ATTACHMENTS

Tree Advisory Committee Meeting
Under Separate Cover

Thursday, 23 February 2023

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Shading properties of native trees

Stephen Reynolds

Charles Darwin University

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Shading properties of native trees: Darwin region

INTRODUCTION

Urban and suburban environments are increasingly likely to experience hotter conditions based on various greenhouse models that indicate that global warming will contribute to warmer temperatures on average both in Australia and across the globe. Warmer than usual conditions are already being experienced, with a string of years with above average temperatures in Australia and an increase in the frequency of extreme heat events (Commonwealth of Australia, 2020). Rainfall patterns have also been changing, northern Australia experiencing wetter than average conditions in recent decades.

The concentration of greenhouse gases in the atmosphere continue to increase, with concomitant effects on the thermal 'blanket' surrounding the earth, trapping outgoing infrared radiation. Gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the main contributors to the enhanced greenhouse effect. Further information on climate change in relation to the Northern Territory is provided by CSIRO (2020).

Land surface temperatures are highest in areas that are open and fully exposed to incoming solar radiation. Urban environments with their roads, concrete surfaces, cleared open areas and buildings are particularly prone to near surface heating, and the heat island effect is well documented. Various heat mitigation strategies have been suggested to reduce the effect of heating in urban situations, and a heat mitigation and adaptation strategy has been developed for Darwin (NT Government and City of Darwin, 2020).

The Darwin CBD acts as a heat island and the suburbs and rural areas show high land surface temperatures where there is a greater proportion of built infrastructure such as rooftops, carparks and paved surfaces, and where there are extensive areas of bare ground (NT Government and City of Darwin, 2020). Cooler areas are found near the coast and in places with dense tree cover (e.g. rainforest and riverine vegetation), other green vegetation, irrigated playing fields, golf courses and gardens.

Amongst the recommendations of the heat mitigation and adaptation strategy for Darwin are planting shade trees to mitigate heat and support action towards increasing tree canopy cover. Planning that incorporates street trees, parks and tracts of trees with dense canopies can help cool urban and suburban areas, and provide amenity and biodiversity benefits (NT Government and City of Darwin, 2020). As noted in the Greening Darwin Strategy (City of Darwin, 2020), Darwin's urban forest plays a major role in cooling through shade.

The major benefit of tree shading is that it is likely to reduce temperatures under the canopy, intercepting radiant energy from the sun and reducing heat loads on people and the environment generally. In addition, reducing the amount of radiation resulting in heating of the ground should reduce radiant infrared heat loss at night, which keeps an area warm into the evening, well after sunset.

Most studies of the effect of tree shading are from Europe or elsewhere in the northern hemisphere, in heavily urbanised environments and with temperate climates. Studies show a benefit of stree greenery on the thermal environment and its influence on personal comfort (Klemm et al., 2015; Streiling & Matzarakis, 2003). There are few studies from tropical environments and none from northern Australia, prior to this study. The effect of shading is likely to be more pronounced and beneficial under (warm to hot) tropical climatic conditions.

A range of tree species have been planted in parks and gardens around Darwin, and over 200 native species occur in the Darwin region. The Darwin region lies in the monsoonal tropics, hence there is a seasonal reversal of winds, bringing rain during the summer wet season and a seasonal drought during the dry season, usually from May until September (Myers et al., 1997). There are a suite of tree species that grow well in a seasonally dry, monsoonal climate. The degree of shading of different species provides an indication of the contribution to ground and air cooling.

This research project was designed to address the question as to what is the nature of the shading properties and thereby cooling benefits of different tree species in the Darwin urban forest ? Dense canopies are expected to provide greater cooling benefits, however, there are no quantitative measures of the canopy cover of tree species in the region, and no published information comparing heating under tree cover and in the open.

Two approaches were used to assess the influence of trees on shading and temperature. To quantify degree of shading, a percentage measure of shade (canopy density) provided by a selection of different tree species was obtained, with a focus on native trees planted or naturally growing in the Darwin region. This information can be used to inform priority tree selection for maximising cooling benefits in the urban forest.

In addition, measurements of surface and air temperatures in shaded and non-shaded sites were used to investigate heating and cooling patterns and the effectiveness of tree shading in a monsoonal environment in two different seasons. This information can be used to assess the effectiveness of shading by trees in comparison to open areas with bare ground surfaces.

Temperature and interception of solar radiation

Radiant energy from incoming solar radiation warms the ground surface and solid objects, which radiate infrared (heat) energy back into the atmosphere. Solar radiation may be direct (or beam), diffuse where it is scattered by the sky and clouds, or reflected from objects such as the ground, trees, walls, roads, etc. (Campbell & Norman, 1998). Radiant flux density is the flux per unit area (Monteith & Unsworth, 2008). In shaded areas or in cloudy weather the flux density is lower.

Humans in hot, tropical environments receive the main heat load from direct solar radiation. Trees and other objects (e.g. roofs) intercept this radiation, providing a cooler environment or microclimate. A proportion of the light penetrates the canopy, depending on the degree of shading, with some radiant energy reaching the ground surface. Radiation from the ground and bare surfaces (particularly those in the sun) results in hotter conditions. This is particular the case close to the ground, where radiant heat can be felt directly and heat transfer by conduction occurs from the ground to the skin.

When humidity is high, the apparent effect of shade is lessened and evaporative cooling is also less effective. Wind (i.e. air movement), air temperature and cloud cover will influence the degree of heating,

Trees provide protection from direct incoming solar radiation, and also from scattered (indirect) radiation. They also absorb much of the radiation that hits the ground, which is re-radiated. These factors reduce the overall heat load impinging on a person (or animal) in the microclimate under the canopy (Figure 2).

Various attributes affect the nature and density of the canopy, for example deciduousness, branching pattern, leaf arrangement and leaf density, as well as the shape, thickness and size of the leaves. Canopy width or circumference influences the overall size of the shaded area, and canopy volume and the overall number of leaves and their density will affect shading.

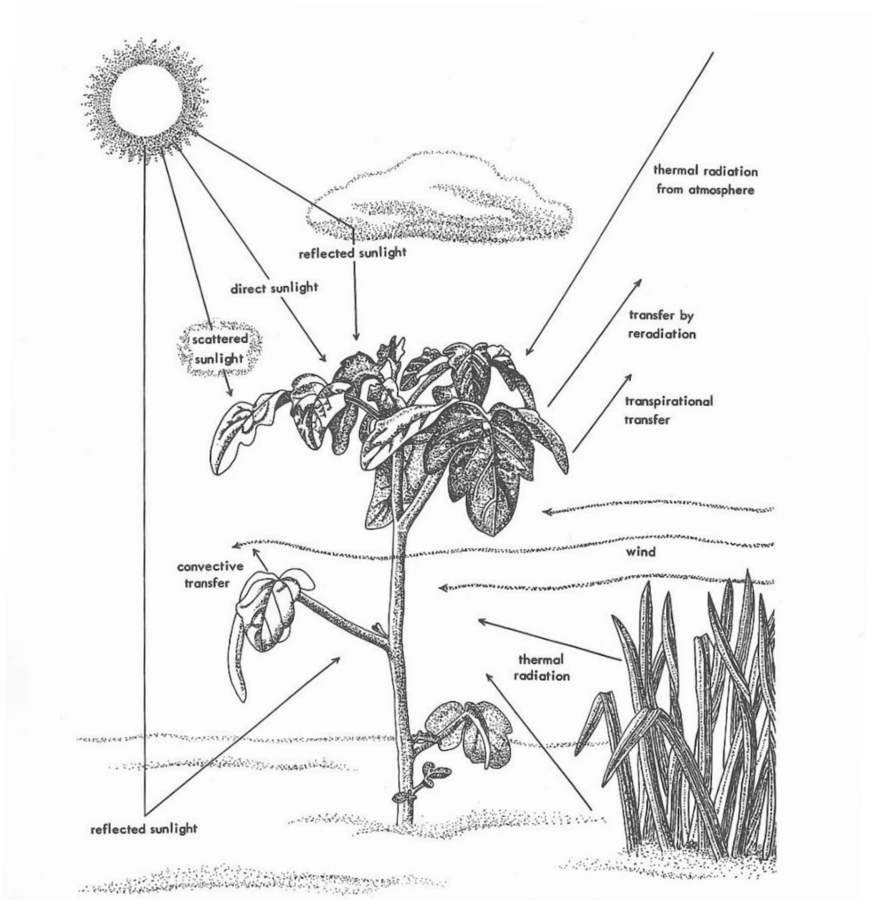

Figure 2.2. Exchange of energy between a plant and its environment by radiation, convection, and transpiration.

Figure 1. Energy exchanges. Diagram from Gates (1980, p. 17).

From the Brazilian comic 'Armandinho', copyright Alexandre Beck.

Translation: 'It's hot It's hot' 'Aahhh' 'It's hot It's hot'

Figure 2. The effect of tree shade in hot climates.

METHODS

Two main approaches were used to assess the properties and influence of shading by trees in the Darwin region – measurement of the shade density of individual trees and assessment of air and surface temperatures in shaded and non-shaded areas.

Tree shade measurements

The shading of a selection of species across a range of canopy cover and shade densities were measured. Canopy cover includes two components - coverage (areal extent) and shade density. Shade density is a consequence of leaf and branch density and layering under the canopy.

There was a taxonomic range of trees sampled across the diversity of species in the area – different families of flowering plants (angiosperms) are represented in the list of tree species (refer to Appendix 1). Nearly all are included in the preferred trees for Darwin list (City of Darwin, 2018). Most are native to the Top End; introduced (non-native) species are denoted with an asterisk (*).

The aim was for a sample size of five or more trees for each species. In some cases eight or more trees were measured to help determine relationships between tree height and shading. For a few species, sample size was less than four, usually for native Top End species growing in savanna woodland environments where it is difficult to find solitary trees or sufficiently spaced trees so that the measurements could be taken accurately.

In order to standardise the measurements, to allow comparison between species, a general method was adopted and trees were selected on the basis of their being greater than 6 m in height (and usually > 8m), i.e. reasonably mature trees. Relatively healthy trees were also chosen, i.e. with an intact canopy and without any major missing branches (leading to 'gaps'), and generally without a major lean. A City of Darwin tree number was noted where present.

Tree height (m) and canopy width (m) were estimated when measuring shading. Diameter at breast height (DBH; in cm) was measured at 1.2m with a ruler. If the trunk was split or the tree had multiple branches, DBH was measured only where the tree had a single trunk at 0.8 m or above.

Four measurements were taken with a densiometer at 0.8 m from the base of the trunk, in four directions (facing outward) at right angles (~90°) from each other. A spherical densiometer, forest Model A was used (Forest densiometers, Forestry Suppliers Inc., USA). These densiometers are widely used to measure forest overstorey density and provides a quantitative percent cover measure. Measures were taken by the same observer to help ensure consisistency. The four measures were averaged for each individual tree.

In general, trees were measured that were well spaced from others. Trees in this situation tend to spread more widely than if they are growing within a forest environment, surrounded and competing with other trees for light. In some cases where trees were close together, cover from adjacent trees was excluded from the measure if they invaded the measurement space.

Measurements were taken during the main part of the wet season (January to March) of 2022, with fully-leafed canopy. This period is recognised in seasonal calendars as the monsoon season, when the majority of rainfall occurs.

Trees were measured at various sites across Darwin city, primarily parks, gardens, school grounds, the university campus and plantings adjacent to car parks, ovals and other recreation areas. A list of sites is as follows (refer also to Figure 3 for locations):

Water Gardens, Jingili
Rapid Creek reserve, Millner
Darwin Cemetery park
Lee Pt. Rd. – park near Salvation Army
Bagot Park and bike area
CDU campus – Blue 5 area
Cahill Park, Nakara and greenbelt
Nightcliff – Bill Bell Park
Nightcliff foreshore – near café
Nakara school grounds

Wong Yung Park, Millner
Casuarina pool - car park
Garamanak Park, Lyons
Wanguri Park
Lakeside Drive parklands
Holmes Jungle picnic area
CDU Casuarina campus grounds – Alawa Hall, cricket oval area
Tiwi oval and park
Casuarina Coastal Reserve – Rocklands Dr.
Rapid Creek foreshore – near footbridge
Airport grounds
Coconut Grove – park on Old McMillans
CDU Casuarina campus – front entrance area
CSIRO grounds, Berrimah
Fannie Bay, park at shops
Howard Springs
Vesteys Lake area

Figure 3. Tree shade measurement locations. Google Earth image.

Temperature measurements

Surface temperatures

We used an IR (infrared or non-contact) thermometer to measure ground (surface) temperatures in shaded and exposed sites. This was done in the middle part of the day to compare under tree shade versus out in the open. Measurements were taken 1/2 hourly, from 10:30 to 15:00. Because the ground radiates heat back up, having cooler ground temperatures under trees is likely to be important to cooling effectiveness.

Locations for surface temperature measurements were in exposed (unshaded) and shaded situations, as follows (Figure 4):

- bare ground area – gravel with sand in full sun
- road surface (single lane sealed) in sun
- grassed area – mowed grass in sun
- single tree - high shade density (*Maranthes corymbosa*), leaf litter
- clump of trees – full shade at base of tree clump, leaf litter. The main shade species was *Carallia brachiata* with *Acacia auriculiformis* in the overstorey, the shrub *Exocarpos latifolius* and some cover of the vine *Parsonsia velutina*
- single tree – moderate density (part shade) under canopy (*Corymbia ptychocarpa*), leaf litter

Figure 4. Surface temperature measurement locations (from top, left to right) – bare ground (gravel and sand), road, grassed area – end of wet season, grassed area – dry season, full shade – *Carallia*, part shade – *Corymbia ptychocarpa*.

Surface temperatures were measured with the IR thermometer at the end of the wet season and in the middle of the dry season at CSIRO Berrimah. Bare ground, full shade and moderate shade were at the same locations as the data loggers (see below).

The IR thermometer senses emitted, reflected and transmitted energy. Emissivity indicates the energy-emitting characteristics of materials. This must be taken into account when measuring surface temperatures. The emissivity of the IR thermometer was set to 0.95, which is suitable for most organic materials. For example, soil has a general value of 0.93-0.96, leaves 0.94-0.98 and water has an emissivity of 0.96 (Campbell & Norman, 1998).

