Field-based Carbon Assessment of the Arboretum at the Logan campus, Griffith University

Field-based Carbon Assessment of the Arboretum at the Logan campus, Griffith University

Catherine Pickering Griffith University, December 2023

Contents

Summary

Forests on the campuses 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 United Nations Sustainable Development Goal (UNSDG) 13: Climate Action and UNSDG 15: Life on Land. This includes the 5.2 ha Arboretum at the Logan campus of Griffith University. To estimate the carbon sequestered in the Arboretum over the initial nine years of growth, field work 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 (DBH) of at least 5 cm in 10m by 15m randomly located quadrats in each of 28 blocks of forest in the Arboretum using standard allometric calculations. These field values were then converted to tons of Above Ground Carbon per ha **(38.9 t C ha^{-1})** which was then combined with area of the Arboretum **(5.2 ha trees)** to give a final estimate of the amount of Above Ground Carbon **(192.5 t carbon)** as well as both Above and Below (in roots) Ground Carbon in woody plants **(240 t carbon)**. These results demonstrate the importance of the Arboretum where an open area of grass has been turned into a high biodiverse urban forest consisting of over **3,500 trees** in 2023 representing 56 species that is cooling the Logan campus, conserving soil, providing habitat for wildlife and wellbeing benefits for staff, students and visitors. It has also already sequestered about 29% (Gold Coast) or 27% (Nathan) of the carbon in the native forests on the other campuses. A rough estimate of the amount of carbon sequestered per year is 27 t per year based on the age of the Arboretum. Ongoing management of Arboretum and other wood vegetation on the Logan campus including trees in the Slakes Creek restoration forests, formal gardens and the small area remnant forest at the Logan Campus of Griffith University will ensure they continue to provide benefits including carbon sequestration.

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.

In this report, we concentrate 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 woody plant Carbon (LAC) and standing dead trees.**

Arboretum at the Logan campus of Griffith University

Across the ~55 ha of the Logan campus of Griffith University there are large areas of lawns and sports fields, riparian vegetation around and in two artificial lakes to the east formal gardens including planted trees near buildings, carparks and roads, some small areas of remnant native forests, and two large of planted forests/trees to the east – the semi-natural Slacks Creek riparian restoration forests, and 5.2ha of Arboretum (Figure 2)(Griffith University 2022a).

