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Speculations on the application of foliar ^{13}C discrimination to reveal groundwater dependency of vegetation and provide estimates of root depth and rates of groundwater use

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Supplementary Material

Table S1: List of species, their functional types, $\Delta^{13}C$ and calculated intrinsic WUE_i (PFT; plant functional type codes: BlT= broad leaf tree, NIT= needle leaf tree and S=shrub)

Species	Site Code[1]	PFT	$\Delta^{13}C$ (‰)	Calculated WUE_i
Acacia aneura	AMU	NlT	19.71±0.21	78.67
Acacia melanoxylon	WR	BlT	22.46±0.46	49.00
Acmena graveolens	CT	BIT	21.96±0.31	54.37
Alphitonia whitei	RC	BlT	24.81±0.58	23.63
Alstonia muelleriana	RC	BlT	23.42±0.4	38.58
Alstonia scholaris	CT	BlT	22.76±0.36	45.75
Anopterus glandulosus	WR	S	25.58±0.44	15.34
Argyrodendron peralatum	CT	BIT	24.89±0.26	22.75
Atherosperma moschatum	WR	BlT	22.57±0.85	47.80
Cardwellia sublimis	CT	BlT	22.46±0.58	48.92
Castanospermum australe	CT	BlT	22.04±0.4	53.48
Ceratopetalum succirubrum	RC	BlT	26.52±0.13	5.21
Corymbia terminalis	AMU	BlT	19.89±0.29	76.65
Cryptocarya mackinnoniana	CT	BlT	24.59±0.12	26.02
Daphnandra repandula	RC	BlT	23.69±0.57	35.69
Doryphora aromatica	RC	BlT	25.41±0.88	17.19
Dysoxylum papuanum	CT	BlT	20.83±0.44	66.59
Elaeocarpus grandis	CT	BlT	22.34±0.1	50.30
Endiandra leptodendron	CT	BlT	26.86±0.6	1.51
Eucalyptus amplifolia	CP	BlT	21.02±0.31	64.53
Eucalyptus camaldulensis	AMU	BlT	20.28±0.35	72.43
Eucalyptus clelandii	GWW	BlT	17.68±0.17	100.56
Eucalyptus dumosa	CM	BlT	19.01±0.42	86.15
Eucalyptus fibrosa	CP	BlT	23.24±0.32	40.57

Species	Site Code[1]	PFT	$\Delta^{13}C$ (‰)	Calculated WUE_i
Eucalyptus miniata	LF	BlT	21.86±0.07	55.39
Eucalyptus moluccana	CP	BlT	21.48±0.24	59.50
Eucalyptus obliqua	WR	BlT	22.01±0.73	53.79
Eucalyptus salmonophloia	GWW	BlT	18.88±0.09	87.56
Eucalyptus salubris	GWW	BlT	18.02±0.19	96.82
Eucalyptus socialis	CM	BlT	19.94±0.18	76.17
Eucalyptus tereticornis	CP	BlT	21.27±0.26	61.85
Eucalyptus tetrodonta	LF	BlT	19.82±0.34	77.39
Eucalyptus transcontinentalis	GWW	BlT	19.75±0.31	78.24
Eucryphia lucida	WR	BlT	22.07±0.06	53.16
Ficus leptoclada	RC	BlT	21.53±0.49	59.01
Ficus variegata	CT	BlT	21.85±0.29	55.60
Flindersia bourjotiana	RC	BlT	23.8±0.43	34.54
Gillbeea adenopetala	RC	BlT	24.41±0.26	27.94
Gillbeea whypallana	CT	BlT	23.22±0.42	40.79
Leptospermum lanigerum	WR	BlT	21.61±0.39	58.15
Litsea leefeana	RC	BlT	23.9±0.48	33.38
Melaleuca squarrosa	WR	BlT	21.94±0.25	54.60
Myristica globosa	CT	BlT	24.04±0.53	31.91
Notelaea ligustrina	WR	BlT	21.2±0.51	62.52
Nothofagus cunninghamii	WR	BlT	21.06±0.59	64.02
Phyllocladus aspleniifolius	WR	S	18.48±0.68	91.93
Pittosporum bicolor	WR	BlT	19.99±0.67	75.63
Polyscias elegans	RC	BlT	22.96±0.6	43.60
Pomaderris apetala	WR	S	23.55±0.44	37.21
Prunus turneriana	RC	BlT	25.83±0.74	12.59
Rockinghamia angustifolia	CT	BlT	22.69±0.35	46.49
Synima cordierorum	CT	BIT	22.8±0.39	45.33
Syzygium johnsonii	RC	BlT	25.7±0.07	13.99