Air temperatures - loggers

Data loggers were used to measure 24 hour cycles of temperature variation under different shading scenarios. HOBO pendant type data loggers (model UA-001-08/64) were deployed. The dataloggers were set to record air temperature at 1.2 m above the ground (standard weather monitoring height as used by the Bureau of Meteorology) and at ground level (approximately 5 cm above the ground). They were placed inside radiation shields to protect the loggers from direct insolation (sunlight) but allow air movement around the logger.

Temperatures were recorded at hourly intervals over a 72 hour period. Loggers measuring air temperature at 1.2 m and near the ground were placed in an open area (full sun; Figure 5), in deep shade (mainly *Carallia brachiata*) and in moderate (dappled) shade (mainly *Corymbia ptychocarpa*; Figure 6). A logger was also placed on the bank of Rapid Creek in densely shaded monsoon forest (under *Carallia brachiata*, *Syzygium angophoroides*, *Carpentaria acuminata*, *Pandanus spiralis*) at 1.2 m height.

The loggers were placed so as to give the best determination of conditions in shade and sun. This facilitates comparison of diurnal temperature variation and average temperatures under different shading regimes. Seven dataloggers were deployed to record over each period.

Dataloggers were deployed at the locations in two different seasons to determine the effect of seasonal differences in temperature. Humidity variation was not measured directly, however, average conditions were determined based on data extracted from the Bureau of Meteorology website for Darwin airport (~3 km distant from the study site).

Times of year for temperature measurements were:

- end of wet season – April to early May. Wet season recession or 'melt down' period. Still humid and relatively high daytime temperatures. Mayilema in Larrakia seasons or Bankerreng of Kakadu region. Early May was chosen so that there was minimal cloud cover; there was some late rain and cloudiness at the end of April 2022.
- dry season – June/July. Cooler conditions at night and lower humidity, south-east winds during the day. Dinidjanggama in Larrakia seasons or Wurrkeng of Kakadu region. Early July was chosen as it had typical, low humidity dry season conditions with no cloud.

The dataloggers were placed at locations at CSIRO Berrimah, and one along Rapid Creek. A relatively secure location was required so that dataloggers were not removed from where they were installed. Shaded and non-shaded sites were selected on the basis of those available in the area, and that were most relevant to tree species shade measures.

Figure 5. Solar shield setup in full sun (data logger inside shield at 1.2 m).

Figure 6. Solar shield setup with dataloggers in partial shade

RESULTS

Tree shade

Tree shade measurements were taken for a total of 228 trees of 37 species. For most species, five or more individual trees were assessed, with up to 13 trees in the case of *Mimusops elengi*, 10 *Maranthes corymbosa* and nine African Mahogany (**Khaya senegalensis*; Table 1). Only two *Canarium australianum* were measured – these were uncommon and mainly in native forest where other trees shaded them.

The majority of tree measurements were recorded in January to March, however, some were taken in April. All trees were fully leafed when measured. Some had a few yellowed leaves later in the season but were measured prior to leaf fall (e.g. *Terminalia ferdinandiana* in mid March). Specimens of the Raintree (*Albizia saman*), which fold their leaves in the evening, were measured mid-morning or mid-afternoon.

The great majority of trees measured were 8 m or more in height (n = 186) and most were 10 m or more (n = 123; Table 1), and many were up to 12 m or more. Twenty two individual trees were 15 m or above. For *Carallia brachiata* and *Diospyros compacta*, most individuals were 7 m or less.

For a number of trees, DBH was not measured as they had multiple trunks arising at under 0.8 m. This was the case for all individuals of *Ficus virens* and *Millettia pinnata* (as indicated by N/A in Table 1), most *Barringtonia acutangula* and individual specimens of other species. DBH varied from as little as 11 cm in *Diospyros compacta*, 13 cm in *Carpentaria acuminata* and 16 cm in *Planchonia careya* and small *Mimusops elengi* to a maximum of 111 cm in a large **Khaya senegalensis*. Large, mature trees were included in the sample for a number of species, notably *Acacia auriculiformis*, **Albizia saman*, *Eucalyptus tetrodonta* and *Tamarindus indica*.

The tallest trees were specimens of Black Wattle *Acacia auriculiformis*, *Corymbia bella*, Stringybark *Eucalyptus tetrodonta* and African Mahogany **Khaya senegalensis*. The greatest canopy width was in these species, Rain Tree **Albizia saman* and Banyan *Ficus virens*. Widths varied from less than five metres in smaller trees such as *Diospyros compacta* and the woodland species *Brachychiton diversifolius* and *Planchonia careya*, to over 15 metres in some individuals of the larger, spreading species and over 20 metres in *Acacia auriculiformis*, **Albizia saman* and **Khaya senegalensis*.

Categorisation

Tree species were placed into shade categories on the basis of separation into Dense (> 80%, Moderate (> 65%) and Sparse (< 60%) canopies. The Dense category which included most species (25 species; Figure 7) was further sub-divided into very dense (~92% or above), dense (88-91%) and moderately dense (80-85%; Table 2). *Nauclea orientalis* and *Millettia pinnata* were borderline very dense (91.6 and 91.8% respectively), but were placed in the sub-category as this is within the error of the measurements. Species with dense canopies included *Alstonia actinophylla*, **Khaya senegalensis*, *Peltophorum pterocarpum* and *Syzygium armstrongii*. The moderately dense sub-category included the woodland and open forest species *Acacia auriculiformis*, *Callitris intratropica*, *Erythrophleum chlorostachys* and *Lophostemon lactifluus*.

Species in the Moderate category (11 species; Figure 8) were mainly eucalypts, paperbarks and other savanna woodland species (Table 2). The Carpentaria Palm *Carpentaria acuminata* had the lowest shade density (23%) and two species of *Corymbia* had values of ~56% and were placed in the Sparse category.

Species such as *Ganophyllum falcatum*, *Maranthes corymbosa*, *Mimusops elengi* and *Syzygium nervosum* consistently had very dense canopies (Figure 7). Large variation in shade density (as identified by high SD values) was observed in *Alstonia actinophylla*, *Corymbia bella*, *C. polycarpa*, *C. ptychocarpa*, *Eucalyptus tetrodonta*, *Melaleuca viridiflora* and *Terminalia ferdinandiana*, most of which are moderate shade species (Figure 8).

Table 1. Number of trees of each species measured and range for diameter at breast height (DBH) and estimated tree height and canopy width. List comprises 37 species in alphabetical order. (P) indicates on City of Darwin preferred trees list, (NR) not recommended, asterisk (*) indicates a non-native species, ² based on 2 or less DBH measures, N/A multi-stemmed.

n	Species	DBH (cm)	Height (m)	Width (m)
7	*Acacia auriculiformis* Black Wattle (NR)	38 – 60	8 – 16	10 – 22
7	**Albizia saman* Rain Tree (P)	44 – 74	8.5 – 13	11 – 22
8	*Allosyncarpia ternata* Anbinik (P)	29 – 52	8 – 14	8 – 13
6	*Alstonia actinophylla* Milkwood (P)	34 – 38 ²	7 – 14	7 – 14
6	*Barringtonia acutangula* Freshwater Mangrove (P)	58 ²	6 – 8	8 – 14
5	*Brachychiton diversifolius* Northern Kurrajong (P)	14 – 27	7 – 11	4 – 8
5	*Callitris intratropica* Northern Cypress (P)	18 – 42	8 – 13	5 – 9
7	*Calophyllum inophyllum* Beauty Leaf (P)	60 – 63	8 – 14	9 – 16
2	*Canarium australianum* Canarium (P)	17 ²	7 – 8	5 – 8
5	*Carallia brachiata* (P)	21 – 26	6 – 10	6 – 12
7	*Carpentaria acuminata* Carpentaria Palm (NR)	13 – 17	7.5 – 11	3 – 4.5
6	*Casuarina equisetifolia* Coastal She-oak (P)	33 – 76	13 – 15	8 – 13
5	*Corymbia bella* Ghost Gum (P)	26 – 47	12 – 16	7 – 12
6	*Corymbia polycarpa* Long-fruited Bloodwood (P)	28 – 47	10 – 15	8 – 13
7	*Corymbia ptychocarpa* Swamp Bloodwood (P)	19 – 31	7 – 12	5 – 12
5	*Diospyros compacta* (P)	11 – 18	5 – 8	5 – 6
4	*Erythrophleum chlorostachys* Ironwood (P)	23 – 41	9 – 13	6 – 12
5	*Eucalyptus miniata* Darwin Woollybutt (P)	34 – 52	13 – 15	10 – 15
6	*Eucalyptus tetrodonta* Stringybark (P)	41 – 50	10 – 16	10 – 13
7	*Ficus virens* Banyan (P)	N/A	7 – 13	11 – 17
4	*Ganophyllum falcatum* (P)	19 – 28	6 – 9	8 – 10
9	**Khaya senegalensis* African Mahogany (NR)	54 – 111	14 – 20	12 – 21
6	*Lophostemon lactifluus* (P)	26 – 28 ²	7 – 11	5 – 8
8	**Mangifera indica* Mango (P)	26 – 48	7 – 12	8 – 13
10	*Maranthes corymbosa* Maranthes (P)	30 – 52	8 – 13	9 – 15
4	*Melaleuca dealbata* (P)	35 – 41	9 – 12	7 – 11
5	*Melaleuca viridiflora* (-)	32 – 38 ²	8 – 15	8 – 10
7	*Millettia pinnata* Pongamia (P)	N/A	6 – 12	9 – 15
13	*Mimusops elengi* (P)	16 – 36	5 – 9	6 – 10
8	*Nauclea orientalis* Leichhardt Tree (P)	23 – 54	8 – 14	7 – 10
8	*Peltophorum pterocarpum* Yellow Flame Tree (P)	25 – 55	6 – 12	9 – 14
3	*Planchonia careya* Cocky Apple (P)	16 – 21	6 – 7	4 – 6
6	*Syzygium armstrongii* (P)	38 – 54	10 – 12	8 – 11
5	*Syzygium nervosum* (P)	34 – 49	10 – 12	10 – 12
5	**Tamarindus indica* Tamarind (P)	35 – 69	9.5 – 13	9 – 14
4	*Terminalia ferdinandiana* Billy Goat Plum (P)	25 – 38 ²	9 – 12	8 – 14
5	*Terminalia microcarpa* (P)	24 – 35	9 – 12	10 – 11

Table 2. Number of trees of each species, average shade density (% cover) and standard deviation (SD), and shade category (Cat) and sub-category. Refer to text for details. Species as in previous Table. Categories are D = dense, M = moderate, and S = sparse shade.

n	Species	% cover	SD	Cat	Sub-category
7	*Acacia auriculiformis*	84.5	2.1	D	moderately dense
7	**Albizia saman*	89.1	2.3	D	dense
8	*Allosyncarpia ternata*	93.0	2.4	D	very dense
6	*Alstonia actinophylla*	89.3	7.0	D	dense
6	*Barringtonia acutangula*	88.0	3.7	D	dense
5	*Brachychiton diversifolius*	76.1	5.4	M	moderate
5	*Callitris intratropica*	82.9	4.3	D	moderately dense
7	*Calophyllum inophyllum*	93.3	2.2	D	very dense
2	*Canarium australianum*	90.6	2.4	D	dense
5	*Carallia brachiata*	95.2	3.0	D	very dense
7	*Carpentaria acuminata*	23.0	6.7	S	sparse
6	*Casuarina equisetifolia*	77.4	3.8	M	moderate
5	*Corymbia bella*	56.3	17.3	S	sparse
6	*Corymbia polycarpa*	56.5	17.2	S	sparse
7	*Corymbia ptychocarpa*	73.3	7.5	M	moderate
5	*Diospyros compacta*	93.7	3.7	D	very dense
4	*Erythrophleum chlorostachys*	80.9	2.5	D	moderately dense
5	*Eucalyptus miniata*	70.5	4.0	M	moderate
6	*Eucalyptus tetrodonta*	66.2	8.2	M	moderate
7	*Ficus virens*	92.7	2.9	D	very dense
4	*Ganophyllum falcatum*	95.0	0.7	D	very dense
9	**Khaya senegalensis*	88.7	2.2	D	dense
6	*Lophostemon lactifluus*	83.5	3.1	D	moderately dense
8	**Mangifera indica*	93.0	2.6	D	very dense
10	*Maranthes corymbosa*	92.4	2.2	D	very dense
4	*Melaleuca dealbata*	71.4	5.5	M	moderate
5	*Melaleuca viridiflora*	67.6	13.6	M	moderate
7	*Millettia pinnata*	91.6	2.1	D	very dense
13	*Mimusops elengi*	95.5	1.1	D	very dense
8	*Nauclea orientalis*	91.8	2.7	D	very dense
8	*Peltophorum pterocarpum*	88.8	2.6	D	dense
3	*Planchonia careya*	73.1	4.2	M	moderate
6	*Syzygium armstrongii*	87.5	2.2	D	dense
5	*Syzygium nervosum*	95.2	2.3	D	very dense
5	**Tamarindus indica*	94.8	1.7	D	very dense
4	*Terminalia ferdinandiana*	70.2	8.0	M	moderate
5	*Terminalia microcarpa*	93.1	2.6	D	very dense

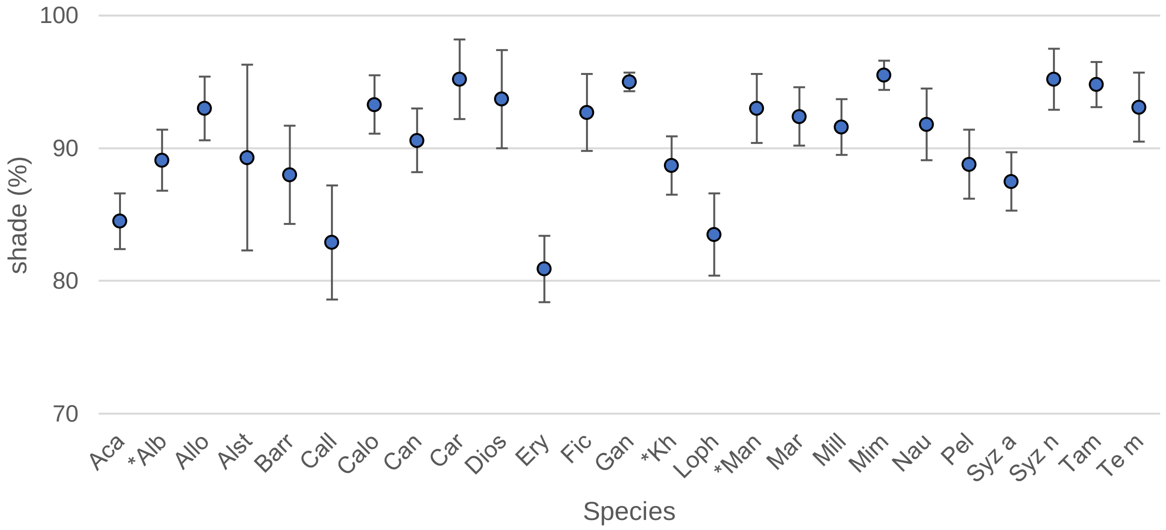

Figure 7. Shade densities (mean with SD error bars) of tree species in the Dense category (n = 25). Species in alphabetical order, as in Table 2.

