Field-based Forest Carbon Assessment
Griffith University, Gold Coast Campus

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Contents

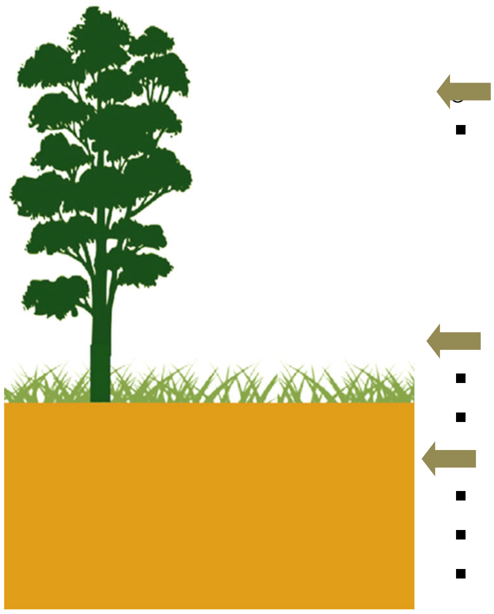
Summary

The native forests of Griffith University contribute a range of ecosystem services and functions including sequestering carbon, and hence are an important component of Griffith University's Sustainability Goals including the United Nations Sustainable Development Goal (UNSDG) 13: Climate Action and UNSDG 15: Life on Land. To estimate the carbon currently stored within the native forests, and the potential for future carbon sequestration, field estimation of the carbon sequestered in the forests on the Gold Coast campus of Griffith University was undertaken in 2023. Specifically, Above Ground Biomass was estimated by converting measurements of the height and width of all woody plants and standing dead trees with a Diameter at Breast Height of at least 5 cm along two randomly located 20 x 50 m transects in the dominant Blackbutt forest Regional Ecosystem (RE) using standard allometric calculations. These field values were then converted to tons of Above Ground Carbon per ha **(126 t C ha^{-1})** which was then combined with the current area of native forest on-campus **(29.2 ha)** to give a final estimate of the amount of Above Ground Carbon **(3,679 t carbon)** as well as both Above and Below (in roots) Ground Carbon in woody plants **(4,672 t carbon) for the campus forests**. These results demonstrate the importance of the forests on the Gold Coast campus in their role as relatively high carbon stocks when compared to other sub-tropical forest types in Queensland. It also emphasises their role as carbon sinks when they recover from past logging, and other types of disturbance, **with an estimated annual sequestration of carbon rate of 85 t per year** based on an estimated carbon flux for that forest type is 2.92 t ha^{-1} y^{-1}. However, they could become a source of carbon (losing more than they sequester) if not appropriately managed, including damage to the few remaining large old trees, which are significant carbon stores, with less than 3% of the trees accounting for more than 52% of the carbon stock on the campus. Inappropriate bushfire management is another important risk that could reduce the sequestration potential of these forests.

Background

Measuring carbon in forests

The type, age and condition of forests and other ecosystems affect the rate at which they sequester and store atmospheric carbon in living and non-living tissues. The term **Total Forest Ecosystem Carbon (TFEC)** refers to the sum of living and non-living biomass and soil that contributes to the total carbon budget of an ecosystem and is made up of three components. These are: **Current Carbon Stock (the current amount of carbon stored in plants, litter and soil, Figure 1),** the **Carbon Carrying Capacity** (the total maximum carbon stock achievable for a particular ecosystem type under a natural disturbance regime but without human-induced disturbances), and the **Carbon Sequestration Potential** which is the difference between the Current Carbon Stock and the Carbon Carrying Capacity.



Live Above-ground biomass

- Woody species biomass (canopy, sub-canopy, shrubs) including living above ground tree carbon stock (LAC) as well as standing dead trees

Understorey biomass (ground-layer plants)

- Standing and suspended woody debris (>25 mm)
- Fallen woody debris (>25 mm)

Soil and roots

- Fine surface litter (< 25 mm)
- Soil horizons
- Living and dead roots

Figure 1. Different components of **Current Carbon Stock** in forests.

Here we will be concentrating on measuring the Current Carbon Stock (the current amount of carbon stored in plants, debris, and soil) but specifically **the amount of carbon in woody plants – e.g., in Live Above-ground wood plant Carbon (LAC) and standing dead trees.**

Native forests at Griffith University

Griffith Universities Gold Coast and Nathan campuses contain regionally significant areas of remnant vegetation including Regional Ecosystems of conservation value listed as Endangered, and of Concern in relation to the Queensland *Vegetation Management Act 1999* (Table 1)(Griffith University, 2022a). These areas contain important habitat, supporting a diverse range of plant and animal species including endangered animals such as Koala (*Phascolarctos cinereus*). These conservation values are just some of the ecosystem services they provide to the community along with others such as protecting soil, improving air quality, enhancing water quality of catchments, and regulating temperature. The forests also provide a range of direct benefits to people visiting them including education, recreation, cultural and spiritual benefits as well as improving peoples' health and wellbeing (Griffith University, 2022a). The carbon values of the forests also contribute to Griffith University's Sustainability Goals and Sustainable Development Goals including SDG13: Climate Action as well as SDG15: Life on Land by reducing its carbon emissions (Griffith University, 2022b). The forests at the Nathan campus were logged in the past with the loss of large old-growth trees, but are regrowing, and hence sequestering carbon (Grieger and Mackey, 2019, Griffith University, 2022a).

Table 1. The Regional Ecosystems (RE) on the Nathan (N) and Gold Coast (GC) campuses (*Area of RE and totals in ha mapped by Nature Pacific, September 2023).

