fed the lake that deposited the (Miocene) Etadunna Formation. The post-Tertiary drying and cooling that initiated formation of gibber deserts at ~2-4 Ma would have been a time of opportunity for *Acacia peuce* (or its ancestor) to evolve (?), spread and prosper on increasingly desiccated floodplains.

Formation of dunes from ~1 Ma and during glacial episodes may have stuffed up the habitat of *Acacia peuce* which was formerly distributed across what is now the Simpson Desert on surfaces that approximate the gibber plains and sand plains they occupy today. If so, the disjunction would have most likely taken place in the 700 ka bracket and would separate eastern and western populations of

Acacia peuce; it is not likely to have affected the area between Birdsville and Boulia as this are is not part of the dunefield.

Desert climates have undergone major fluctuations in sympathy with glacial / interglacial cycles. There has also been a general drying trend superimposed on those cycles. The current interglacial is the driest ever; if *Acacia peuce* was happier under wetter conditions, it may have been widespread in earlier interglacials; the most recent of these peaked at around 125 ka. Any wider distribution driven by climatic processes would have gone into decline post 125ka. It is possible that this might just about be in the right ballpark to explain the disjunction between the populations in Birdsville and Boulia.

An alternative interpretation might be that *Acacia peuce* is a species adaptable enough to have occupied sites within the Simpson dunefield and that its absence today is a product of Aboriginal burning. In this case the disjunct populations would date from less than 46ka. How might you attempt to decide between the options?

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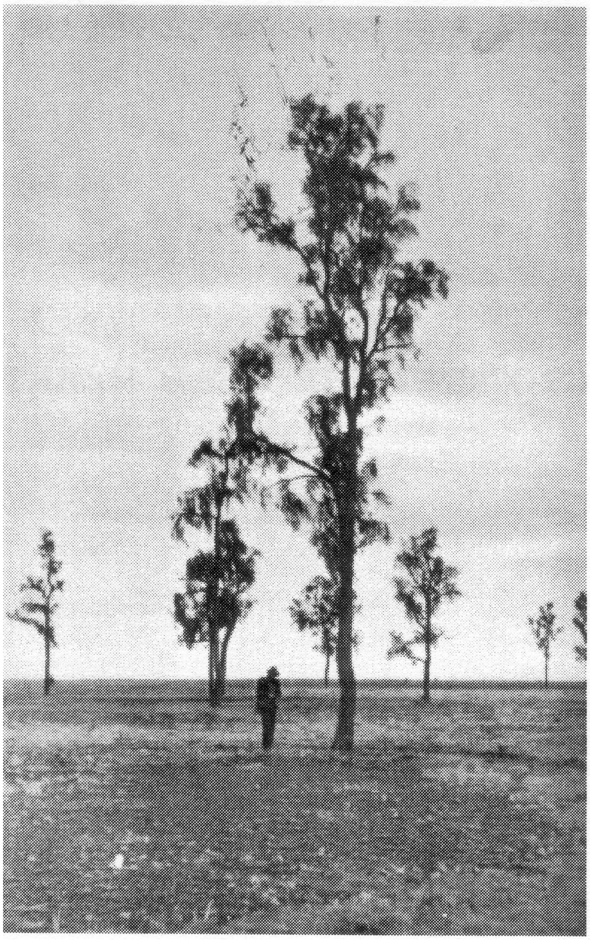

Waddi trees on Old Andado Station 300 km or so southeast of Alice Springs, as seen by the Madigan expedition in 1939. This stand is now included in the Mac Clarke (*Acacia peuce*) Conservation Reserve