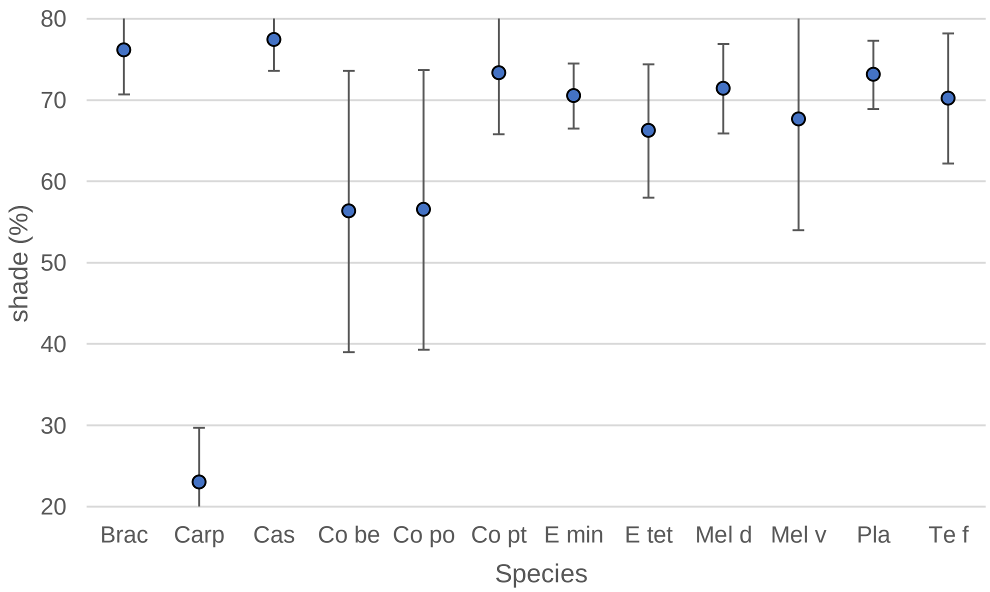

Figure 8. Shade densities (mean with SD error bars) of tree species in the Moderate and Sparse categories (n = 12). Species in alphabetical order, as in Table 2. Note difference in scale (%) from Figure 1.

Temperatures

Temperatures in full sun, part shade and full shade were recorded during the end of wet season (or wet season recession) period and in the middle of the dry season. Air temperature data is presented for 72 hours from midday 3rd to 6th of May and midday 5th to 8th July 2022. Surface temperatures are for the middle part of the day on the 4th May (end of wet) and 6th July 2022 (dry season).

The shade density under *Carallia brachiata* was 93% and under *Corymbia ptychocarpa* was 76%. The full sun, road and grassed areas experienced sun for most of the day, including the surface temperature measurement period.

Surface temperatures

End of wet season

Weather conditions were mainly bright and sunny for the surface temperature (IR thermometer) measurements on 4th May 2022. Mid-level cloud cover in the morning was mostly gone by 11:00 and had cleared by midday. Some patchy cloud developed after 13:00 (maximum 3/8) and there were light winds up to 20 km/h in the afternoon. Air temperature (BoM, Darwin airport) was above 32°C from 11:00 onward and reached a maximum of 33.9°C at 13:30 and 14:00 (Figure 9, 10). The previous evening minimum temperatures reached 25°C at 5 a.m. The day was moderately humid – humidity was 56% at 10:30 and dropped to 43% in the afternoon with the increase in air temperature. Day length was 11hr 38 minutes with sunrise at 6:54, sunset at 18:32 and solar noon at 12:43 (GMT + 9:30).

The road surface in full sun was usually one to two degrees warmer than bare ground in full sun (Figure 9). However, the bare ground varied more in temperature, depending on gravel and sand components. Bare ground peaked at 56°C and the road surface at 57°C, with the hottest temperatures at 14:00 and 14:30. There was a gradual increase in surface temperatures in the morning, with a fall at the 13:00 measurement due to a patch of cloud. The grassed area in full sun was considerably cooler, being 10-15°C lower than the road temperature. Bare surfaces were consistently 15-20°C (or more) hotter than air temperatures. The temperature of the road surface was consistently high across the site, with relatively little variation – the thermal image showing temperatures of 50 – 53°C during the middle of the day (Figure 11a).

In shaded areas the surface temperature was within 1-2°C of air temperature (Figure 10). The densely shaded areas experienced the drop in temperature with cloud at 13:00, and in the Carallia shade, a Scrubfowl turned the leaf litter, exposing cooler material at 13:30 and 14:00. Where exposed by the Scrubfowl, the soil under the leaf litter was at 25-26°C, hence around 5°C cooler than the surface of the leaf litter. The dappled shade under *Corymbia ptychocarpa* received more sunlight and was consistently warmer than dense shade. The leaf litter in dappled (part) shade experienced variable temperatures depending on the degree of shading, as seen in the thermal image where the blue, cooler area is shaded by the trunk of the tree (Figure 11c). Part sun resulted in higher surface temperatures from 13:30 and at 15:00 the area was fully exposed to the sun, resulting in greatly increased temperature (mean of 48°C; Figure 10).

Dry season

Prior to the dry season surface temperature measurements there was a period of cloudy weather with some rainfall. This unusual system (for the dry season in Darwin) resulted in cool days with extensive cloud and maxima less than 27°C. As a result, the surface temperature measurements were postponed to the following week. By this time the weather had transitioned to more typical conditions, with low humidity (RH < 30% at 3 pm), cool nights and clear skies on the 6th July. There were light winds (13-20 km/h) from the south-east during the day, no cloud and some smoke to the east in the afternoon. Air temperature (BoM, Darwin airport) dropped to a low of 16°C overnight. It was 23°C in the mid-morning period and approached 27°C in the afternoon (Figure 12, Figure 13). Day length was 11 hr 25 minutes with sunrise at 7:08, sunset at 18:33 and solar noon at 12:51 (GMT + 9:30).

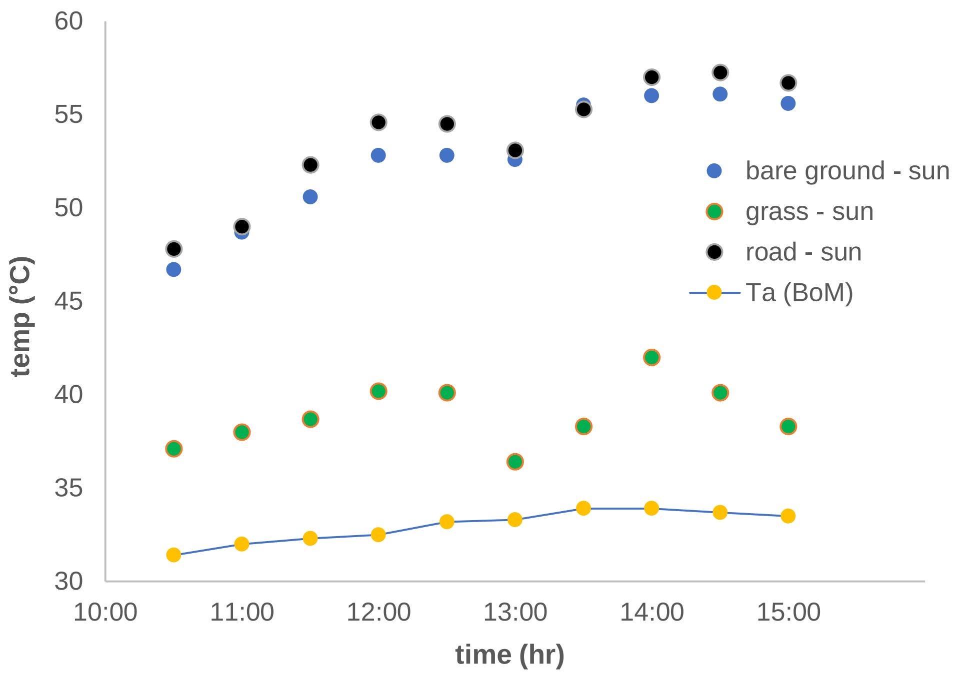

Figure 9. Surface temperatures at the end of the wet season in full sun and air temperature (BoM Darwin airport), 4th May.

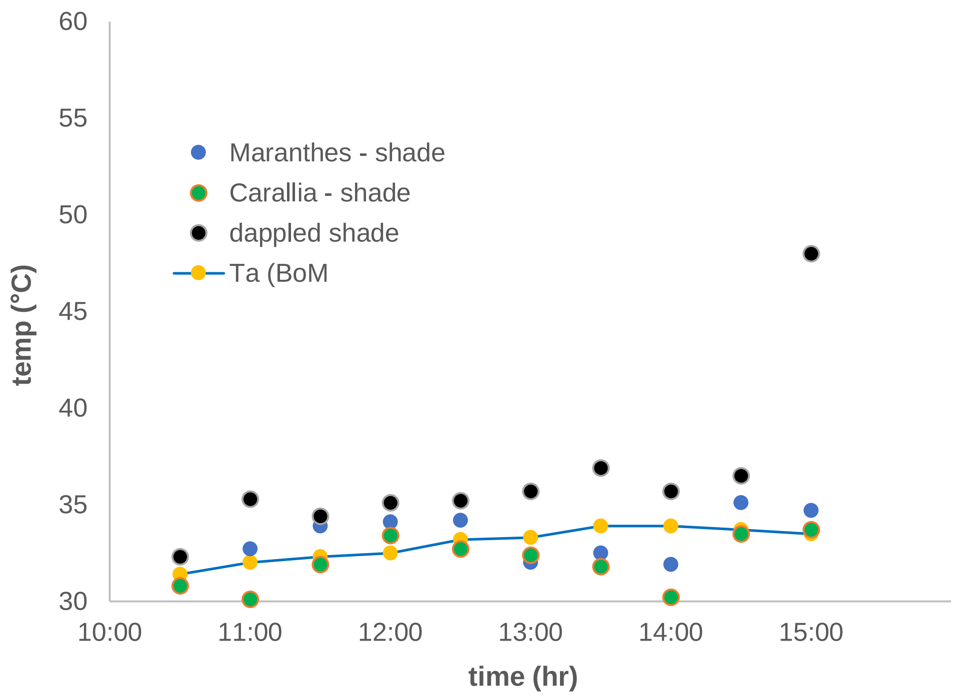

Figure 10. Surface temperatures at the end of the wet season in dense shade or part shade and air temperature, 4th May. Note that the scale is the same as in the previous Figure.

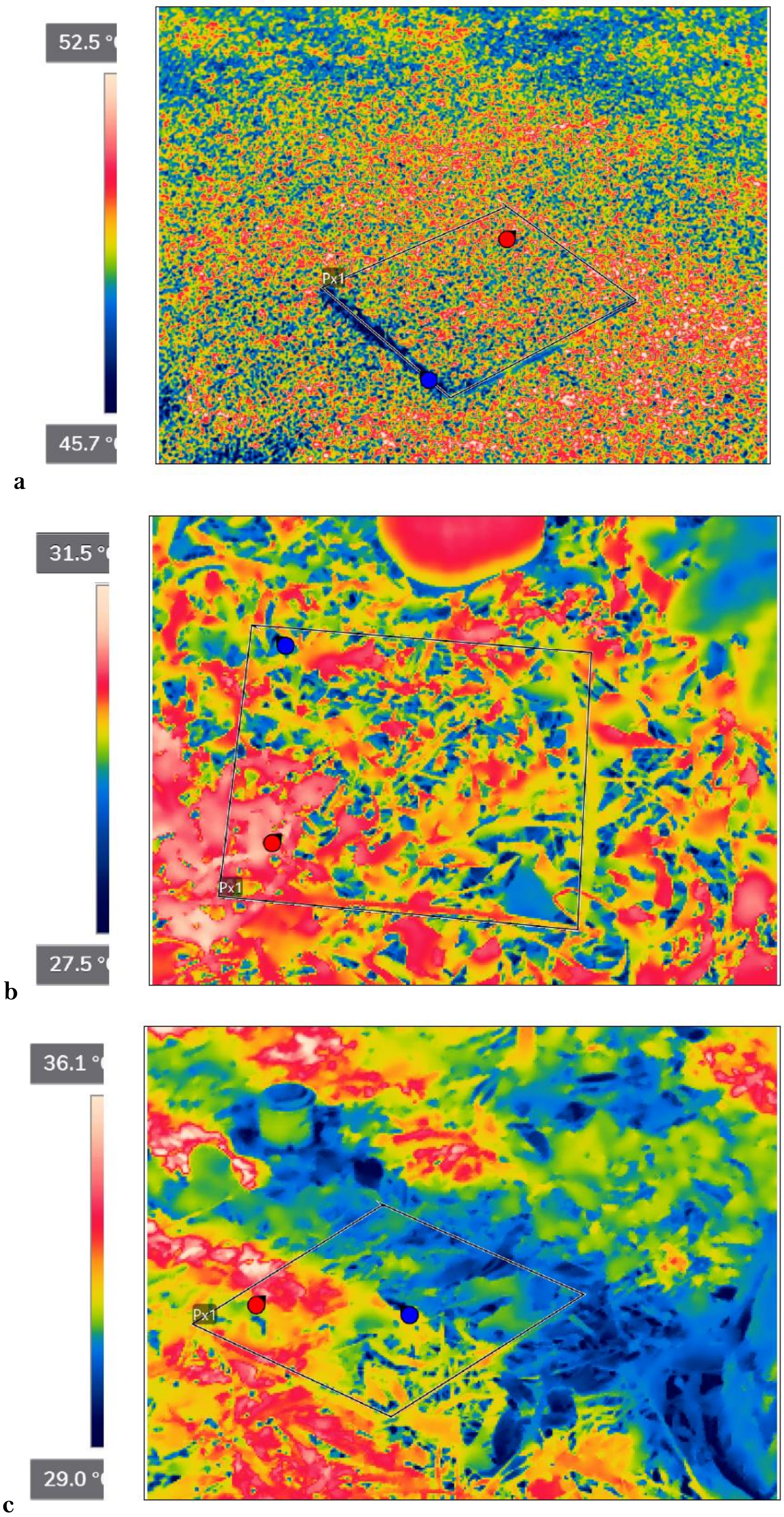

Figure 11. Thermal images showing variation in peak temperature at a microscale, 4th May (end of wet season); a) road in sun, b) full shade (*Carallia*), c) part shade. Note different temperature scales associated with each image. Images courtesy of Steve Cook, CSIRO.