Species	Site Code[1]	PFT	$\Delta^{13}C$ (‰)	Calculated WUE_i
Syzygium sayeri	CT	BlT	23.01±0.46	43.04
Tasmannia lanceolata	WR	S	21.8±0.26	56.03
Xanthophyllum octandrum	CT	BlT	22.64±0.6	47.08

[1] AMU = Alice Mulga; WR = Warra tall eucalypt; CT = Cape Tribulation; RC = Robson's Creek; GWW = Great Western Woodlands; CM = Calperum Mallee; LF = Litchfield forest; CP = Cumberland Plain.

Table S2: List of climate variables used in climate analysis

WorldClim Code	Variables
BIO_1	Mean Annual Temperature
BIO_2	Mean Diurnal Range
BIO_3	Isothermality
BIO_4	Temperature Seasonality
BIO_5	Max Temperature of Warmest Month
BIO_6	Min Temperature of Coldest Month
BIO_7	Temperature Annual Range
BIO_8	Mean Temperature of Wettest Quarter
BIO_9	Mean Temperature of Driest Quarter
BIO_{10}	Mean Temperature of Warmest Quarter
BIO_{11}	Mean Temperature of Coldest Quarter
BIO_{12}	Mean Annual Precipitation
BIO_{13}	Precipitation of Wettest Month
BIO_{14}	Precipitation of Driest Month
BIO_{15}	Precipitation Seasonality
BIO_{16}	Precipitation of Wettest Quarter
BIO_{17}	Precipitation of Driest Quarter
BIO_{18}	Precipitation of Warmest Quarter
BIO_{19}	Precipitation of Coldest Quarter

Table S3: Relationships of leaf traits with Mean Annual Precipitation and Moisture Index