Regional Ecosystem	Biodiversity status	Campus	Area on campus*	Dominant vegetation
12.11.23	Endangered	GC	25.3	*Eucalyptus pilularis* open forest on coastal metamorphics and interbedded volcanics
12.11.27	Endangered	GC	1.2	*Eucalyptus racemosa* subsp. *racemosa* and/or *E. seeana* and *Corymbia intermedia* woodland on metamorphics +/- interbedded volcanics
12.3.5	No concern at present	GC	2.7	*Melaleuca quinquenervia* open forest on coastal alluvium
Total Gold Coast			**29.2 ha**	
12.9-10.4	No concern at present	N	17.5	*Eucalyptus racemosa* subsp. *racemosa* woodland to open forest.
12.9-10.17c	No concern at present	N	24.9	Open forest of *Eucalyptus carnea* and/or *E. tindaliae* and/or *E. helidonica* +/- *Corymbia citriodora* subsp. *variegata*, *Eucalyptus crebra, Eucalyptus major, Corymbia henryi, Angophora woodsiana, C. trachyphloia, E. siderophloia, E. microcorys, E. resinifera and E. propinqua*.
12.9-10.26	Of concern	N	55.5	*Eucalyptus baileyana* and/or *E. planchoniana* woodland to open forest.
12.11.24	No concern at present	N	10.2	*Eucalyptus carnea, E. tindaliae, Corymbia intermedia* +/- *E. siderophloia* or *E. crebra* woodland
12.11.25	Of concern	N	6.4	*Corymbia henryi* and/or *Eucalyptus fibrosa* subsp. *fibrosa* +/- *E. crebra, E. carnea, E. tindaliae* woodland
12.11.26	Of concern	N	9.1	*Eucalyptus baileyana* and/or *E. planchoniana* woodland to open forest
12.11.3	No concern at present	N	1.3	*Eucalyptus siderophloia, E. propinqua* +/- *E. microcorys*, *Lophostemon confertus, Corymbia intermedia, E. acmenoides* open

				forest on metamorphics +/- interbedded volcanics
12.3.6	No concern at present	N	0.2	*Melaleuca quinquenervia* +/- *Eucalyptus tereticornis*, *Lophostemon suaveolens*, *Corymbia intermedia* open forest on coastal alluvial plains
12.5.1g	No concern at present	N	0.5	*Eucalyptus planchoniana* and/or *E. baileyana* woodland to open forest +/- *C. trachyphloia*, *E. carnea*, *Angophora woodsiana*, *E. psammitica*, *E. crebra*, *E. racemosa* subsp. *racemosa*. Occurs on remnant Tertiary surfaces.
12.5.3a	Endangered	N	9.0	*Corymbia intermedia, Eucalyptus seeana* +/- *E. racemosa* subsp. *racemosa*, *Angophora leiocarpa, E. siderophloia, E. microcorys, C. citriodora* subsp. *variegata, Lophostemon suaveolens* woodland
12.9-10.12	Endangered	N	0.5	*Eucalyptus seeana, Corymbia intermedia, Angophora leiocarpa* woodland on sedimentary rocks
12.9-10.17d	No concern at present	N	0.8	Open forest generally containing *Eucalyptus siderophloia*, *E. propinqua* or *E major*, *Corymbia intermedia*. Other characteristic species include *Lophostemon confertus*, *Eucalyptus microcorys* and *E. acmenoides* or *E. portuensis*. Other species that may be present locally include *Corymbia trachyphloia* subsp. *trachyphloia*, *C. citriodora* subsp. *variegata*, *E. longirostrata*, *E. carnea*, *E. moluccana* and occasional vine forest species. Hills and ranges on Cainozoic and Mesozoic sediments.
Total Nathan			**135.9 ha**	

Methods

Regional Ecosystems

In Queensland all native vegetation has been classified and mapped as Regional Ecosystems (RE) based on climatic zones, soil types and dominant vegetation (Queensland Government, 2022). Data about each Regional Ecosystem includes its past and current extent, conservation value, dominant plant species and natural fire regimes. For Griffith University campuses, data on the location and extent of each RE were mapped by Natura Pacific with these new values given in Table 1. The fifteen REs across the campuses are all types of native open forest and are classed as semi-mature in terms of succession. BioCondition and Above Ground Biomass were estimated along two randomly located transects within each of the REs at Nathan and the Gold Coast campuses with an area above 1 ha and where there is room for a 100 m transect (Neldner et al., 2022, Natura Pacific, 2023). BioCondition sampling was conducted as per Eyre et al. (2015).

The sampling of Biomass and Carbon for the native forest at Griffith University focuses on **live above ground woody plant carbon stocks (LAC) as well as dead standing trees**. On the Gold Coast and at Nathan, sampling of woody biomass (living and standing dead) was done in conjunction with BioCondition monitoring in each RE of suitable size and then extrapolating the above ground carbon for that forest (RE) type. This involved estimating the biomass of living and standing dead wood plants as **Diameter at Breast Height (DBH) combined with height (for some estimates). These values** were then converted into estimates of biomass and carbon using wood specific gravity for all species with these data, along with density and area of each RE, then multiplied by the area of forest on the campus to give a final value.

Gold Coast Field sampling

There are three REs on the Gold Coast campus, the Endangered RE 12.11.23 tall open Blackbutt (*Eucalyptus pilularis*) forest (around 25.3 ha) and then a small area of 12.11.27 Scribbly Gum (*Eucalyptus racemosa*) woodland (1.2 ha) and two small patches of 12.3.5 Broad-leaved Paperbark (*Melaleuca quinquenervia*) open forest (totaling around 2.7 ha). Only RE 12.11.23 was large enough to satisfy spatial criteria for BioCondition assessment (Tables 1 and 2). Two randomly located transects were established in remnants of RE 12.11.23, away from access trails, roads and paths, edges of the forest, other types of disturbances including clearing as well as away from ponds and waterways, with the full 100 m transect located parallel to contours and with the ends permanently marked with star pickets (Figure 2). Fieldwork measuring BioCondition and carbon in the forests for the Gold Coast occurred in May and June 2023 by a team consisting of Prof. Catherine Pickering from Griffith University, and Kate Leopold from Natura Pacific, with sampling taking just over one day per transect.

Table 2. Location details of the two BioCondition transects in the RE 12.11.23 on the Gold Coast Campus of Griffith University.