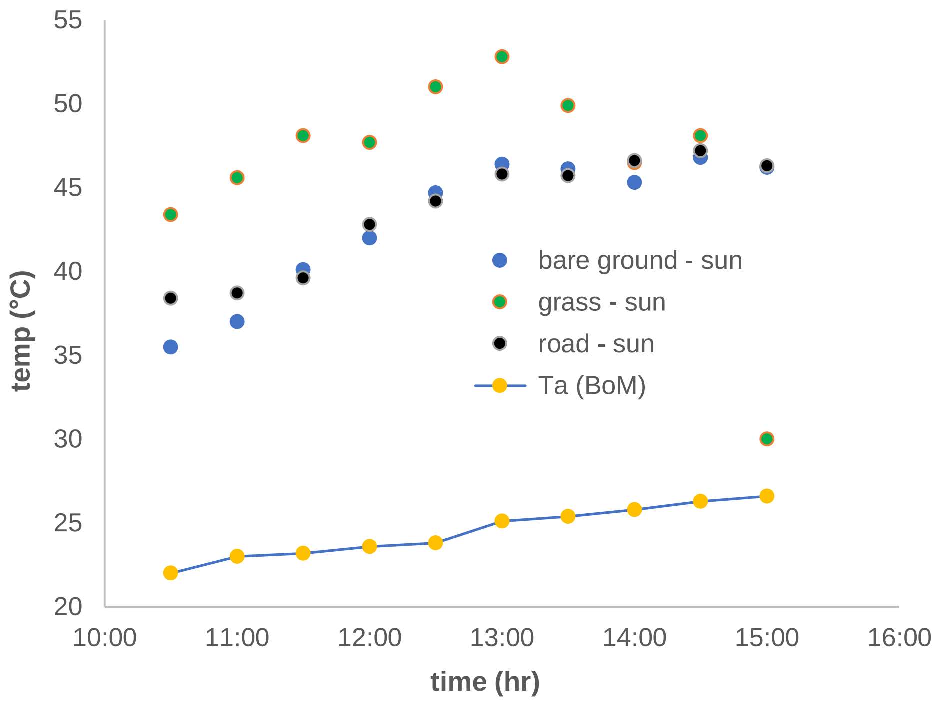

Figure 12. Surface temperatures in the dry season in full sun and air temperature (BoM Darwin airport), 6th July.

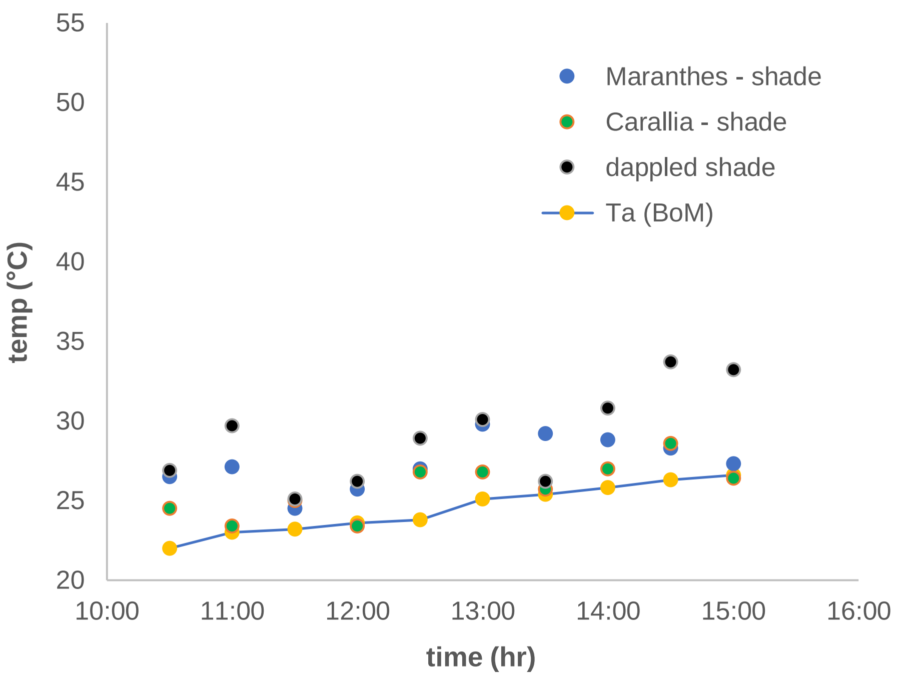

Figure 13. Surface temperatures in the dry season in dense shade or part shade and air temperature, 6th July. Note that the scale is the same as in the previous Figure.

There was a gradual warming of exposed surfaces from from mid-morning, increasing from the cooler temperatures overnight. Surface temperatures in the dry season on bare ground and on the road in full sun were less than 40°C at 10:30, and reached a maximum of 47°C at 14:30 (Figure 12). Bare surfaces were consistently 15-20°C warmer than air temperature. The measurements for grass in the sun were up to 50°C, with the grass having browned off (Figure 4). The high recorded temperatures may partially be due to the high reflectivity of the grass, which may have influenced the IR measurements. Surface temperatures of bare surfaces were consistently 6 to 8°C less than at the end of the wet season.

In the shaded sites, surface temperatures were below 30°C for the entire day in the fully shaded *Maranthes* and *Carallia* sites, and remained below 27°C for most of the day in the *Carallia* site. Temperatures in full shade remained slightly higher than air temperatures, generally within 2-4°C. In the partially shaded site, temperatures reached 33°C in the afternoon (maximum at 14:30) as the site became fully exposed to the sun.

Air temperatures

End of wet season

Air temperatures in full sun at 1.2 m reached 35°C during the middle of the day, and dropped to 25°C around 5 or 6 a.m. (Figure 14). Close to the ground air temperatures exceeded 40°C on the first two days, and were also warmer than the temperature at 1.2 m at night. At night (22:00 to 05:00) temperatures were 1 to 1.5°C warmer and during the day (10:00 to 17:00) were 2 to 4.5°C warmer near the ground. The effect of heating of the ground thus has an effect on air temperature close to the ground.

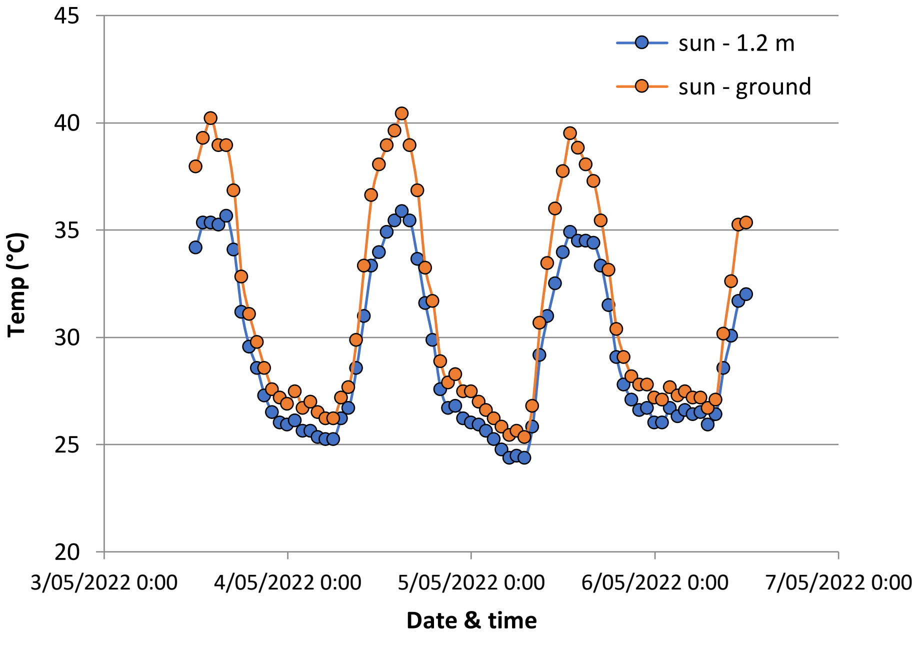

Figure 14. Air temperatures end of wet season in full sun at 1.2 m and at ground level, 3 – 6 May. Measurements are at hourly intervals.

In part shade produced by *Corymbia ptychocarpa*, air temperature near the ground exceeded 40°C for brief periods during the day; these coincided with the late afternoon when the logger (shield) was in full sun. Ground temperatures were higher than temperatures at 1.2 m above the ground, with maxima of 35°C and minima of 24°C at 1.2 m (Figure 15). Air temperature was consistently warmer at ground level.

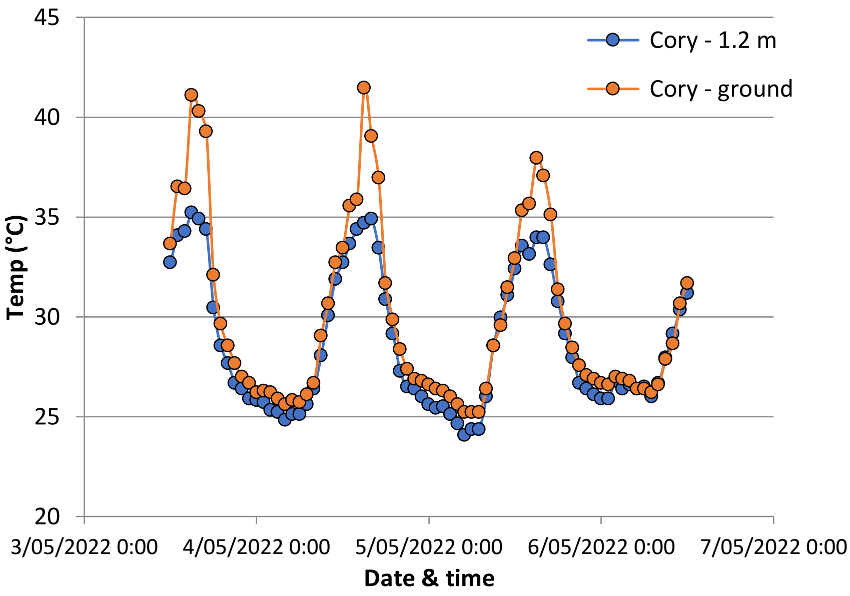

Figure 15. Air temperatures end of wet season in partial shade at 1.2 m and at ground level, 3 – 6 May. Measurements are at hourly intervals.

In contrast to full sun, full shade air temperature at 1.2 m and near the ground did not exceed 35°C (Figure 16). Temperatures near the ground were consistently lower during the day, by an average of ~1°C (10:00 to 17:00). At night the near ground air temperature was slightly warmer than at 1.2 m.

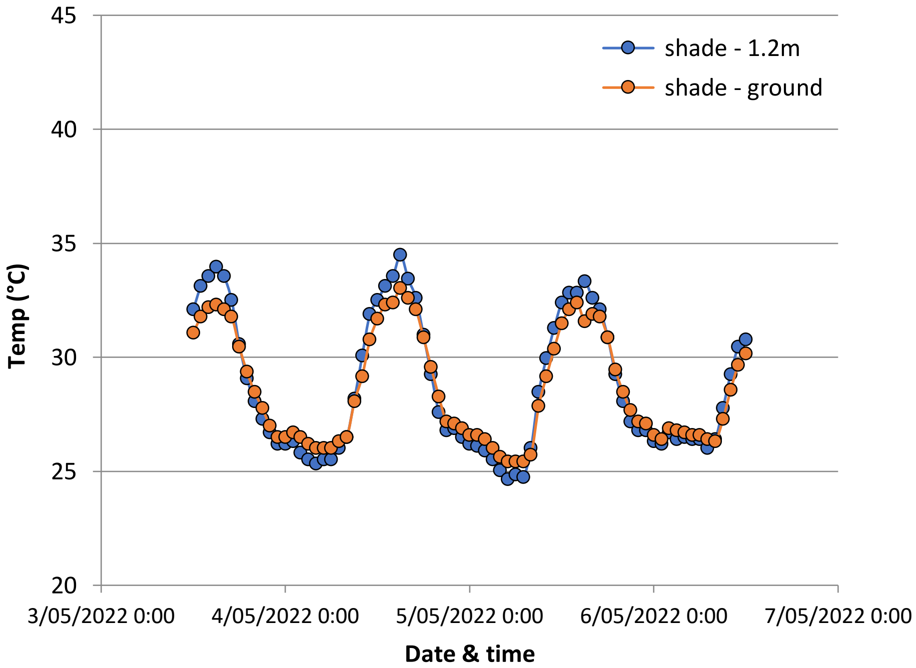

Figure 16. Air temperatures end of wet season in full shade at 1.2 m and at ground level, 3 – 6 May. Measurements are at hourly intervals. Note that the scale is the same as in the previous Figures.

The difference between near ground temperatures in strong shade and in full sun are illustrated in Figure 17. The difference varied from as much as 8°C during the day but was usually less than 1°C at night. On the 4th May the average difference in temperature during the day (10:00 to 17:00) was 6.1°C and at night (22:00 to 05:00) was 0.5°C.