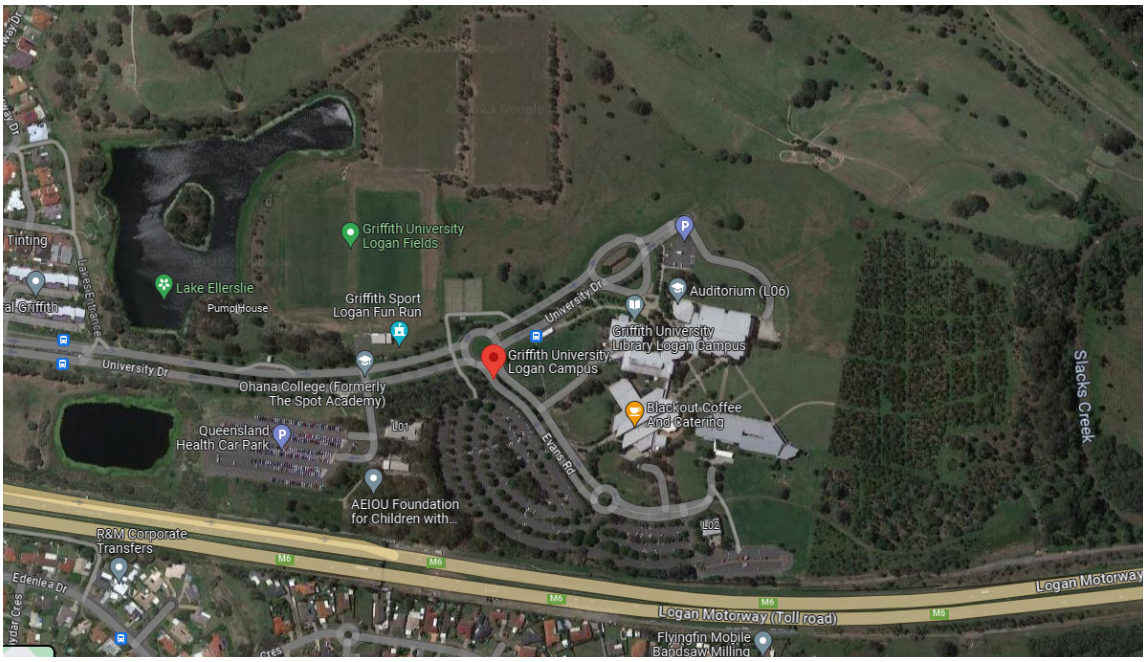

Figure 2. The general layout of the Logan campus of Griffith University including different types of vegetation including the Arboretum. Image from Google Earth.

Figure 3. Comparison of the area of the Arboretum in 2013 prior to planting showing round 20 exiting trees, and then the Arboretum in 2022. Images from Google Earth.

The main Arboretum consists of 28 blocks of trees covering 5.2 ha (excluding paths) is the results of a collaboration between the Logan City Council, the Water and Carbon group and Griffith University as the land owner (Griffith University 2022, Water and Carbon Group 2023). The project was initially funded by the Australian Government from 2013 to 2018 (Water and Carbon Group 2023). The goal for the Arboretum was to highlight the diversity of native species that would have occurred in and around the Logan campus including important food trees, European timber trees, and rare and threatened plants. Prior to the establishment of the arboretum there were a few (~20) established trees mostly in the south of the area (Figure 3). In September 2014, Phase 1 planting commenced concentrating on pioneer and canopy species with around 79 species and around 17,000 individuals planted including ~4,543 individual trees and tall shrubs from around 56 species (Table 1). The trees were planted in ~28 blocks representing different native vegetation communities including open forest, dry rainforest, subtropical rainforest and riparian rainforest (Table 1, Figures 3 and 4). In September 2015 there was additional planting as part of Phase 2, including many understory plants (mostly *Lomandra, Dianella, Carex* and *Imperata*) and around 130 more rainforest trees (*Araucaria cunninghamii* – 60, *Allocasuarina torulosa* – 40, *Polyscias elegans* – 30) in the Subtropical Rainforest blocks. In March 2018 some final additional planting of 100 more understory and rainforest species occurred in the Riparian Rainforest Zone. Since 2018 when Griffith University took over day to day responsibility for the Arboretum there has been ongoing weed control and maintenance of the paths between the blocks, as well as some thinning of trees/branches and clearing of the understory in the blocks closest to the campus (east)(pers. com. Vatsal Naik, 2023).

Figure 5. The Arboretum in September 2023, including areas where there is limited understory (left) compared to areas with more intact understory (right) and the paths between the blocks.

Ten years after initiation, and nine years since the first planting of trees, the Arboretum provides a range of ecosystem services for the campus and community such as protecting soil, improving air quality, enhancing water quality of catchments, and regulating air temperature. It also provides direct benefits to people visiting the Arboretum including education, recreation, cultural and spiritual benefits as well as improving people's health and wellbeing (Griffith University, 2022a). The carbon values of the Arboretum also contribute to Griffith University's Sustainability Goals in relation to United Nations Sustainable Development Goal (UNSDG) 13: Climate Action and UNSDG 15: Life on Land, by reducing carbon emissions (Griffith University, 2022a,b).

Table 1. Diversity and number of trees planted in the Arboretum at the Logan campus of Griffith University during the first phase of planting in September 2014. Data from the Water and Carbon Group Phase 1 Planting Schedule. Wood density data from Llic et al., (2000) in (g cm^{-3}).