Transect Code	RE	Start Post Location		Mid Location (no post)		End Post Location	
		Latitude	**Longitude**	**Latitude**	**Longitude**	**Latitude**	**Longitude**
GC1	12.11.23	-27.96899	153.3793	-27.96859	153.37934	-27.96816	153.37942
GC2	12.11.23	-27.97268	153.3783	-27.97237	153.37925	-27.97254	153.37879

Figure 2. Map of Regional Ecosystems at the Gold Coast campus of Griffith University, including the location of the two (2) BioCondition transects, GC1 and GC2 within the RE 12.11.23 Blackbutt forest.

Because there were only two transects for the Gold Coast campus, the Diameter at Breast Height (DBH) and height of all woody plants (living and standing dead wood trunks) were recorded in the full 20 x 50 m central plot that is also used to estimate course woody debris for BioCondition (Figure 3). This is different to Nathan where there were 14 transects, so carbon was only estimated in half the area per transect, e.g., 10 x 50 m at Nathan (see details in the corresponding report for Nathan campus).

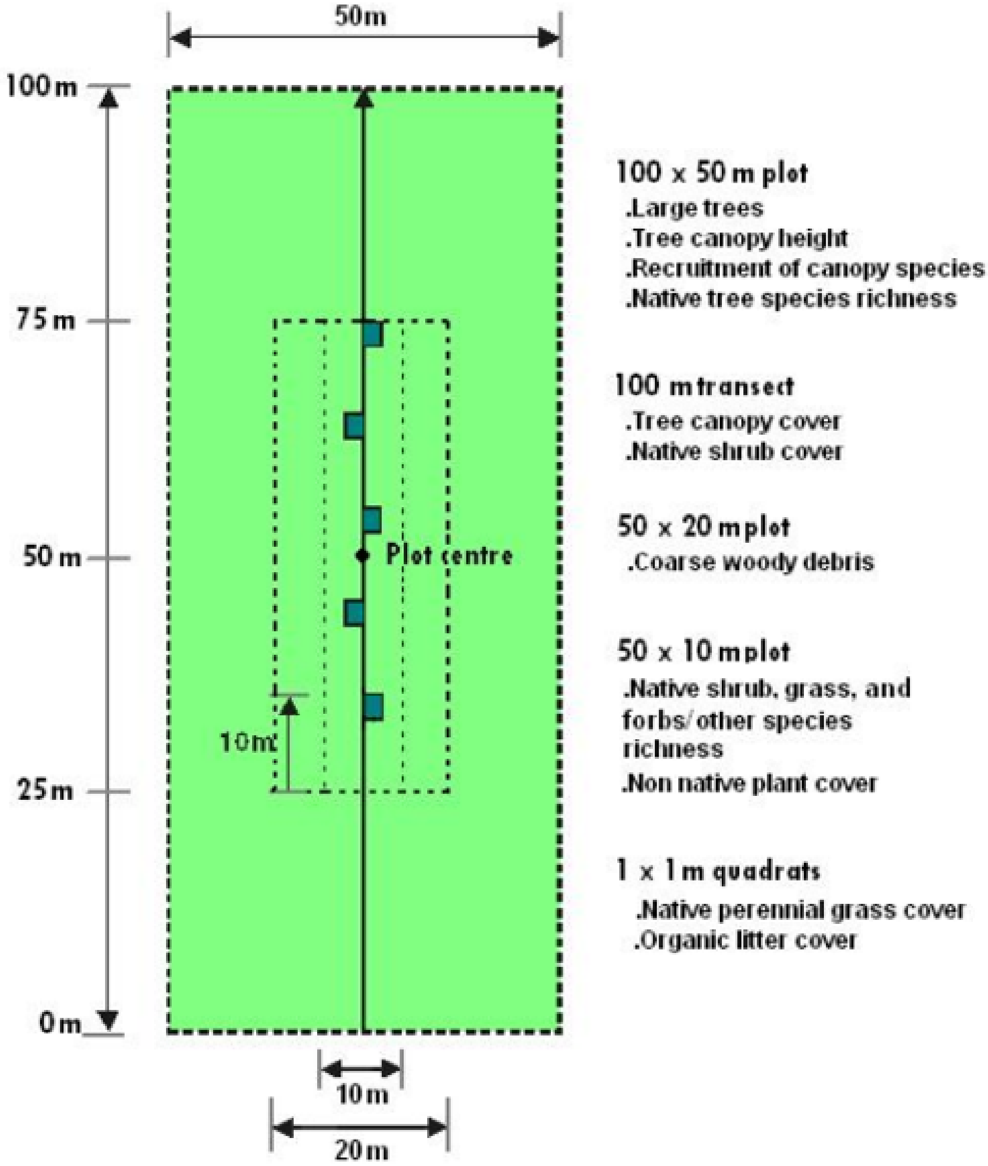


Figure 3. Layout of BioCondition transects, plots and quadrats modified from Queensland Government BioCondition Assessment Manual (Neldner et al., 2020).

Starting in the corner of the 20 x 50 m plot, woody vegetation above 2 m in height was measured, with one person recording, and the other identifying the species of woody plant and then measuring its DBH in cm at 1.3 m from the ground (Figure 4). Then, the height of the tree (highest point in the canopy) was measured using a clinometer(Vertex

5 ultrasonic height measure) in meters. If there were multiple trunks or stems at the DBH measurement height, the diameter of all stems was recorded.