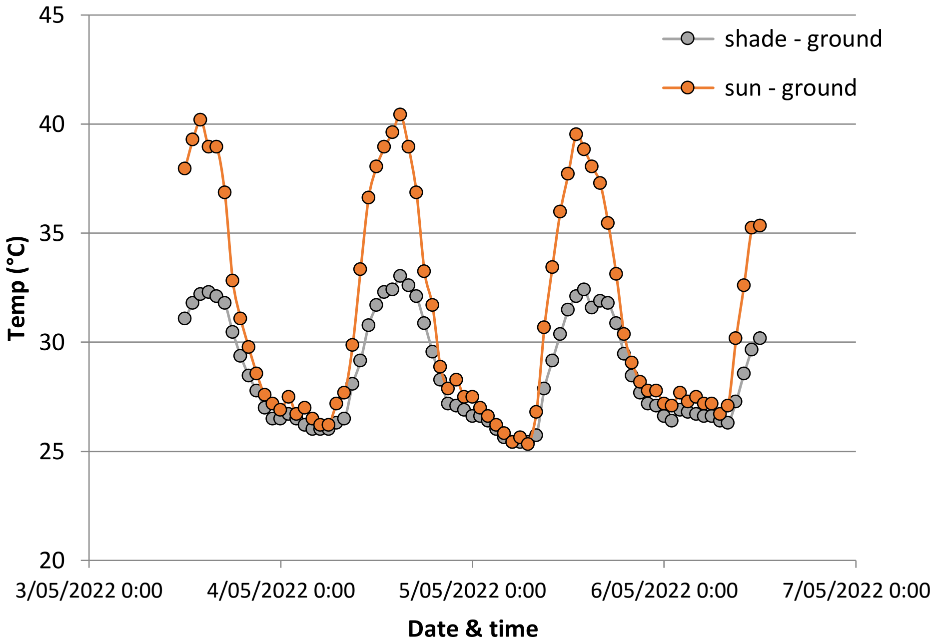

Figure 17. Air temperatures end of wet season – comparison of full shade and full sun at ground level, 3 – 6 May. Measurements are at hourly intervals.

Dry season

Air temperatures were below 30°C during the dry season measurement period in July 2022. Near ground level in full sun the temperature exceeded 30°C and reached a maximum of 33°C with peaks in the afternoon at 14:00 to 16:00 (Figure 18). Near ground air temperatures were greater than temperatures at 1.2 m by 0.8-1.5°C at night and up to 4°C during the day. Temperatures in part shade were consistently below 30°C during the day except for a peak at 15:00 when the logger (shield) was in full sun (Figure 19). Air temperatures dropped as low as 15°C at night into the early morning, gradually falling until just before sunset (7:00).

In full shade the temperatures at 1.2 m and near the ground were similar, however, near ground temperatures were slightly cooler during the day (Figure 20), up to around 1.4°C different. Maximum temperatures reached 27°C near the ground and 28.5°C at 1.2 m.

The difference between near ground temperatures in strong shade and in full sun in the dry season varied from 2 to 6°C during the day (Figure 21), but there was minimal difference at night. Temperatures peaked at 33°C in full sun and 27°C in the shade. An interesting effect of warmer air temperatures under the canopy was discernible at night in the dry season (Figure 22). At 1.2 m the temperature was 0.4 to 1.1°C warmer throughout the night, however, average temperature over 72 hours was almost identical in the sun and shade (20.9°C in shade vs 20.8°C in sun).

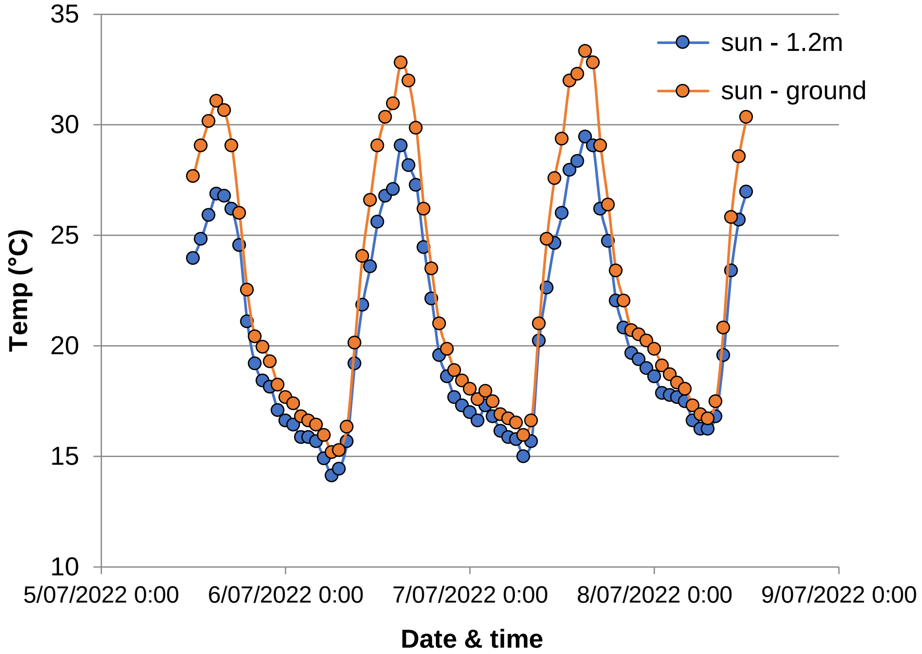

Figure 18. Air temperatures in the dry season in full sun at 1.2 m and at ground level, 5 – 8 July. Measurements are at hourly intervals. Note that the scale is shifted down compared to the end of wet season Figures.

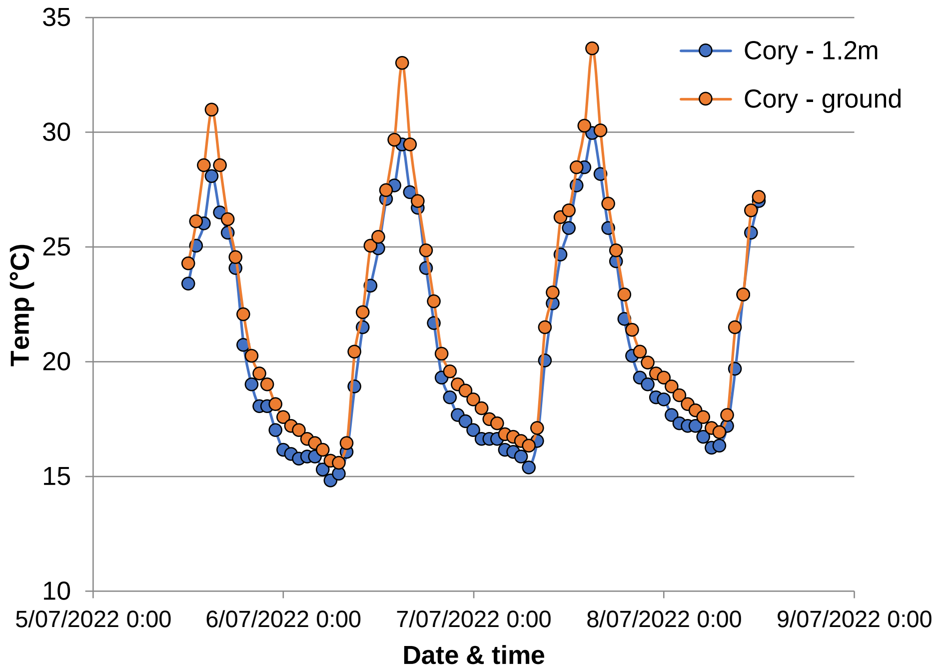

Figure 19. Air temperatures in the dry season in partial shade at 1.2 m and at ground level, 5 – 8 July. Note that the scale is the same as in the previous (dry season) Figure.

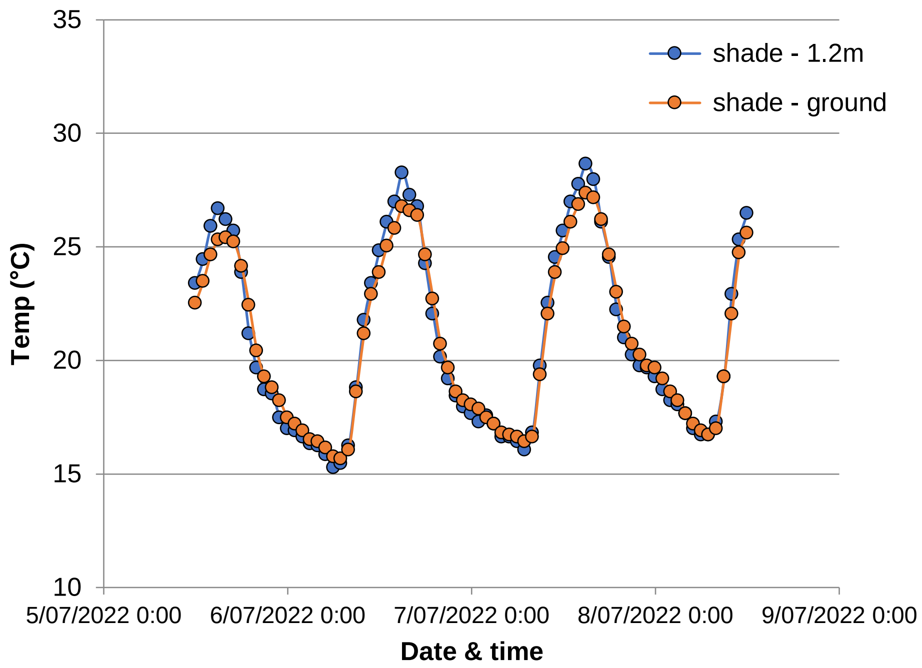

Figure 20. Air temperatures in the dry season in full shade at 1.2 m and at ground level, 5 – 8 July.

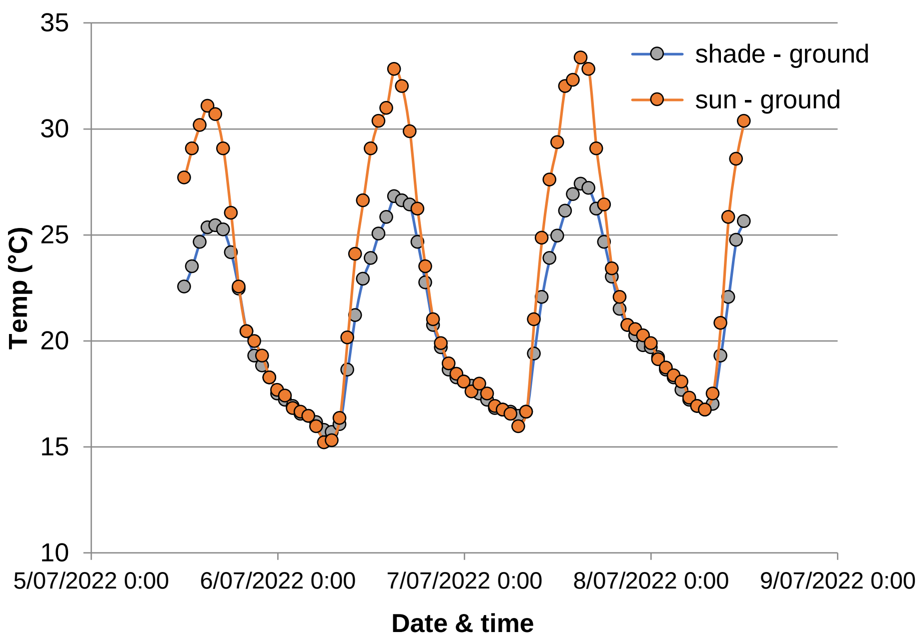

Figure 21. Air temperatures in the dry season – comparison of full shade and full sun at ground level, 5 – 8 July. Measurements are at hourly intervals.

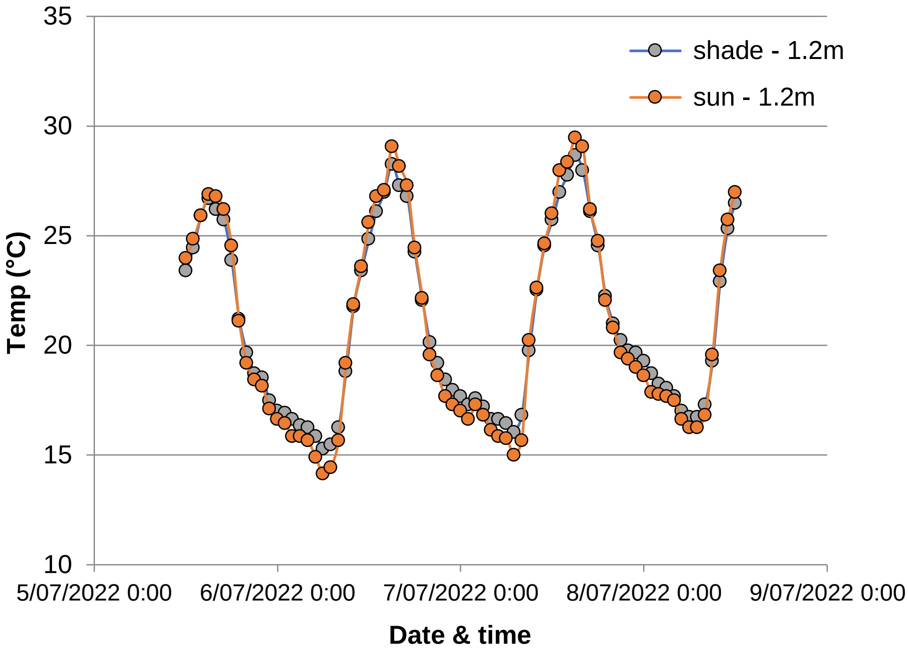

Figure 22. Air temperatures in the dry season – comparison of full shade and full sun at 1.2 m, 5 – 8 July. Measurements are at hourly intervals.

As a comparison with the air temperature measures at CSIRO Berrimah, air temperatures along Rapid Creek in a densely shaded site were recorded from 29th June midday to 9th July midday (Figure 23). During this extended period, there were typical dry season conditions 2nd into 3rd July, and clear skies on the 6th for surface temperature measurements, with temperatures dropping to 15°C on the 6th July. Cloudy conditions and light rain on the 30th June are indicated by the low diurnal variation in temperature (~ 5°C; Figure 23).