Traits[1]	Correlated with ln MAP						Correlated with MI					
	Dry-season			Wet-season			Dry-season			Wet-season		
	Adj r^2	*slope*	*p*	*Adj r^2*	*slope*	*p*	*Adj r^2*	*slope*	*p*	*Adj r^2*	*slope*	*p*
A_{400}	**0.224**	+	<0.0001	NS		> 0.05	**0.071**	+	< 0.05	NS		> 0.05
Ln E_{400}	**0.140**	+	<0.001	**0.142**	+	< 0.01	0.04	+	> 0.05	NS		> 0.05
Ln $vpdL_{400}$	**0.281**	-	<0.0001	NS		> 0.05	**0.119**	-	<0.0001	NS		> 0.05
sqrt g_{s400}	**0.414**	+	<0.0001	**0.119**	+	< 0.01	**0.142**	+	<0.01	NS		> 0.05
Ln WUE_i	**0.481**	-	<0.0001	**0.420**	-	<0.0001	**0.206**	-	<0.0001	**0.357**	-	<0.0001
C_i/C_a	**0.332**	+	<0.0001	**0.337**	+	<0.0001	**0.192**	+	<0.0001	**0.380**	+	<0.0001
C_{i400}	**0.352**	+	<0.0001	**0.439**	+	<0.0001	**0.199**	+	<0.0001	**0.443**	+	<0.0001
LDMC	**0.349**	-	<0.0001	**0.331**	-	<0.0001	**0.277**	-	<0.0001	**0.366**	-	<0.0001
Ln LMA	**0.569**	-	<0.0001	**0.534**	-	<0.0001	**0.412**	-	<0.0001	**0.504**	-	<0.0001
Ln FMA	**0.532**	-	<0.0001	**0.516**	-	<0.0001	**0.369**	-	<0.0001	**0.452**	-	<0.0001
Ln Leaf N_{mass}	**0.192**	+	<0.001	**0.264**	+	<0.001	NS		> 0.05	**0.302**	+	<0.0001
Ln Leaf P_{mass}	**0.259**	+	<0.0001	NS		> 0.05	NS		> 0.05	NS		> 0.05
Ln Ratio N/P	**0.102**	-	<0.01	**0.167**	+	< 0.01	NS		> 0.05	**0.09**	+	< 0.05
Ln Leaf N_{area}	**0.178**	-	<0.0001	**0.269**	-	<0.001	**0.363**	-	<0.0001	**0.204**	-	<0.01
Ln Leaf P_{area}	N/S		> 0.05	**0.399**	-	<0.0001	**0.228**	-	<0.001	**0.286**	-	<0.0001
A_{400}.N	**0.403**	+	<0.0001	**0.162**	+	<0.01	**0.396**	+	<0.0001	NS		> 0.05
Ln A_{400}.P	**0.106**	+	< 0.01	**0.272**	+	<0.001	**0.334**	+	<0.001	**0.119**	+	<0.01

NS = Non-significant

[1]E = transpiration rate; VPD = vapour pressure deficit; g_s = stomatal conductance; WUEi = intrinsic water-use-efficiency; Ci/Ca = ratio of internal to external concentrations of CO_2; LDMC = leaf dry matter content; LMA = leaf mass to area ratio; ; FMA = foliar mass per unit area; N_{mass} = foliar N content expressed per unit dry weight; P_{mass} = foliar P content per unit mass; N_{area} = foliar N content expressed per unit leaf area; P_{area} = foliar P content per unit leaf area;

Table S4: Variation in $\Delta^{13}C$ and WUE_i by biome

Mean and s.e of wet and dry season $\Delta^{13}C$ and WUE_i. Means followed by different letters across sites in each season are significantly different (Tukey HSD, confidence level of 0.05).

Biome[1]	$\Delta^{13}C$ (‰)		WUE_i (‰)	
	Dry-season	Wet-season	Dry-season	Wet-season
SW	19.75±0.49c	19.15±0.32a	78.14±5.26a	84.60±4.30a
STS	19.82±0.25c	20.15±0.40a	77.35±2.74a	73.85±3.45a
TW	20.16±0.25c	20.18±0.28a	73.84±4.10a	73.57±3.03a
HTS	20.77±0.38b,c	-	67.21±2.84a,b	-
TWF	21.54±0.55b,c	23.51±0.56b	68.80±5.91a,b	37.68±6.12a,b
LTR	22.98±0.46a,b	23.02±0.39b	43.25±4.93a,b	42.86±4.17a,b
UTR	24.05±0.76a	24.31±0.52b	31.74±8.16a	29.04±5.62b

[1] SW = semi-arid woodland; STS = semi-arid tropical savanna; TW = tropical woodland; HTS = high rainfall tropical savanna; TWF = temperate wet forest; LTR = lowland tropical rainforest; UTS = upland tropical rainforest

Brief site descriptions of the seven Supersites (8 nodes)

Calperum Mallee (CM)

The Calperum Mallee SuperSite is in the mallee semi-arid ecosystem located approximately 25 km north of Renmark in South Australia. The landscape is an extensive plain with undulating mallee woodland and riverine vegetation that fringes the River Murray and its anabranches. The vegetation is dominated by upper storey Eucalypt trees of four species (*Eucalyptus dumosa, Eucalyptus incrassata, Eucalyptus oleosa* and *Eucalyptus socialis*) (Meyer *et al.*, 2015).