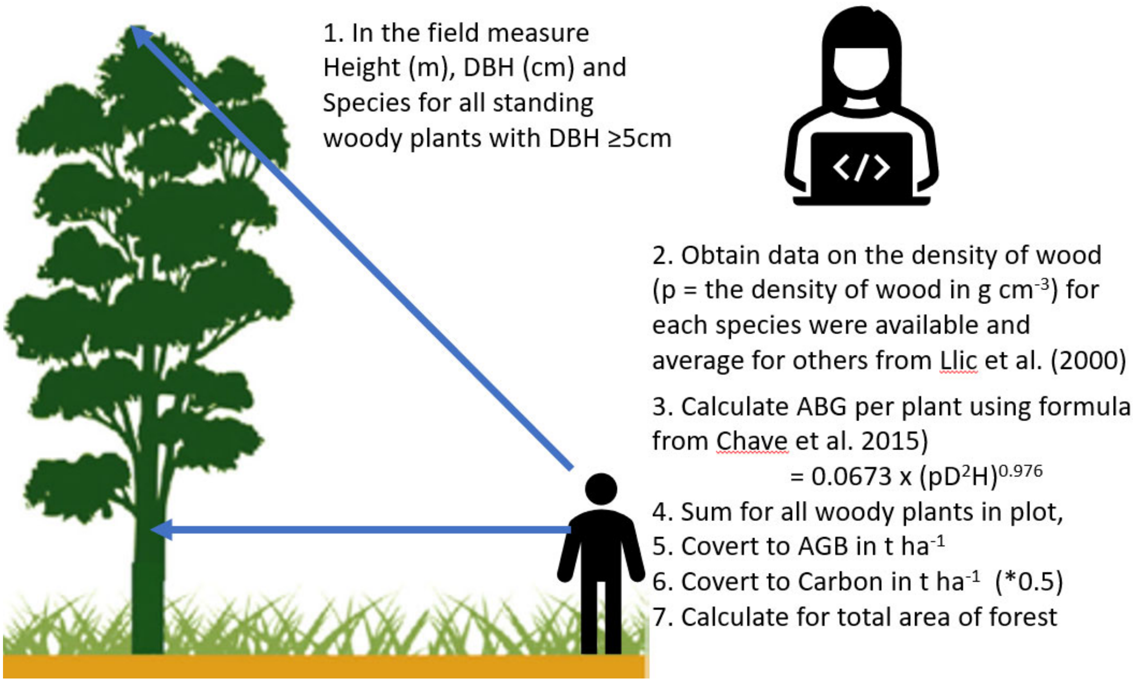


Figure 4. Schematic showing each stage in calculating carbon for the forests at Griffith University.

Initially all woody plants with a minimum DBH of 2 cm and height above 2 m were recorded. This initial data was then graphed, determining that 44 of the small woody plants (2-5 cm DBH) recorded accounted for 35% of all woody plants (e.g., out of 127 woody plants), but only <1% of the volume of wood in the forest (Figure 5). As a result, the method was adjusted to only record trees with DBH of 5 cm or above on the Gold Coast and Nathan campuses. This adjustment is also consistent with methods used in Ngugi et al. (2014) and Chave et al. (2015).

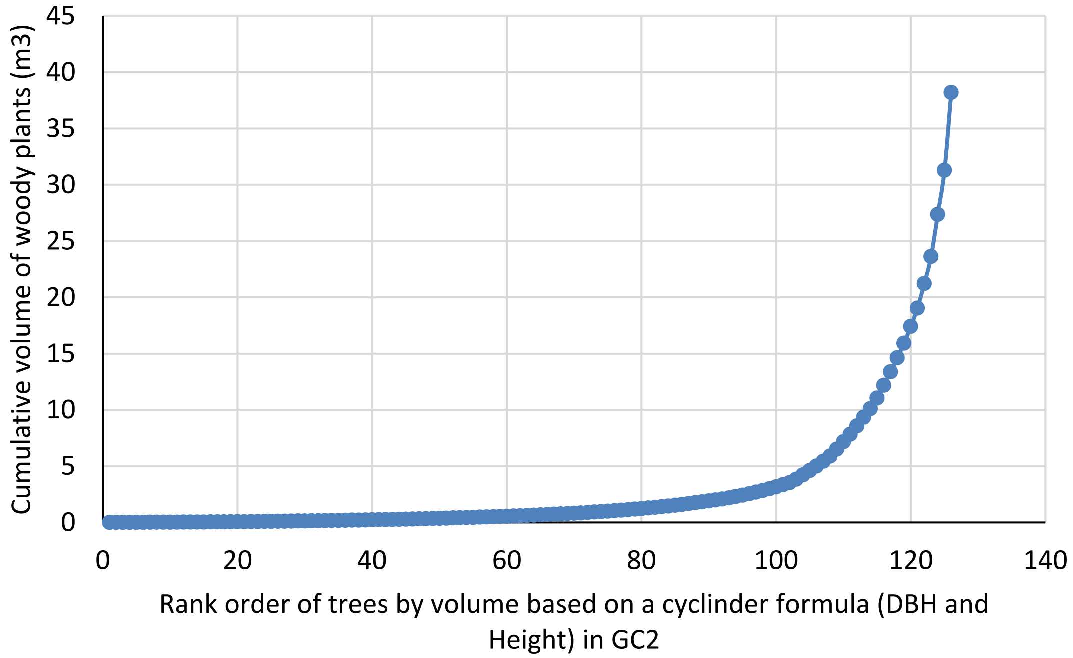


Figure 5. The initial estimate of the cumulative volume of the 127 single stemmed woody plants above 2 m in height and DBH of 2 cm based on a cylinder form in the Blackbutt forest on the Gold Coast in GC2 (50 x 20 cm plot).

Results

There were an estimated 1,100 woody plants per ha and 100 standing dead wood trunks with 5 cm or greater DBH in RE 12.11.23 Blackbutt forest at Griffith University's Gold Coast campus (Table 3). The most common woody plants in this forest were Black She-oak (*Allocasuarina littoralis*, 19% woody plants), Pink Bloodwood (*Corymbia intermedia*, 14%), Brush Box (*Lophostemon confertus*, 14%), Rough-barked Apple (*Angophora woodsiana*, 12%) and 100 standing dead wood trunks (9%) (Table 3, Figure 6).

Transect GC1 (RE 12.11.23)	**Transect GC2 (RE 12.11.23)**

Figure 6. Characteristics of the forest at the two transects.

Calculating Biomass and Carbon per ha in the forest

Values for Above Ground Biomass (AGB, which here is equivalent to LAC + standing deadwood trunks) were used to calculate the amount of carbon held for all woody plants and standing dead wood trunks. This was calculated in three (3) ways.