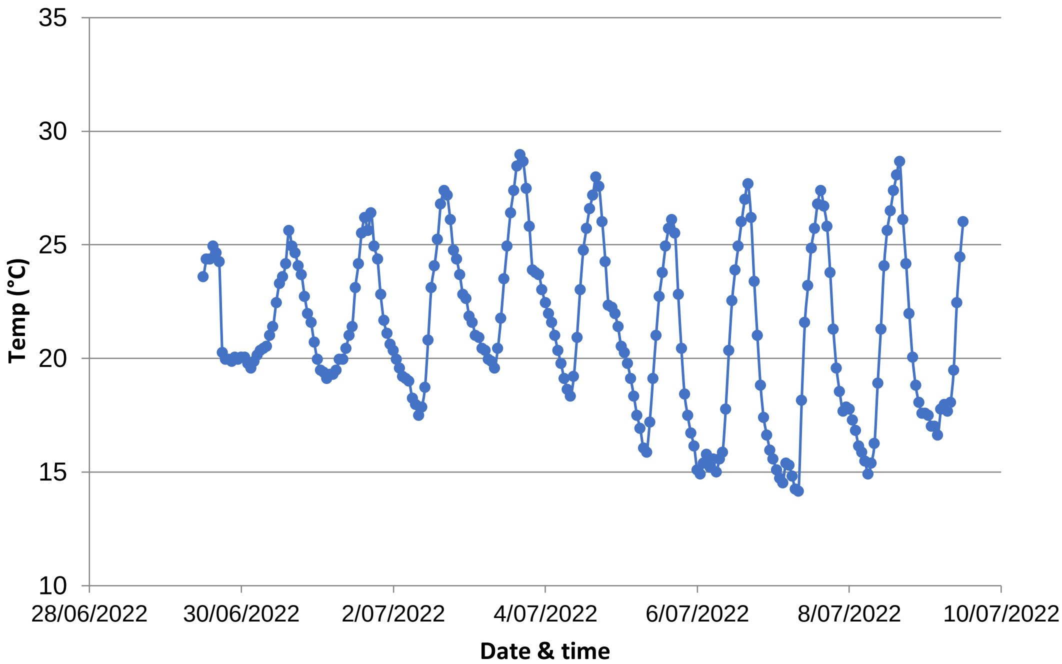

Figure 23. Air temperatures in the dry season along Rapid Creek, 29th June to 9th July.

Temperatures were consistently 1 to 2.5°C cooler along Rapid Creek when compared with the fully shaded site at Berrimah (Figure 24). The difference was particularly evident at night, with the Rapid Creek site cooling faster from 21:00 to approximately 04:00 each night.

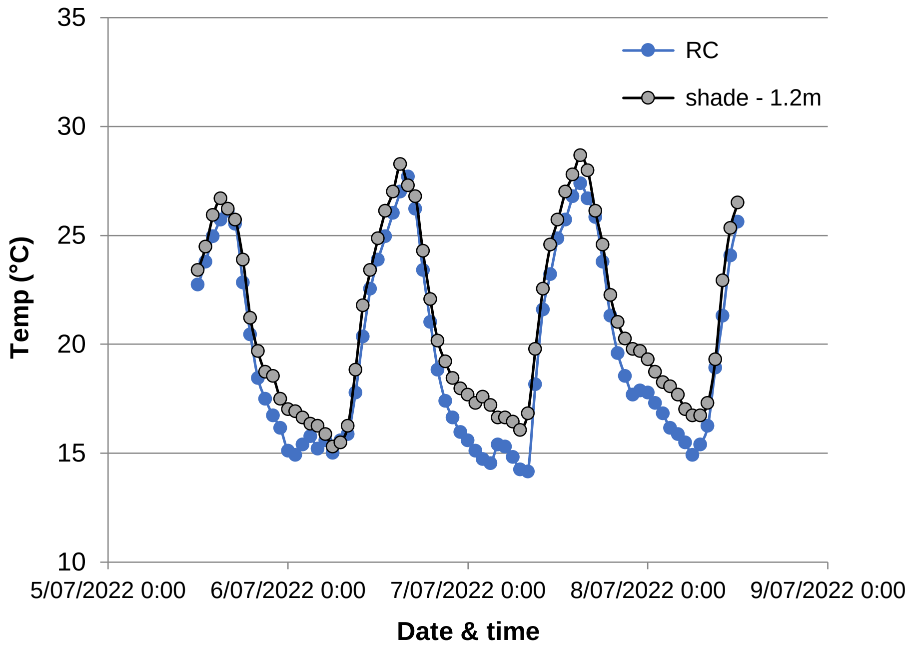

Figure 24. Air temperatures in the dry season – comparison of Rapid Creek (RC) and full shade at Berrimah at 1.2 m, 5 – 8 July.

DISCUSSION

Tree species and shading

Species producing dense shade were mostly monsoon forest species (e.g. *Carallia brachiata*, *Ganophyllum falcatum*, *Syzygium nervosum*, *Terminalia microcarpa*), along with species from riparian communities (e.g. *Nauclea orientalis*) and coastal monsoon vine thickets (e.g. *Mimuspos elengi*, *Millettia pinnata*). Forest and woodland (savanna) species including overstorey eucalypts and *Corymbia* spp. and mid-storey *Planchonia careya* and *Terminalia ferdinandiana* tended to produce only moderate shade.

Most tree species were allocated to the Dense shade category (Table 3). This was partly due to the selection of species for the study. Any of the species in the very dense sub-category provide dense shade that reduces the heat load under the canopy and the amount of solar radiation reaching the ground surface. Canopy cover around Darwin can be increased by using these kinds of species that maximise shading.

Species such as *Mimusops elengi*, *Millettia pinnata*, *Maranthes corymbosa*, *Carallia brachiata* and *Allosyncarpia ternata* (Anbinik) have been planted widely or grow naturally in the Darwin region and contribute significantly to the urban forest. *Ganophyllum falcatum* provides very dense shade but has not been planted extensively – it is a potential species for wider use. *Calophyllum inophyllum* and *Syzygium nervosum* have been planted in some locations and provide useful shade, but are only suitable in parks and gardens where there is ample space due to their large size at maturity. *Terminalia microcarpa* provides good shade in the wet season (it is decidous in the late dry season), however, it has colonised numerous Darwin gardens (seeds are dispersed by birds) where its potential large size is an issue, as well as its habit of dropping leaves, flowers and then fruit. The small tree *Diospyros compacta* is slow growing but is resilient and provides dense shade – it is a potentially useful shading species for urban gardens.

Alstonia actinophylla (Milkwood) generally provides dense shade, although some individuals develop relatively poorly. It has been planted abundantly across Darwin and is very hardy, but perhaps other species should be considered in parks and along roads. One such species is the native *Canarium australianum* which grows to 20 m on suitable sites. It provides dense shade and is a potential replacement for the African Mahogany where these are being removed.

Trees in the moderate category were mainly myrtaceous species, including species of *Melaleuca*, *Corymbia* and *Eucalyptus*. These trees have relatively sparse leaves and frequently an upright habit. Most still contributed close to 70% shade, and are likely to be useful in park settings where some shade is required. The native overstorey eucalypts *E. miniata* and *E. tetrodonta* are common in remnant woodland near Darwin, and some specimens occur in parks. *Casuarina equisetifolia* is a useful species in coastal situations, although its hard seed pods ('porcupines') can be troublesome. Species such as the ghost gum *Corymbia bella* are planted as feature trees, even though they produce little shade. Lowest shading was from the Carpentaria Palm, due to large gaps in the canopy (between fronds) and the small extent of the canopy. This species and indeed most palms are of limited use in terms of shading.

Further details on the characteristics of tree species are provided in Appendix 2.

The degree of shading depends to some extent on the form of the tree – whether spreading or upright, the branching pattern and the overall canopy architecture. Large interstices or gaps in the canopy and scattered shade due to sparse leaves reduce the effectiveness of shading. High shade density under the canopy reduces temperatures near the ground, as described in the next section.

Table 3. Tree species by shade density category.

Dense – very dense	**Moderate**
Allosyncarpia ternata	*Brachychiton diversifolius*
Calophyllum inophyllum	*Casuarina equisetifolia*
Carallia brachiata	*Corymbia ptychocarpa*
Diospyros compacta	*Eucalyptus miniata*
Ficus virens	*Eucalyptus tetrodonta*
Ganophyllum falcatum	*Melaleuca dealbata*
**Mangifera indica*	*Melaleuca viridiflora*
Maranthes corymbosa	*Planchonia careya*
Millettia pinnata	*Terminalia ferdinandiana*
Mimusops elengi	
Nauclea orientalis	**Sparse**
Syzygium nervosum	*Carpentaria acuminata*
**Tamarindus indica*	*Corymbia bella*
Terminalia microcarpa	*Corymbia polycarpa*
Dense – dense	**Dense** – moderately dense
**Albizia saman*	*Acacia auriculiformis*
Alstonia actinophylla	*Callitris intratropica*
Barringtonia acutangula	*Erythrophleum chlorostachys*
Canarium australianum	*Lophostemon lactifluus*
**Khaya senegalensis*	
Peltophorum pterocarpum	
Syzygium armstrongii	

Tree height is an important consideration in shading, as low trees provide minimal shade and are not able to provide useful shade during the middle of the day, whereas very tall trees provide shade under the canopy only at certain times depending on the angle of the sun. Optimal height for shading is generally 6-8 m for smaller tree species (e.g. *Mimusops elengi*, *Diospyros compacta*, *Carallia brachiata*) and 8-10 m for larger species (e.g. *Maranthes corymbosa*, *Calophyllum inophyllum*, *Allosyncarpia ternata*). A number of tress had been pruned of their lower branches, resulting in a well-formed and sheltered canopy that provides useful shade for people.

Shade areal extents are likely to be a factor contributing to the overall shade generated by tree species. Some species had width to height ratio >1, and have a wide shade area. Large, spreading species may perform better in terms of providing greater overall shade coverage, even if they have a slightly less dense canopy. In terms of the density of trees, spacing is important where the aim is to create almost complete cover as in a closed forest formation (overall cover > 80 %) or more of an appearance of an open forest (50-80% cover).

There are benefits in planting clusters of trees (Streiling & Matzarakis, 2003) in terms of the greater area shaded and potentially dense shade due to multiple species contributing cover. This is common in native forest where trees are often clumped together. In terms of plantings, this has the advantage of being able to mow around the clump, rather than each individual tree. Extensive shading as at Howard Springs and Rapid Creek provides continuous shade which may result in greater cooling benefits (Figure 24).

A number of native species lose their leaves in the dry season (Williams et al. 1997); these include semi-deciduous and fully deciduous species. In this study fully deciduous species included *Terminalia microcarpa*, *Ficus virens*, *Planchonia careya*, *Brachychiton diversifolius*, and *Terminalia ferdinandiana*. Ironwood *Erythrophleum chlorostachys* is a semi-deciduous species (canopy falls below 50% of full canopy; Williams et al. 1997) and *Barringtonia acutangula* also loses most or all of its leaves in the dry season. The loss of leaves in the dry season would reduce their effective shading. However, leaf flush occurs in the build-up, often prior to major rain, hence these trees are fully leafed for most of the warmer part of the year.

Temperatures

By the middle of the day and into the afternoon in the warmer part of the year, surface temperatures were above 50°C in exposed sites and reached 57°C on the road and 56°C on bare ground. This emphasises the high temperatures reached and the necessity for shading bare ground during the day and/or reducing the area of bare surfaces in the city and suburbs. Roads, bare ground and concrete paths all contribute to the general heating of the region (Meyers et al. 2020). Green grass in the sun (end of wet season) was invariably more than 10°C cooler than bare surfaces, hence green grass also has considerable cooling benefits. It is not clear at this stage whether browned grass in the dry season affected surface temperature, but it appears that there is negligible benefit of dry grass.

As expected, surface temperature were hotter at the end of the wet season in comparison to dry season temperatures. Greater levels of insolation due to the sun being at a higher angle and longer days result in greater heating over an extended period. Surfaces heated up relatively rapidly during the morning, reaching maxima in the mid-afternoon, with slow cooling into the evening.

The temperature of bare ground was some 15-20°C hotter than shaded surfaces in both the wet season and dry season. Air temperatures and surface temperature were cooler in the dry season. In contrast, in shaded areas the temperature of the surface of the ground was similar to air temperature (usually within 1-4°C), demonstrating the clear effect of tree shading on reducing surface temperatures. Areas exposed to the sun for even brief periods heated up rapidly, with the part shade location experiencing rapid heating when exposed to the sun in the afternoon. These thermal transients were noticeable also in the air temperature measurements, and depending on the duration of heating, may influence the ability of the ground surface to cool down in the evening. In the case of deciduous tree species, the decrease in the degree of shading as leaves fall in the dry season is likely to affect the temperature under the canopy.

Thermal images show the variation in temperature at a microscale. Bare surfaces were consistently hot, whereas thermal images indicate that leaf litter provides insulation – the ground (i.e. soil) under the leaf litter in shaded environments was around 5°C cooler than the surface of the leaf litter exposed to the air (and partial sunlight).

Periodic drops in surface temperature suggest that scattered cloud may cause a temporary reduction in temperature of 2-3° on bare surfaces such as roads, footpaths and gravel areas over a relatively short timeframe. Once re-exposed to direct sun, these bare surfaces heat up again. The water droplets and ice crystals in clouds absorb and scatter direct solar radiation and absorb less than 30% of incoming radiation in the case of high (and thin) cirrus clouds, but may reflect and absorb nearly 90% of incident radiation in the case of a large cloud (Monteith, 1973).

The overall effect of heating of the ground surface is to cause heat (infrared radiation) to radiate from the ground to a person standing or walking in the sun, thus increasing the heat load impinging on them. This has an effect on personal comfort, although the amount of heat radiated declines rapidly with distance from the ground surface. This heat can be felt particularly in car parks and on roads and pavements. There is also an effect of radiation from heated walls that are exposed to the sun in highly urbanised areas. Humidity will also have an effect on personal comfort in the wet season, as evaporative cooling is less effective.

Air temperature curves recorded with data loggers were fairly typical for days with little or no cloud. Daily maximum temperatures were in the afternoon and daily minimum temperatures overnight or near dawn. Maximum air temperature (at 1.2 m) was usually at 14:00 – 16:00 at the end of the wet season and at 15:00 – 16:00 in the dry season.

Air temperature differences in the open and in the shade were not as substantial as for surface temperatures, however, the effect of heating of the ground did have an effect on air temperature close to the ground. This was particularly noticeable in the full sun location, where temperatures at the end of the wet were 2 to 4.5°C warmer during the day and 1 to 1.5°C warmer at night. In the dry season they were 2 to 4°C warmer during the day and 0.8 to 1.5°C warmer at night (Figure 25). Temperatures near the ground remained warmer even at night, presumably a result of residual heat from the ground. This is in contrast to the more typical situation in cooler climates, where on cold nights the temperature near the ground is cooler than at 1-2 m above the ground (Figure 26).

Temperatures near the ground in full shade were lower than at 1.2m during the day. Other than the effect of shading in reducing the amount of insolation, the main benefit is in shading the ground. This results in cooler temperatures near the ground, and less radiant heat. This was particularly noticeable in the comparison of near ground air temperature in full sun and full shade, where the difference was as much as 8°C during the day. In the partial shade situation direct sun during the afternoon resulted in peaks of temperature near the ground similar to those in full sun. Air temperature at 1.2 m was fairly similar across fully shaded, partially shaded and full sun conditions.