Great Western Woodlands (GWW)

The Great Western Woodlands located in south-west Western Australia is the largest remaining intact semi-arid temperate woodland in the world. The vegetation comprises a 16-million hectare mosaic of mallee, scrub–heath and woodland and is locally determined by edaphic factors and influenced by historic disturbances (Gosper *et al.*, 2013). Mean annual rainfall is ~250 mm with the highest-mean rainfall months in winter. *Eucalyptus salubris* constructs the dominant crown layer in association with other *Eucalyptus* species (*E. salmonophloia, E. longicornis and E. moderata)* (Gosper *et al.*, 2013).

Alice Mulga (AMU)

The semi-arid Alice Mulga SuperSite is located approximately 200 km north of Alice Springs, in the Northern Territory of Australia. The climate is characterized as having hot summers and warm winters. Mean annual rainfall is ~300 mm and is highly seasonal, mostly occurring in large rainfall events during summer. Vegetation is dominated by Mulga (*Acacia aneura* and related species) woodlands, occasionally with large areas of spinifex under sparse woodland of *Corymbia* and other *Acacia* species (Cleverly et al., 2016).

Cumberland Plain (CP)

The Cumberland Plain is a sclerophyll *Eucalyptus* woodland west of Richmond in New South Wales. The soil is characterized by nutrient-poor alluvium from sandstone and shale bedrock in the Blue Mountains deposited by the Nepean River. Despite being nutrient poor, this SuperSite supports high regional biodiversity and endemic biota and is dominated by *Eucalyptus fibrosa*, *E. moluccana* and *E. tereticornis* in the overstorey. Mean annual precipitation of this site is 900 mm (Table 1).

Warra Tall Eucalypt (WR)

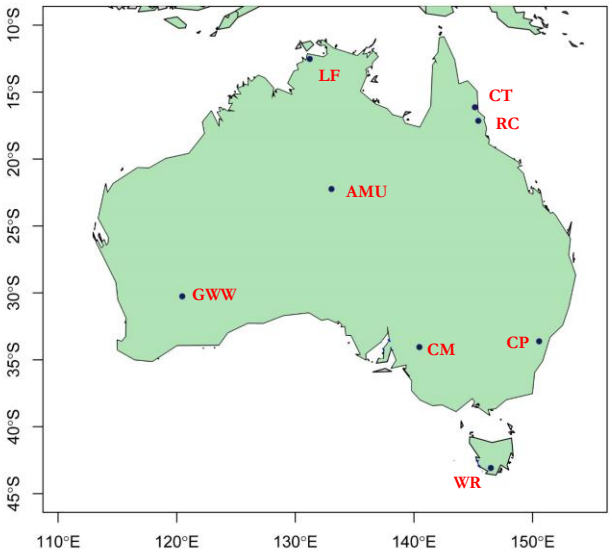
The Warra Tall Eucalypt SuperSite is a cool, wet temperate forest located in Tasmania. Vegetation is dominated by tall *Eucalyptus obliqua* occurring in a full range of successional stages from young regrowth forests to old-growth mixed forests (Hickey *et al.*, 1999). Mean annual temperature at this site is the lowest (~10°C), with a mean annual precipitation of 1474 mm (Table 1).

Litchfield Savanna Forest (LF)

The Litchfield Savanna SuperSite is a ~1.5 km^2 tropical savanna 70 km south of Darwin in northern Australia. This site is representative of the dominant ecosystem of that region. Climate of this site is typical of northern Australia with extremely seasonal and high rainfall and approximately 56% of this site is burnt annually (Murphy *et al.*, 2010). However, in this study, data collected from Howard Springs (approximately 65 km north of Litchfield SuperSite; (Cernusak *et al.*, 2011) have been used as a representative of this particular SuperSite. This approach is justified because both of these sites had very similar vegetation and climate conditions as well as frequency of occurrence of fire. The stand structure in these two sites are sufficiently similar as to not shift physiological properties at the leaf-scale given the species occurred in both sites largely overlap (Bowman *et al.*, 2001; Hutley and Beringer, 2010; Murphy *et al.*, 2010).