Method One used an allometric formula from Chave et al. (2015) that is often used for tropical trees (Figure 4). It combines DBH and height data for each plant from the field with the density of wood per species from databases to calculate AGB using the following allometric calculation:

$$\text{AGB estimate per tree} = 0.0673 \times (pD^2H)^{0.976},$$

where Diameter (DBH in cm), H = height in m, and p = the density of wood in g cm^{-3}.

The density of wood for different species uses data from Llic et al. (2000). The estimates of biomass were Basic Density (g cm^{-3}) values which were available for seven of the 18 species of trees in the forest. These values ranged from 0.557 g cm^{-3} (*Glochidion ferdinandi*) to 0.663 kg m^{-3} (*Eucalyptus pilularis*) with an average of 0.590 g cm^{-3}. Where data were not available for a species, the average wood density (0.590 g cm^{-3}) for trees at the site was used, including for standing dead wood trunks (Table 4).

Method Two involved calculating the volume of every woody plant and standing dead wood trunk using DBH and height to give a volume based on a cylinder (Table 4), and then converting that into AGB using the density of wood. This value was again changed to per ha, then converted to carbon equivalent above ground, and then for above and below ground biomass. This approach has been used in some studies but is considered to overestimate the final AGB and hence carbon.

Method Three used an allometric calculation for *E. pilularis* based on just DBH from Eamus et al. (2000), as it is the dominant species in the forest (Table 4). The formula for this is:

$\log_{10}Y = a + b\log_{10}X$,

where y is in kg and x = DBH in cm, a = -1.3086 and b = 2.6803.

This formula is based on nine (9) trees from Fraser Island and gives total above ground dry weight in kg. There are a range of formulae for estimating the AGB for *E. pilularis* based on different locations and sampling and hence give different results. There are a range of studies that have estimated AGB using the dominant tree, but these can over/ underestimate the values if the dominant tree is not characteristic of the other trees in the site; solely using DBH does not fully reflect the shape and hence AGB of trees (Eamus et al. 2000, Ngugi et al. 2014).

It is important to recognise for the forests on the Gold Coast campus the importance of specific species, and in particular a few big, old trees, to the amount of carbon in the forest (Figure 7, Table 4). In terms of size and hence AGB, the dominant species were Blackbutt (*E. pilularis*, 5% trees, but 51% of AGB), and *Corymbia intermedia* (13.5% of trees, 17.5% AGB) estimated using the allometric formula from Chave et al. (2015) (Figure 6). In addition, just six big trees (four *E. pilularis*, one *C intermedia* and one *E. resinifera*) representing just 2.7% of the trees surveyed accounted for 52% of the total AGB in the transects and hence carbon in the forest estimated using Method One (Table 4).

Table 3. The number of woody plants (≥5 cm DBH, ≥2 m height, living and standing dead trees) and the Above Ground Biomass (AGB in kg) and Carbon (kg) (using Method One based on DBH and height, wood density and the allometric formula from Chave et al. (2015)) in each of two 20 x 50 m transects, the two (2) transects combined and per ha in RE 12.11.23 Blackbutt forest on the Gold Coast campus of Griffith University.

Species	**GC1**		**GC2**		**Both transects**			**Per Ha**		
	#	**AGB (kg)**	**#**	**AGB (kg)**	**#**	**AGB (kg)**	**Carbon (kg)**	**#**	**AGB (kg)**	**Carbon (kg)**
Acacia concurrens			3	65.2	3	65.2	32.6	15	325.8	162.9
Acacia disparrima	6	354.8	5	106.6	11	461.4	230.7	55	2307.0	1153.5
Allocasuarina littoralis	32	562.8	11	246.7	43	809.5	404.8	215	4047.6	2023.8
Alphitonia excelsa	9	268.0			9	268.0	134.0	45	1339.8	669.9
Angophora woodsiana	9	976.0	17	3676.2	26	4652.2	2326.1	130	23260.8	11630.4
Casuarina cunninghamiana	1	7.8			1	7.8	3.9	5	38.9	19.4
Corymbia gummifera	1	545.6			1	545.6	272.8	5	2727.9	1363.9
Corymbia intermedia	13	2487.8	17	6343.1	30	8830.9	4415.5	150	44154.6	22077.3
Eucalyptus acmenoides			5	1631.4	5	1631.4	815.7	25	8157.0	4078.5
Eucalyptus pilularis	11	25686.3			11	25686.3	12843.1	55	128431.4	64215.7
Eucalyptus resinifera	1	2873.8	6	1019.1	7	3892.8	1946.4	35	19464.2	9732.1
Eucalyptus tindaliae			6	1980.0	6	1980.0	990.0	30	9899.8	4949.9
Glochidion ferdinandi	2	18.8			2	18.8	9.4	10	93.9	47.0
Leptospermum polygalifolium	3	17.9			3	17.9	9.0	15	89.5	44.8
Leptospermum trinervium	2	15.6			2	15.6	7.8	10	78.1	39.0
Lophostemon confertus	26	714.0	2	39.0	28	753.1	376.5	140	3765.3	1882.7
Lophostemon suaveolens	11	227.7			11	227.7	113.9	55	1138.6	569.3
Persoonia adenantha	2	16.4	1	6.7	3	23.1	11.6	15	115.5	57.8
Standing dead wood	6	158.0	14	304.3	20	462.3	231.2	100	2311.6	1155.8
Grand Total	**135**	34931.2	**87**	15418.2	**222**	50349.4	25174.7	**1110**	251747.25	125873.6