A final point of interest was the warmer air temperatures under the canopy at night in the dry season. This was a relatively small but detectable difference, and is likely to be due to the retention of heat under the canopy in contrast to open areas that radiate heat freely to the atmosphere.

This study demonstrates the benefits of shade in not only keeping the ground surface cooler, but also maintaining lower air temperatures. Strongly shading trees, including many rainforest species, provide the densest shade and have the greatest effect. In comparison, unshaded bare surfaces are heated the most, as revealed by measurements of pavement and road surface temperature in late April (Figure 27). These temperatures exceed 50°C in the afternoon and were still above 35°C at 10 o'clock at night, and show a substantial difference from air temperature.

Further investigations should focus on the effect of daytime shading on the temperature of footpaths and road surfaces during the day and also effectiveness of cooling at night. Shaded paths feel cooler than adjacent unshaded footpaths in the early evening. Shading bare surfaces may contribute strongly to cooling of the urban environment, as these bare areas will radiate less heat (infrared radiation) at night. It may also be worthwhile to investigate the effect of green grass on reducing ground temperatures, as this appears to have some benefit, albeit less than that of tree shading.

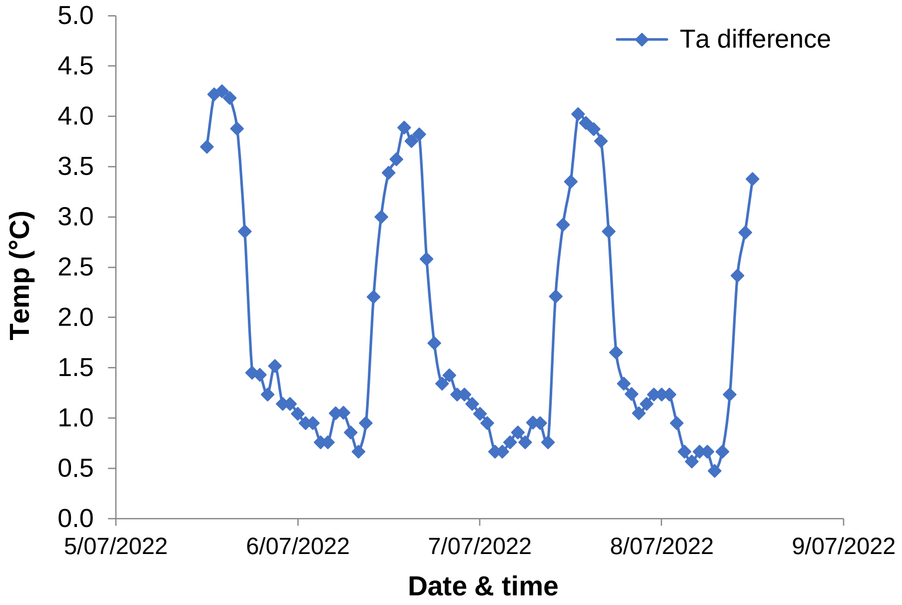

Figure 25. Difference between near ground temperature and temperature at 1.2 m in the dry season. Temperatures were consistently warmer near the ground.

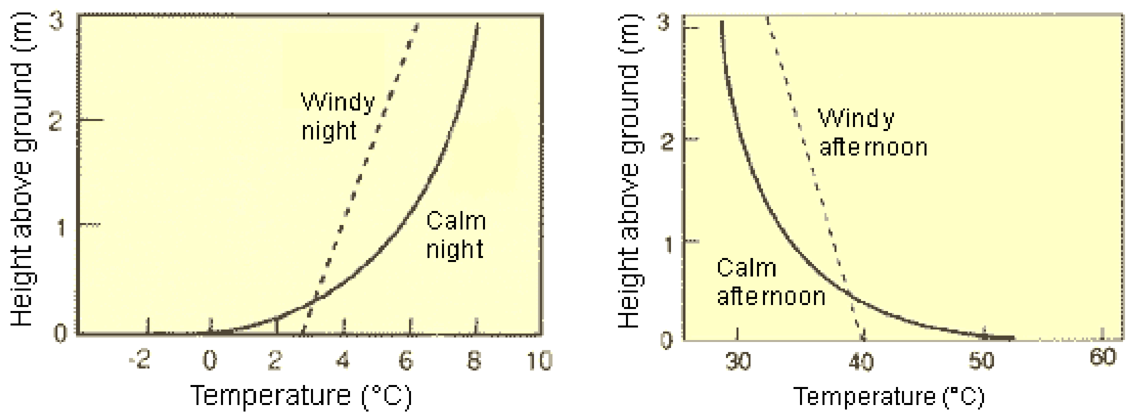

Figure 26. Examples of variation in air temperature close to the ground on a cold night (left) and a hot day (right). Figure from Australian Bureau of Meteorology.
http://www.bom.gov.au/climate/data-services/faqs.shtml#tabs=Observations

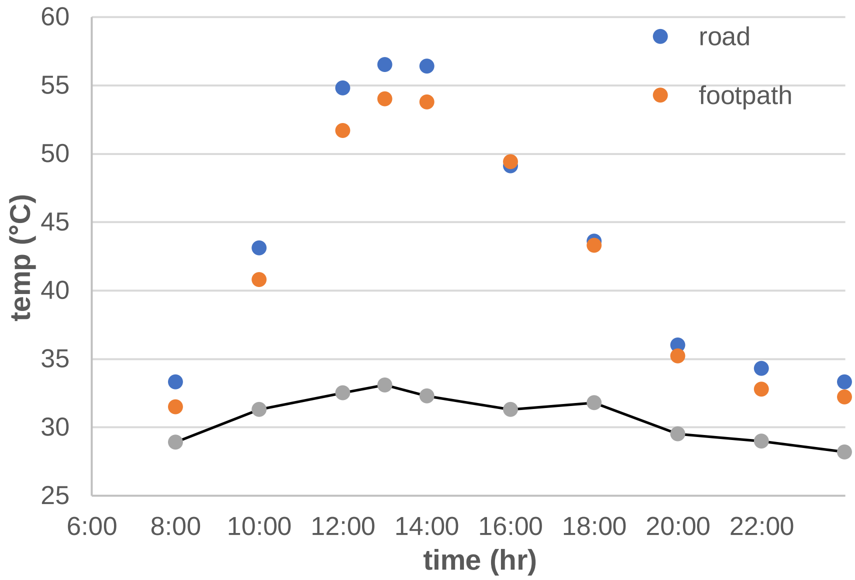

Figure 27. Surface temperatures of pavement (footpath) and road surface in late April in suburban Darwin (Millner). Air temperature (Ta) is for Darwin airport (data from Bureau of Meteorology).

Fauna were observed using habitat provided by trees in the Darwin urban forest (some examples are listed in Appendix 3). The Greening Darwin Strategy (City of Darwin, 2020) alludes to biodiversity outcomes – these include tree species diversity but also influence the diversity of animal species that are able to inhabit these areas. The use of a variety of tree species can enhance biodiversity outcomes and increase canopy cover of the urban forest. Trees provide habitat and resources for native fauna, including birds, mammals, reptiles and insects (Figure 28).

Figure 28. Lemon-bellied Flyrobin *Microeca flavigaster* using a tree as a perch.

References and Further Reading

Barwick, M. 2004. *Tropical and Subtropical Trees.* Thames & Hudson, London.

Brock. J. 2001. *Native Plants of Northern Australia.* Reed New Holland, Sydney.

Campbell, G.S. and Norman, J.M. 1998. *An Introduction to Environmental Biophysics.* 2nd edition. Springer, New York.

City of Darwin. 2018. *Establishing A Resilient Urban Forest For Darwin: Best Practice Guidelines.* City of Darwin, Darwin.

City of Darwin. 2018. *Creating Habitat for Darwin Gardens.* City of Darwin, Darwin.

City of Darwin. 2020. *Greening Darwin Strategy 2030.* City of Darwin, Darwin.

Clark, M., Traynor, S. and Dunlop, A. 1987. *Plants of the Tropical Woodland.* Conservation Commission of the Northern Territory, Darwin.

Commonwealth of Australia. 2020. *State of the Climate 2020.* CSIRO and Bureao of Meteorology.

CSIRO. 2020. *Climate Change in the Northern Territory: State of the Science and Climate Change Impacts.* Report for NT Government, NESP Earth Systems and Climate Change Hub, Melbourne.

Gates, D.M. 1980. *Biophysical Ecology.* Springer-Verlag, New York.

Hearne, D.A. 1975. *Trees for Darwin and Northern Australia.* Australian Government Publishing Service, Canberra.

Klemm, W., Heusinkveld, B.G., Lenzholzer, S. and van Hove, B. 2015. Street greenery and its physical and psychological impact on thermal comfort. *Landscape and Urban Planning* 138: 87-98.

Monteith, J.L. 1973. *Principles of Environmental Physics.* edward Arnold, London.

Monteith, J.L. and Unsworth, M.H. 2008. *Principles of Environmental Physics.* 3rd edition. Elsevier, Amsterdam.

Meyers, J., Langston, A., Devereux, D. and Lin, B.B. 2020. *Mapping land surface temperatures and heat-health vulnerability in Darwin.* CSIRO, Australia.

Myers, B.A., Duff, G.A., Eamus, D., Fordyce, I.R., O'Grady, A. and Williams, R.J. 1997. Seasonal variation in water relations of trees of differing leaf phenology in a wet–dry tropical savanna near Darwin, northern Australia. *Australian Journal of Botany* 45: 225-240.

Northern Territory Herbarium. 2021. FloraNT Northern Territory Flora Online. Department of Land Resource Management. <http://eflora.nt.gov.au>

NT Government and City of Darwin. 2020. *Feeling Cooler in Darwin - Darwin Heat Mitigation and Adaptation Strategy.* NT Government and City of Darwin, Darwin.

Short, P.S. and Cowie, E.D. (eds) 2011. *Flora of the Darwin Region.* Northern Territory Herbarium, Palmerston.

Smith, N. 2007. *Native Plants for Top End Gardens.* Greening Australia, Darwin.

Streiling, S. and Matzarakis, A. 2003. Influence of single and small clusters of trees in the bioclimate of a city: a case study. *Journal of Arboriculture* 29: 309-316.

Wightman, G. and Andrews, M. 1989. *Plants of Northern Territory Monsoon Vine Forests.* Conservation Commission of the Northern Territory, Darwin.

Williams, R.J., Myers, B.A., Muller, W.J., Duff, G.A. and Eamus, D. 1997. Leaf phenology of woody species in a north Australian tropical savanna. *Ecology* **78:** 2542-2558.

Appendix 1. Tree species listed by family

(P) indicates on City of Darwin preferred trees list
(NR) not recommended
asterisk (*) is a non-native species

ANACARDIACEAE
**Mangifera indica* Mango (P)

APOCYNACEAE
Alstonia actinophylla Milkwood (P)

ARECAECEAE
Carpentaria acuminata Carpentaria Palm (NR)

BURSERACEAE
Canarium australianum (P)

CASUARINACEAE
Casuarina equisetifolia Coastal She-oak (P)

CHRYSOBALANACEAE
Maranthes corymbosa Maranthes (P)

COMBRETACEAE
Terminalia microcarpa (P)
Terminalia ferdinandiana Billy Goat Plum (P)

CLUSIACEAE
Calophyllum inophyllum Beauty Leaf (P)

CUPRESSACEAE
Callitris intratropica Northern Cypress (P)

EBENACEAE
Diospyros compacta (P)

FABACEAE
Acacia auriculiformis Black Wattle (NR)
**Albizia saman* Rain Tree (P)
Erythrophleum chlorostachys Ironwood (P)
Millettia pinnata Pongamia (P)
Peltophorum pterocarpum Yellow Flame Tree (P)
**Tamarindus indica* Tamarind (P)

LECYTHIDACEAE
Barringtonia acutangula Freshwater Mangrove (P)
Planchonia careya Cocky Apple (P)

MALVACEAE
Brachychiton diversifolius Northern Kurrajong (P)

MELIACEAE
**Khaya senegalensis* African Mahogany (NR)

MORACEAE
Ficus virens Banyan (P)

MYRTACEAE
Allosyncarpia ternata Anbinik (P)
Corymbia bella Ghost Gum (P)
Corymbia polycarpa Long-fruited Bloodwood (P)
Corymbia ptychocarpa (P)
Eucalyptus miniata Darwin Woollybutt (P)
Eucalyptus tetrodonta Stringybark (P)
Lophostemon lactifluus Swamp Box (P)
Melaleuca dealbata (P)
Melaleuca viridiflora (-)
Syzygium armstrongii (P)
Syzygium nervosum (P)

RHIZOPHORACEAE
Carallia brachiata (P)

RUBIACEAE
Nauclea orientalis Leichhardt Tree (P)

SAPINDACEAE
Ganophyllum falcatum (P)

SAPOTACEAE
Mimusops elengi (cultivated ?) (P)

Appendix 2. Tree species descriptions

Information in this section derived from Brock (2001), Smith (2007), Hearne (1975), Northern Territory Herbarium (2021) and personal observations.

Shade categories derived from this study.

Each description includes the scientific and common name, family, whether it is a preferred tree, a brief description, deciduousness, characteristic features and the shade category.

Acacia auriculiformis Black Wattle

Family: Fabaceae

Not recommended

Large spreading tree growing in rainforests and along drainages; unusually large for an *Acacia.* Found across the Top End and widely planted as part of restoration projects.

Evergreen

Characteristic features: yellow flowers, siny green phyllodes

Shade category: moderately dense

Large *Acacia auriculiformis* near Rapid Creek (shade tree no. 11).

**Albizia lebbeck* Rain Tree

Family: Fabaceae

Preferred tree for Darwin

Exotic tree planted in parks. Growing to around 12 m with wide spreading branches. Leaves fold down in the evenings.

Evergreen

Characteristic features: compound leaves, pinkish fluff flowers in season

Shade category: dense.

Allosyncarpia ternata Anbinik

Family: Myrtaceae

Preferred tree for Darwin

Large spreading tree growing to 30 m on favourable sites, usually less than 15 m where planted. Native to fire-protected sites and rainforest patches of the sandstone landscapes of West Arnhem Land and Kakadu.