FNQ Rainforest (RC and CT)

The Far North Queensland Rainforest SuperSite is located in a tropical wet forest ~140 km north of Cairns in Far North Queensland. This SuperSite is structurally divided into two transects – a) the lowland rainforest based in the Daintree rainforest near Cape Tribulation (CT; MAT = 25.2 °C, Ozflux site average MAP = 5700 mm) and b) the upland rainforest based around Robson Creek (RC; MAT = 21 °C, MAP = 2140 mm). Precipitation is highly seasonal with most occurring during summer (Weerasinghe *et al.*, 2014). FNQ supports 10% of Australian flora despite of occurring in only 0.2% its landmass. Consequently a substantial number of the species in this study comes from this SuperSite. Data from two nodes of this SuperSite, i.e., Cape Tribulation and Robson Creek were collected and analysed independently in this study because of significantly different environmental clines (altitude, MAT and MAP) that exists in these two nodes of the Far North Queensland sites.



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120 **Figure S1:** **Location of SuperSites (represented by black dots).**

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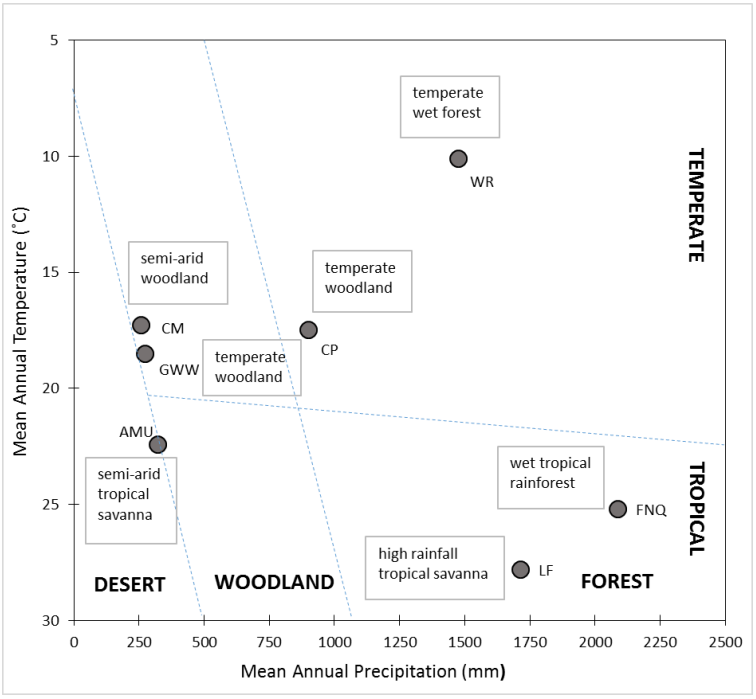

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124 **Figure S2:** **Mean annual temperature, mean annual precipitation, and biomes of the study**
125 **sites.**
126 Each SuperSite is plotted in the Whittaker Biome Diagram (Whittaker, 1975) using the MAT
127 and MAP observations generated for each site from the WorldClim data.