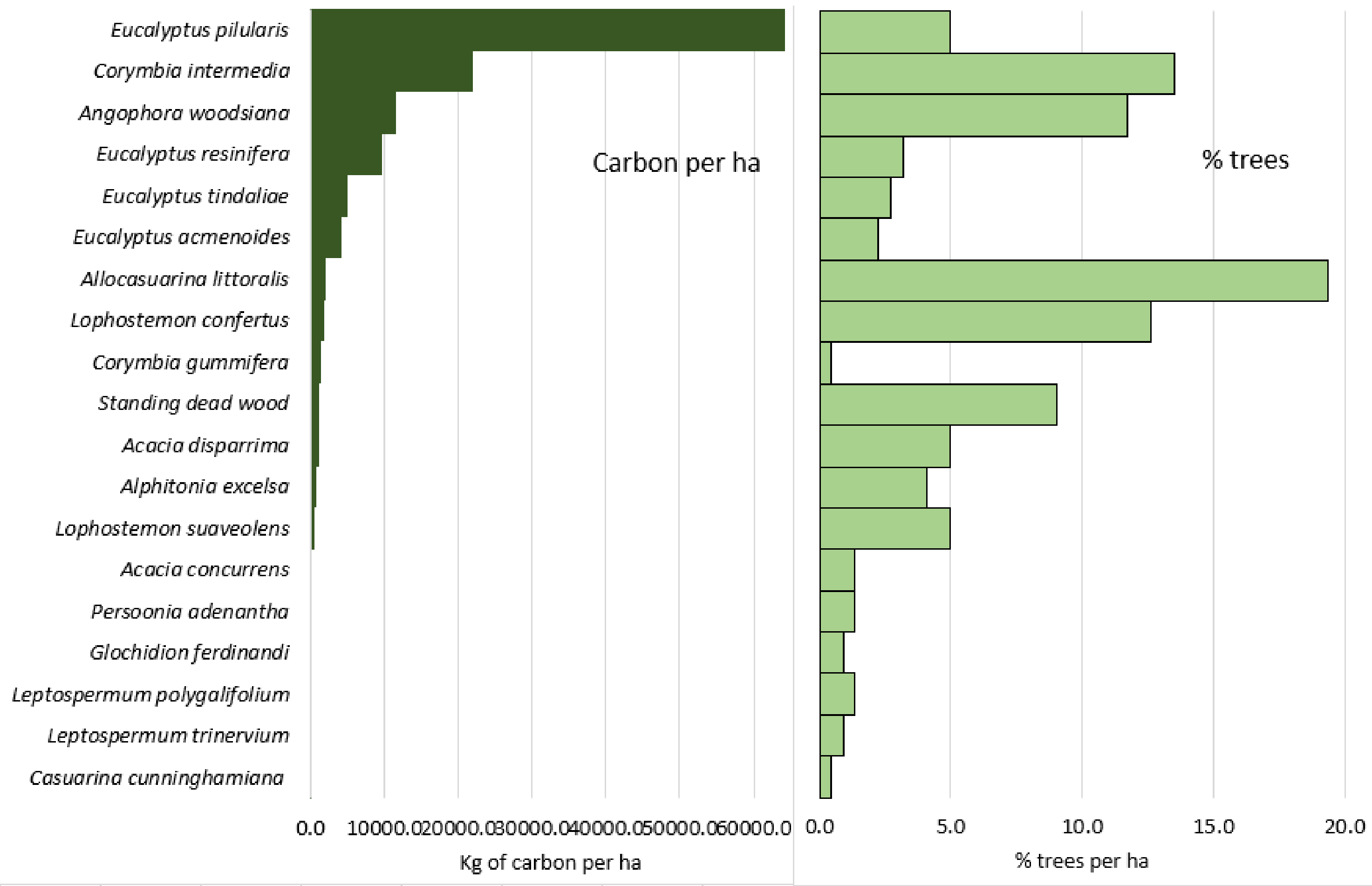


Figure 7. Total estimated kg of carbon per ha per species (using Method One based on Diameter at Breast Height and height, wood density and the allometric formula from Chave et al., 2015) and % of trees across two (2) transects in RE 12.11.23 Blackbutt forest on the Gold Coast campus of Griffith University.

Table 4. Details of the six largest trees recorded across two 20 x 50 m plot, the two plots combined and per ha in RE 12.11.23 Blackbutt forest on the Gold Coast campus of Griffith University.

Species	DBH (cm)	Height (m)	Density of wood	AGB (Kg)	Carbon (Kg)
Eucalyptus pilularis	77.1	35.7	0.663	7124.4	3562.2
Eucalyptus pilularis	68	32.2	0.663	5041.2	2520.6
Eucalyptus pilularis	83.7 + 9.2*	16.4 + 3.8*	0.663	3927.0	1963.5
Eucalyptus resinifera	53.8	32.5	0.59	2873.8	1436.9
Eucalyptus pilularis	44.5	39.7	0.663	2702.9	1351.5
Corymbia intermedia	55.9	28.2	0.59	2696.2	1348.1

* Tree has two trunks

Unfortunately, the largest and oldest tree on the Gold Coast campus (*E. pilularis* with DBH of 161 cm and estimated height of 39.6 m – see photo on the front cover) which was just outside one of the transects was extensively damaged during a poorly-managed prescribed burn. This tree has an estimated age of 350 years, and if solid pre burn would have contained an estimated 33,180 kg biomass, and 16,590 kg of carbon, although with the centre of the trunk hollow it would have been less than this. Although initially there was some indications that the tree survived with some epicormic growth, it appears that it may not recover.

The estimated AGB using each of the three methods for the two transects in the Blackbutt forest was then converted into a per ha value (Table 5). This total estimate of AGB per ha was converted into carbon by multiplying the AGB by 0.5 which is a standard conversion value (Keith et al., 2014). Then, Above and Below Ground living Biomass was calculated by adding another 25% based on an average shoot to root ratio of 0.25 for *Eucalyptus* species (Keith et al., 2014).