Evergreen

Characteristic features: leaves in groups of three around stem, leaves shiny

Shade category: very dense

Allosycarpia ternata at Casuarina Pool car park (shade tree no. 123).

Alstonia actinophylla Milkwood

Family: Apocynaceae

Preferred tree for Darwin

Large tree with corky bark growing to 30 m but usually less than 15 m where planted around Darwin. Native to savanna and edges of monsoon vine thicket across the Top End. Resistant to termites and planted widely in recent times; also relatively fire resistant.

Evergreen

Characteristic features: slender leaves in whorls, corky bark, white sap in stems

Shade category: dense

Barringtonia acutangula Freshwater Mangrove, Itchy Tree

Family: Lecythidaceae

Preferred tree for Darwin

Low, spreading tree to around 8 m, often with multiple trunks. Associated with rivers, wetlands and floodplains, often on seasonally inundated sites. Widespread across the Top End.

Deciduous

Characteristic features: spreading tree, hanging red flowers

Shade category: dense

Barringtonia acutangula near Rapid Creek (shade tree no. 19).

Brachychiton diversifolius Northern Kurrajong

Family: Malvaceae (previously Sterculiaceae)

Preferred tree for Darwin

Upright medium-sized tree to 15 m with conical crown. Native to savannas and a widespread mid-storey tree across the Top End. Occasional plantings in Darwin.

Semi-deciduous

Characteristic features: smooth leaves varying in shape, large boat shaped fruit capsules

Shade category: moderate

Callitris intratropica Northern Cypress

Family: Cupressaceae

Preferred tree for Darwin

Upright pine-like tree to 15 m with cone-shaped crown. In fire-protected sites in savannas and rocky areas. Termite resistant wood used for building in the past and plantations established at Howard Springs and elsewhere.

Evergreen

Characteristic features: tiny leaves in whorls, dark rough bark

Shade category: moderately dense

Calophyllum inophyllum Beauty Leaf

Family: Clusiaceae

Preferred tree for Darwin

Large spreading ornamental tree to 20 m with dense foliage and large shiny leaves (hence the common name). Native to coastal areas of the Top End and widely planted as an ornamental.

Evergreen

Characteristic features: large glossy leaves with numerous veins, dark rough bark

Shade category: very dense

Calophyllum inophyllum near Alawa Hall (shade tree no. 156).

Canarium australianum Canarium

Family: Burseraceae

Preferred tree for Darwin

Large tree with spreading crown to 20 m or more in favourable sites. Native to rainforests and vine thickets of the Top End and occasionally in unburnt savanna. Could be planted more widely as a replacement for African Mahogany.

Evergreen

Characteristic features: large tree with compound leaves, grey bark

Shade category: dense

Carallia brachiata Carallia

Family: Rhizophoraceae

Preferred tree for Darwin

Generally small tree with shiny green leaves but may grow to 15 m. Prefers wet areas in rainforests and riparian communities (e.g. adjacent to Rapid Creek).

Evergreen

Characteristic features: shiny leathery leaves, pointed tip (terminal stipule) between leaves at end of branch, ripe fruit/berries red

Shade category: very dense

Carallia brachiata at Jingili Water Gardens (shade tree no. 16).

Carpentaria acuminata Carpentaria Palm

Family: Arecaceae

Not recommended

Upright palm tree with fairly large fronds, usually to around 12 m where planted in Darwin but can grow to 20 m. Native to wetter areas of the Top End and planted extensively after Cyclone Tracy. Bracts with numerous red fruit when ripe attract bats and birds but the caustic fruits and other features make this a less desirable tree.

Evergreen (frequently dropping fronds)

Characteristic features: palm tree with single upright trunk

Shade category: sparse

Casuarina equisetifolia Coastal Sheoak

Family: Casuarinaceae

Preferred tree for Darwin

Tall spreading tree with hanging branches. Usually near coastal.

Evergreen

Characteristic features: thin leaves, hard nuts

Shade category: moderate

Casuarina equisetifolia near Rapid Creek footbridge (shade tree no. 180).

Corymbia (previously *Eucalyptus*) *bella* Ghost Gum

Family: Myrtaceae

Preferred tree for Darwin

Moderate-sized tree to 15 m with spreading crown and clusters of flowers in season. Usually in seasonally flooded areas near creeks but also near the coast.

Evergreen

Characteristic features: smooth white bark, drooping foliage

Shade category: sparse

Corymbia (previously *Eucalyptus*) *polycarpa* Long-fruited Bloodwood

Family: Myrtaceae

Preferred tree for Darwin

Upright tree 10-15 m with spreading crown. Usually in seasonally inundated areas. Widespread across the Top End.

Evergreen

Characteristic features: rough grey bark, thin leaves

Shade category: sparse

Corymbia polycarpa at Jingili Water Gardens (shade tree no. 51).

Corymbia (previously *Eucalyptus*) *ptychocarpa* Swamp Bloodwood

Family: Myrtaceae

Preferred tree for Darwin

Medium-sized tree with large leaves and hanging foliage. Prefers swampy areas with seasonally wet soils, but grows well in parks and well watered gardens.

Evergreen

Characteristic features: large leathery leaves, showy pink to red flowers, hard fruits

Shade category: moderate

Diospyros compacta

Family: Fabaceae

Preferred tree for Darwin

Small dense tree to 8 m. A type of ebony, it occurs in vine thickets. Not commonly planted in Darwin region.

Evergreen

Characteristic features: smallish leathery leaves, round fruits

Shade category: very dense

Erythrophleum chlorostachys Ironwood

Family: Fabaceae (previously Caesalpiniaceae)

Preferred tree for Darwin

Generally upright tree with dark green foliage and rough bark. A species of savanna woodlands, it produces hard timber that is termite resistant.

Semi-deciduous, often dropping leaves in dry season and flush of new leaves in early wet season

Characteristic features: compound leaves, tessellated bark

Shade category: moderately dense

Eucalyptus miniata Darwin Woollybutt

Family: Myrtaceae

Preferred tree for Darwin

A common eucalypt of the savannas of the Top End, *E. miniata* can grow to 20 m. It has rough bark on the lower trunk (which protects it from fire) and is smooth on the upper trunk and branches.

Evergreen

Characteristic features: orange flowers, fibrous bark

Shade category: moderate

Eucalyptus miniata in airport grounds (shade tree no. 187).

Eucalyptus tetrodonta Stringybark

Family: Myrtaceae

Preferred tree for Darwin

An upright tree growing to 20 m in the Darwin region, it has rough, fibrous bark. It is a common eucalypt of the savannas of the Top End, and some remnants exist in Darwin parks.

Evergreen

Characteristic features: rough stringybark on trunk and branches, falcate leaves

Shade category: moderate

Eucalyptus tetrodonta in park near cemetery (shade tree no. 35).

Ficus virens Banyan

Family: Moraceae

Preferred tree for Darwin

Large spreading tree with aerial roots that reach the ground and provide support. Found in rainforests and planted fairly widely in Darwin parks.

Deciduous

Characteristic features: multiple aerial roots, leathery leaves, white sap in stems

Shade category: very dense

Ganophyllum falcatum

Family: Sapindaceae

Preferred tree for Darwin

Medium sized tree with dense foliage gowing to 15 m. Mainly a species of monsoon forests.

Evergreen

Characteristic features: leaves made up of alternate shiny green leaflets, rough brown bark

Shade category: very dense, consistently high

Large *Ganophyllum falcatum* near Rapid Creek, Jingili (shade tree no. 15).

**Khaya senegalensis* African Mahogany

Family: Meliaceae

Not recommended

Extremely large exotic tree with spreading crown and large trunk in older specimens. Planted extensively around ovals after Cyclone Tracy. No longer planted as frequently blows over in cyclones and large branches considered dangerous.

Evergreen

Characteristic features: large tree, produces round woody nuts

Shade category: dense

Lophostemon lactifluus Swamp Box

Family: Myrtaceae

Preferred tree for Darwin

A medium sized, usually upright tree that grows in wetter sites around swamps and near creeks (e.g. Rapid Creek). Not commonly planted.

Evergreen

Characteristic features: reddish flaky bark, smooth leaves

Shade category: moderately dense

**Mangifera indica* Mango

Family: Anacardiaceae

Preferred tree for Darwin

Exotic tree planted in thousands for its tasty fruit. Flowers in the cool part of the dry season and fruits in the build-up. There are occasional specimens in Darwin parks.

Evergreen

Characteristic features: dark green leaves, large edible fruits

Shade category: very dense

Maranthes corymbosa Maranthes

Family: Chrysobalanaceae

Preferred tree for Darwin

Large tree with a spreading crown and often with hanging branches. A rainforest species, it has been planted extensively in Darwin, although many trees are yet to attain great height.

Evergreen

Characteristic features: drooping foliage, paired dots (glands) at base of leaf

Shade category: very dense

Melaleuca dealbata

Family: Myrtaceae

Preferred tree for Darwin

A spreading paperbark tree with brown and white papery bark. Grows naturally near streams, swamps and also fringing coastal plains.

Evergreen

Characteristic features: hairy new leaves, blue-grey foliage

Shade category: moderate

Melaleuca viridiflora

Family: Myrtaceae

Not listed

A paperbark tree with white papery bark and dark green hanging foliage. Often grows as a stunted tree to 8 m but occasionally to 15 m in suitable areas.

Evergreen

Characteristic features: relatively broad leaves, white layered paperbark

Shade category: moderate

Millettia (previously *Pongamia*) *pinnata* Pongamia

Family: Fabaceae

Preferred tree for Darwin

A low spreading medium sized tree of coastal areas (e.g. Rapid Creek foreshore). Often multi-stemmed, it has a rounded crown and glossy leaves.

Deciduous

Characteristic features: leaves of 5 – 7 leaflets, pea flowers in season

Shade category: very dense

Mimusops elengi

Family: Sapotaceae

Preferred tree for Darwin

A small tree with a dense canopy. This monsoon forest and coastal species has dark green leaves. Planted extensively in Darwin, along footpaths and in parks. Most in Darwin region appear to be a cultivated variety.

Evergreen

Characteristic features: dark green glossy leaves,

Shade category: very dense, consistently high

Mimusops elengi near cemetery (shade tree no. 36).

Nauclea orientalis Leichhardt Tree

Family: Rubiaceae

Preferred tree for Darwin

A large tree with horizontal branching. Grows near swamps and lagoons and on banks of streams.

Semi-deciduous

Characteristic features: large leaves with obvious stipules

Shade category: very dense

Nauclea orientalis at Jingili Water Gardens, near Rapid Creek (shade tree no. 10).

Peltophorum pterocarpum Yellow Flame Tree

Family: Fabaceae (previously Caesalpiniaceae)

Preferred tree for Darwin

A medium-sized, spreading rainforest tree with numerous small leaflets.

Deciduous

Characteristic features: rusty-hairy branches, pinnate leaves, yellow flowers

Shade category: dense

Planchonia careya Cocky Apple

Family: Lecythidaceae

Preferred tree for Darwin

A small, irregularly shaped tree of the savannas, usually less than 8 m but can grow to 12 m. Produces pear shaped fruits.

Deciduous

Characteristic features: corky bark, leaves turn pink in mid to late dry season before falling

Shade category: moderate

Syzygium armstrongii

Family: Myrtaceae

Preferred tree for Darwin

An upright tree with pale bark, producing white fruit in the wet season. Planted along streets.

Evergreen

Characteristic features: leaves in pairs (opposite), pale bark

Shade category: dense

Syzygium armstrongii at Charles Darwin University (shade tree no. 55).

Syzygium nervosum

Family: Myrtaceae

Preferred tree for Darwin

A large shady tree of rainforests and riparian zones. Infrequently planted. Produces purple-black fruits.

Evergreen

Characteristic features: shiny opposite leaves with distinct smell when crushed

Shade category: very dense

Syzygium nervosum at Jingili Water Gardens (shade tree no. 88).

**Tamarindus indica* Tamarind

Family: Fabaceae

Preferred tree for Darwin

Large upright tree 12-20 m with spreading crown. Originally introduced by Macassans and found around the coastline. Commonly cultivated for the edible fruit and as a shade tree. Fairly slow growing.

Evergreen

Characteristic features: fairly fine pinnate leaves, brown pods

Shade category: very dense

Tamarindus indica at Jingili Water Gardens (shade tree no. 164).

Terminalia ferdinandiana Billy Goat Plum, Kakadu Plum, Gubinge

Family: Combretaceae

Preferred tree for Darwin

A mid-storey tree of the savannas. It has large leaves that fall in the dry season, often leaving the tree completely leafless.

Deciduous

Characteristic features: large leaves in clusters at ends of branches, green fruits

Shade category: moderate. Individuals that were measured were fairly large, leafy trees for this species. In the dry season shading would be minimal (due to leaf loss).

Terminalia ferdinandiana near cricket oval at CDU (shade tree no. 158).

Terminalia microcarpa (previously *T. sericocarpa*)

Family: Combretaceae

Preferred tree for Darwin

A large, rapidly growing rainforest tree with layered branching. It is generally not suited for gardens as it can become very large, and it drops its leaves in the dry season, as well as producing numerous flowers and fruits that fall. It is spread by birds and naturally germinates in gardens.

Deciduous

Characteristic features: clusters of leaves at ends of branches, red leaves in dry season

Shade category: very dense

Terminalia microcarpa near Rapid Creek (shade tree no. 20).

Appendix 3. Fauna observed

Terrestrial vertebrate fauna observed in treed areas while undertaking tree shade measurements in the Darwin region.

Birds

Masked Lapwing

Orange-footed Scrubfowl

Bar-shouldered Dove

Peaceful Dove

Sulphur-crested Cockatoo

Rainbow (Red-collared) Lorikeet

Forest Kingfisher

Rainbow Bee-eater

Brown Honeyeater

White-gaped Honeyeater

White-throated Honeyeater

Rufous-banded Honeyeater

Lemon-bellied Flyrobin

Striated Pardalote

Weebill

Spangled Drongo

Magpie-lark

Yellow (Green) Oriole

Figbird

Mammals

Brushtail Possum

Northern Brown Bandicoot (diggings)

Black Flying-fox

Reptiles

Leaf-litter Skinks *Carlia* spp.

Wall Skink *Cryptoblepharus* sp. ?*cygnatus*

Frillneck Lizard *Chlamydosaurus kingii*

Ta-ta Dragon Lizard *Tropicagama* (previously *Lophognathus*) *temporalis*