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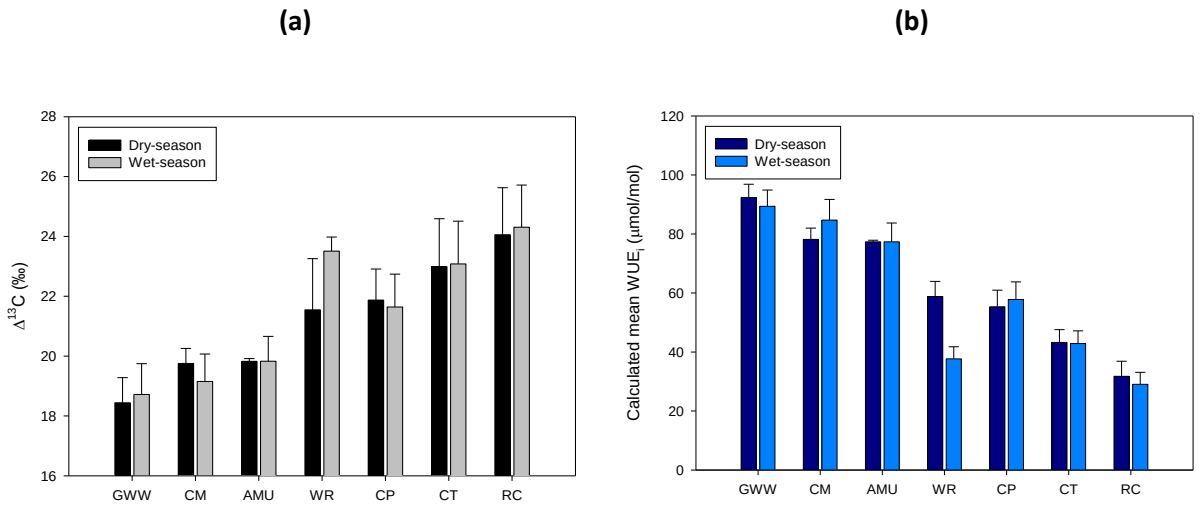


Figure S3: **Site mean values of (a) $\Delta^{13}C$ and (b) WUE_i**
Dark and light bars represent mean of dry and wet-season respectively and the error bars represent standard errors.