Table 5. Three methods used to calculate tons of Above Ground Biomass (AGB) and carbon per ha in the forests at Gold Coast campus of Griffith University. AGB = Above Ground, BGB = Below Ground Biomass

Method used to calculate values	AGB in t ha^{-1}	AGB+BGB in t ha^{-1}	AG C in t per ha^{-1}	Above and below ground C in t per ha^{-1}
1. DBH + height + allometric relationship to estimate volume, then use density wood to calculate AGB	252	315	126	157
2.DBH and height used to calculate volume per species as a cylinder and average biomass based on species with data	368	460	168	230
3. DBH times allometric value for *E. pilularis*	151	193	77	97

The AGB and carbon values vary, with Method One based on the single allometric value from Chave et al., (2015) giving medium estimates while Method Two using a cylinder for each tree gave high estimates and the values based on just DBH and an allometric value for *E. pilularis* gave the lowest estimate. In comparison Ngugi et al., (2014) using field measurements of DBH and then allometric formula for different tree species to estimate mean carbon stock (just AGB for living trees) for a range of Broad Vegetation Groups (BVG) (Figure 8). Specifically, they estimated a value of a mean carbon stock of 136.0 ± 9.3 t C ha^{-1} in forests in South East Queensland dominated by *E. pilularis* (BVG 8 b) and 146.4 ± 11.1 t C ha^{-1} in coastal wet tall open forests (Ngugi et al. 2014) (Figure 7). However, they also found values up to 421 t C $^{-1}$ for forests in the region. Other estimates of carbon based on field measurements of tall wet eucalypts forests (but in temperate areas) ranged from 400 to 1040 t C ha^{-1} depending on forest age and disturbance history in south-eastern Australia (Keith et al. 2014).

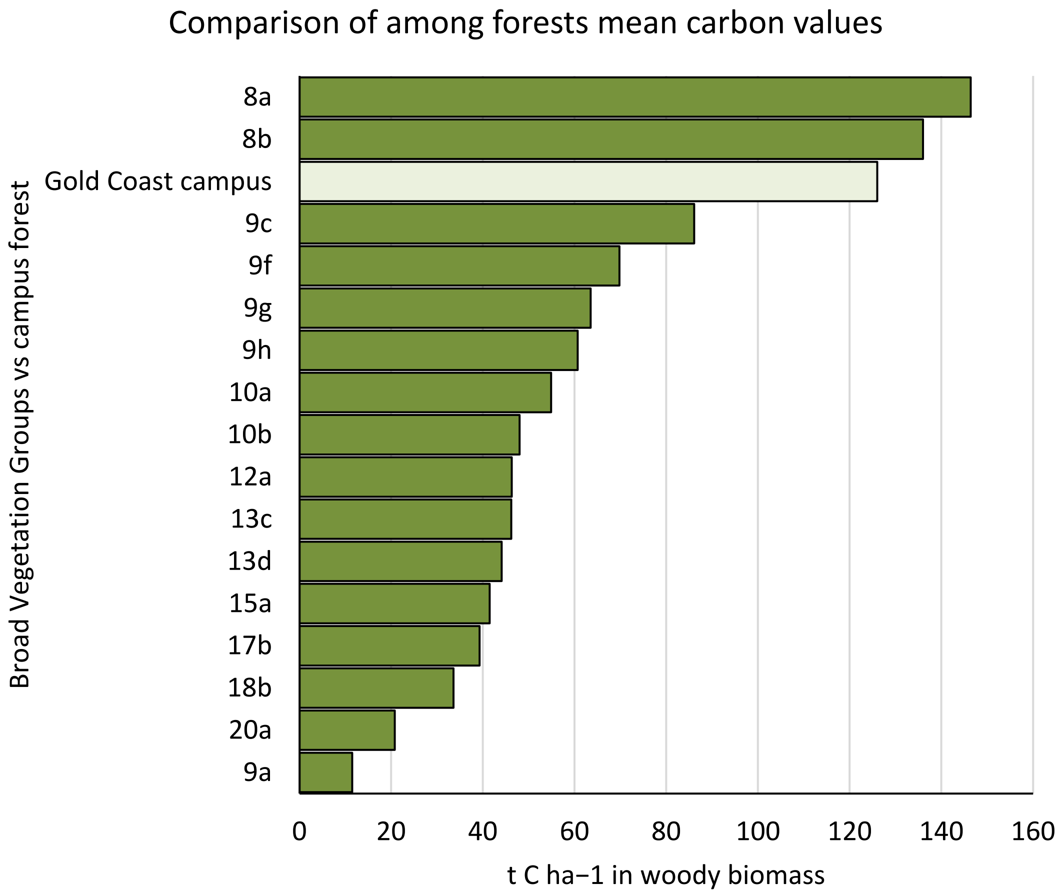


Figure 8. Comparison of the Above Ground Carbon in woody biomass from the 12.11.123 RE Blackbutt forest including standing dead trees, with that for living trees for different subtropical forest types as reflected by Broad Vegetation Groups (BGV) in Queensland (Ngugi et al., 2014). Note that BVG 8b is dominated by *E. pilularis* as well.

To calculate the total AGB of woody plants on the campus, the per ha values were converted into total area of forest on the campus using the 126 t C ha^{-1} value obtained using Method One (Table 6, Figure 4). This gives a value of 3187.8 t C in woody biomass in Blackbutt forest, 340.2 1 t C in the Melaleuca forest and 151.2 t C in the scribbly gum forest and 3679.2 t C on the Gold Coast campus overall. When the below ground values are included, the total for the campus is 4,672 t C.

Table 6. Estimates of total carbon in the forests on the Gold Coast campus of Griffith University based on field sampling.

RE	Area (ha) on Gold Coast	t C in woody biomass	t C in Above and Below ground
Blackbutt forest 12.11.23	25.3	3,187.8	3,972.1
Melaleuca forest 12.3.5	2.7	340.2	423.9
Scribbly gum forest 12.11.27	1.2	151.2	276
Totals		3,679.2	4,672

It is also possible to estimate the carbon flux for the forest using data from Ngugi et al., (2014) for equivalent forest types in the region (Broad Vegetation Groups). The most similar forest type is Moist Open Forests (BGV 8b) which has the closest Landscape Mean Lack stock (Figure 6). The estimated carbon flux for that forest type is 2.92 t ha^{-1} y^{-1}. Using this value, the Gold Coast forests may be sequestering carbon from the atmosphere at the rate of 85 t C y^{-1}. However, it may be much less than this, and could even become a carbon source if there is clearing, frequent fires and damage/loss of large old trees.