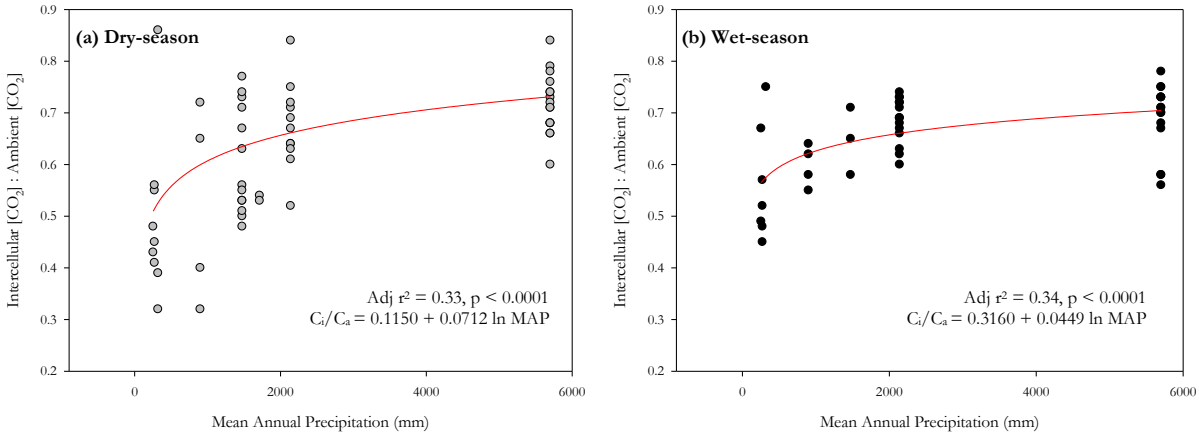
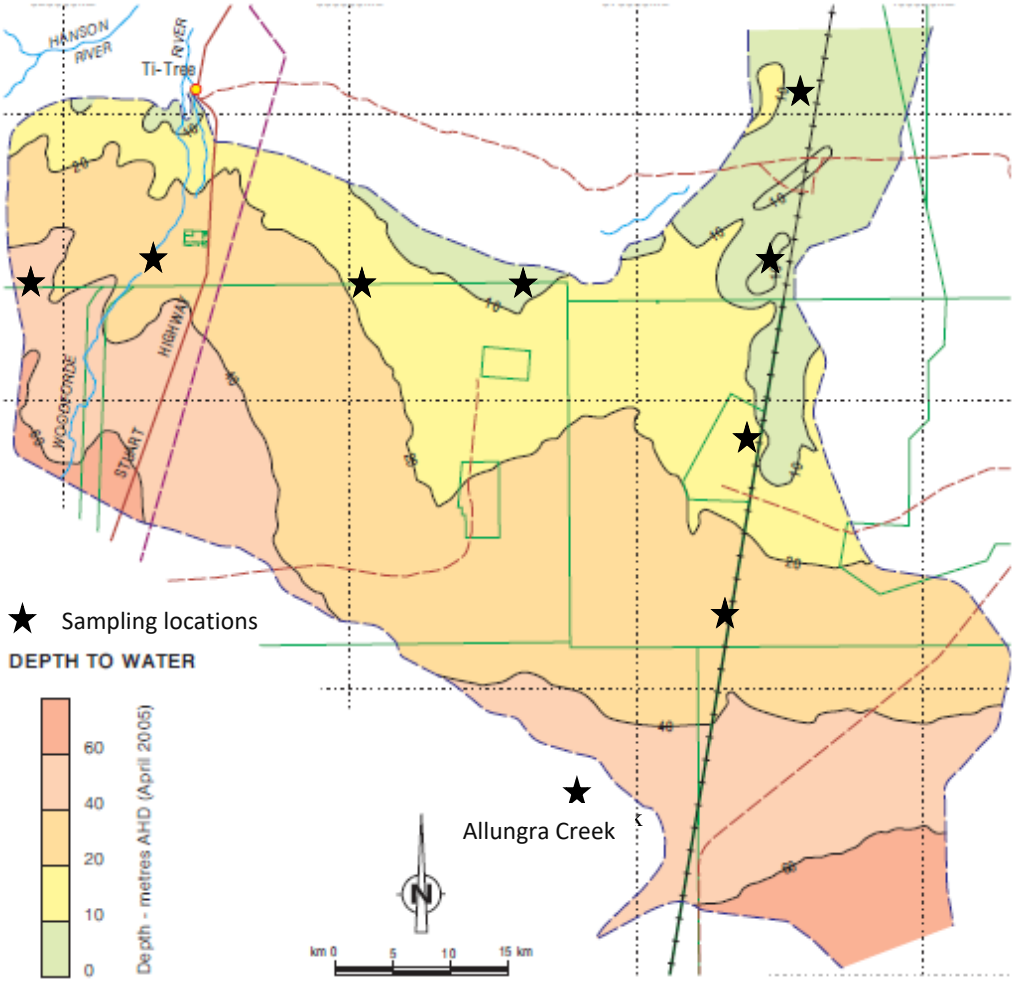


Figure S4: Ratio between intercellular and ambient [CO_2] (C_i/C_a) for both seasons plotted as functions of mean annual precipitation (MAP).

Left and right panels are plotted from dry- and wet-season data respectively. Statistically significant correlations with MAP are plotted with red regression lines.



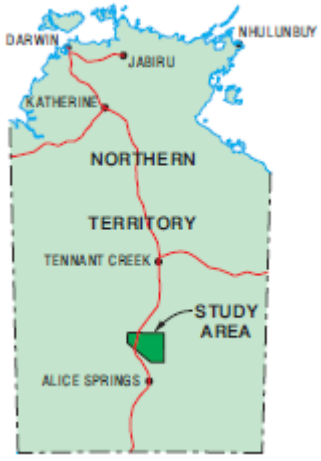


Figure S5: Map of the Northern Territory (NT) of Australia and the study area within the NT and the Ti Tree basin. Green lines represent property boundaries. AHD = Australian Height Datum