Results in Comparison to Past Desktop Assessment

These values are much higher than those obtained previously based on a desktop analysis (Grieger and Mackey, 2019). They calculated values based on desktop assessments using data from a study of live above ground tree carbon stocks (LAC) in sub-topical Queensland (Ngugi et al., 2014). Unfortunately, the value for the live above-ground carbon (LAC) stock was used instead of biomass so the values are half what they should be based on 146.4 ± 11.1 t C ha^{-1}, resulting in an underestimate value of 1,822 t for the Gold Coast, and 10,440 t for Nathan based on the type and area of REs (Table 7). Also, the area of the different RE used in that study differs from the last mapping based on information from the Queensland Government and the campus boundaries (Table 1 and Figure 2).

Table 7. Summary values from desktop estimate of carbon in forests at Griffith University from Grieger and Mackey (2019). *** These values are incorrect as they are carbon per ha in Ngugi et al., (2014)**

RE	Area (ha)	Total vegetation biomass/ha*	Biomass (t)	Carbon (t)	Standard Error
Gold Coast					
12.11.23	22.9	146	3354.4	1677.2	83.9
12.3.5	2.1	119.5	246.2	123.1	6.2
Other campuses					
12.11.24	17.3	146	2521.2	1260.6	63
12.11.25	5.9	146	872.7	436.3	21.8
12.11.26	8.3	146	1213.2	606.6	30.3
12.11.27	0.8	146	122.2	61.1	3
12.11.3	1.2	146	177.4	88.7	4.4
12.11.5	8.5	146	1246.6	623.3	31.2
12.3.6	0.1	140.9	13.1	6.6	0.3
12.5.3	2.1	97	208.6	104.3	5.2
12.9-10.12	0.3	96.9	27.3	13.7	0.7
12.9-10.17	21.1	175.8	3708.6	1854.3	92.7
12.9-10.26	50.7	150.4	7629.5	3814.8	190.7
12.9-10.4	16.7	163.5	2736.6	1368.3	68.4

Potential Errors

There are a range of potential errors with estimating biomass and hence carbon for forests (Eamus et al., 2000; Llic et al., 2000; Ngugi et al., 2014; Chave et al., 2015; Greiger and Mackey, 2019). First and foremost, the assessment method used for the native forests at Griffith University was Above Ground Biomass and specifically LAC biomass (just woody plants above ground both living and standing dead), and hence did not also include course woody debris, litter, or soil carbon. Estimating the other components is considerably more time and resource intensive. However, the current methods do provide insight into the carbon contribution of the living components of the forest and over time (Ngugi et al., 2014).

There are a range of uncertainties affecting general estimates of biomass and carbon due to limited available data when converting estimates of size of Above Ground Biomass focusing on LAC (woody plants) from the field into biomass and hence carbon. There were also potential errors relating to the sampling protocols used here, although where possible these were minimised.

General sources of error in estimating carbon values in forests include:

- Variation in shape of plants/species (moderate)
- Variation in density of wood within a plant (moderate)
- Different estimates of wood density direct measures as well as allometric both in why calculated, and in where data are from (moderate)

- No data for some species, so having to use data from similar species (moderate)
- Errors in allometric relationships for species with increased variance for larger trees

There were also specific errors associated with field protocols used in this study including:

- Limited spatial sampling due to the use of BioCondition plots (moderate)
- Errors in estimating tree height using clinometer (moderate)
- Errors in measuring DBH (very low)
- Misidentification of species (low)
- Errors in estimating area of REs on campus (low-moderate with changes in forest cover)

Carbon Sequestration and future management of the forest

The BioCondition assessment of the forest on the Gold Coast campus conducted at the same time as the carbon monitoring highlighted that there were below average numbers of large trees in the Blackbutt forest RE, reflecting historical logging practices (Natura Pacific, 2023). Therefore, with good management, the forest should continue to recover contributing to further carbon sequestration at an estimated rate of 85 $t\ y^{-1}$. However, there are a range of threats to the forest including its values as a carbon sink and for future carbon sequestration. This includes further clearing, fragmentation/loss of connectivity, weed infestations, inappropriate fire regimes (prescribed burning and wildfire) and dry conditions with climate change (Griffith University, 2022a; Natura Pacific, 2023). Some of these threats are within the direct control of the University (clearing, fragmentation, and prescribed burning regimes), while others are broader-based impacts of the surrounding landscape (loss of connectivity with other forests, wildfire, drought and other climate change impacts). As the current custodians of the forest, it is therefore important that Griffith University continues to take action to mitigate threats to the forest including limiting or if at all possible, stopping, further clearing of the forests.

Conclusions

The forests on the campus of Griffith University are important for the range of ecosystems services they provide including functioning as stores of carbon and, as they recover from past logging, carbon sequestration. Damage to the forests, including clearing, reduces the area of these ecosystems, including the already endangered RE 12.11.23 and therefore these harmful activities should be minimised or ideally, ceased, with consideration of other options for management where necessary. This is particularly important considering Griffith University's commitments to sustainability and the UN Sustainable Development Goals (UNSDGs) including an aim of reaching net zero carbon emissions by 2029 (Griffith University, 2022b).

The current areas of Blackbutt tall open forests, Melaleuca open forests and Scribbly gum forest on the Gold Coast campus contain an estimated 3,679 t of carbon in standing above ground wood vegetation, and 4,672 t including roots, and this estimate is likely even greater if future studies include other stores of carbon such as leaf litter and soil horizons. The forests may be sequestering carbon at the rate of 85 t y^{-1}, but, importantly, could become a source of carbon if not appropriately managed. For example, the few remaining large old trees that survived past logging in the forest are critical carbon stores, as although they account for less than 3% of the trees, they contain over 52% of all the carbon assessed in the forests. These trees need to be conserved as a priority, not only due to their carbon values, but also for their cultural and habitat values, which are an important natural asset to the University.

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