#	Species	Broad group	Wood density	Total
1	*Acacia fimbriata*	Acacia		910
2	*Allocasuarina littoralis*	Sheoak	0.57	370
3	*Macaranga tanarius*	Rainforest	0.46	290
4	*Callistemon (Melaleuca) salignus*	Bottlebrush	0.76	170
5	*Eucalyptus tereticornis*	Eucalypts	0.778	120
6	*Alphitonia excelsa*	Rainforest	0.562	210
7	*Lophostemon confertus*	Eucalypts	0.69	155
8	*Homalathus nutans*	Rainforest		140
9	*Jagera pseudorhus*	Rainforest	0.63	90
10	*Guoia semiglauca*	Rainforest		95
11	*Commersonia bartramia*	Rainforest	0.41	110
12	*Flindersia australis*	Rainforest	0.798	65
13	*Corymbia tessellaris*	Eucalypts	0.919	170
14	*Flindersia schottiana*	Rainforest	0.586	60
15	*Glochidion ferdinandi*	Rainforest	0.557	60
16	*Lophostemon suaveolens*	Eucalypts	0.6	90
17	*Glochidion sumatranum*	Rainforest	0.57	55
18	*Grevillea robusta*	Rainforest	0.525	85
19	*Mallotus philippensis*	Rainforest	0.6	55
20	*Acacia concurrens*	Acacia	0.69	100
21	*Acacia disparrima*	Acacia		100
22	*Corymbia intermedia*	Eucalypts	0.752	150
23	*Eucalyptus siderophloia*	Eucalypts	0.913	40
24	*Hibiscus heterophyllus*	Rainforest		40
25	*Melia azedarach*	Rainforest	0.37	40
26	*Corymbia trachyphloia*	Eucalypts		40
27	*Acacia melanoxylon*	Acacia	0.546	66
28	*Eucalyptus racemosa**	Eucalypts	0.94	55
29	*Alphitonia petriei*	Rainforest	0.43	70
30	*Araucaria cunninghamii*	Rainforest	0.437	30
31	*Cryptocarya triplinervis*	Rainforest	0.6	30
32	*Eucalyptus microcorys*	Eucalypts	0.796	30
33	*Eucalyptus propinqua*	Eucalypts	0.834	30
34	*Eucalyptus resinifera*	Eucalypts	0.792	30
35	*Eucalyptus seeana**	Eucalypts	0.832	30
36	*Elaeocarpus grandis*	Rainforest	0.419	25

37	*Castanospermum australe*	Rainforest	20
38	*Eucalyptus grandis*	Eucalypts	20
39	*Eucalyptus robusta**	Eucalypts	60
40	*Ficus fraseri*	Rainforest	20
41	*Melaleuca bracteata*	Bottlebrush	20
42	*Melaleuca linariifolia*	Bottlebrush	20
43	*Cupaniopsis anarcardioides*	Rainforest	45
44	*Flindersia xanthoxyla**	Rainforest	15
45	*Podocarpus elatus*	Rainforest	15
46	*Polyscias elegans*	Rainforest	15
47	*Toona ciliata**	Rainforest	15
48	*Dysoxylum fraserianum*	Rainforest	10
49	*Ficus coronata*	Rainforest	10
50	*Petalostigma triloculare*	Rainforest	10
51	*Polyscias murrayi*	Rainforest	10
52	*Rhodosphaera rhodanthema**	Rainforest	10
53	*Streblus brunonianus*	Rainforest	10
54	*Gmelina leichhardtii*	Rainforest	8
55	*Ficus macrophylla*	Rainforest	2
56	*Ficus obliqua*	Rainforest	2

Figure 5. Details of the different blocks of trees and associated planting themes in the Logan Arboretum at the Logan campus of Griffith University. Image from Griffith University, 2014. The estimates of carbon do not include the existing Mixed Riparian Rainforest, Casuarina Grove or Vine Scrub Thicket that are part of the Slacks Creek restoration project to the east of the central part of the Arboretum. Figure is missing one path separating a block of Subtropical Rainforest Cabinet Timbers, with 28 blocks in the field rather than 27 blocks of vegetation shown here. There have also been changes in the naming of the vegetation types within blocks over time.

Methods

On-ground sampling of Biomass and Carbon for the Arboretum at the Logan campus Griffith University focused on **live above ground woody plant carbon stocks (LAC) as well as dead standing trees**. Because the Arboretum is planted, no BioCondition assessment was undertaken in contrast to the assessments of the native forests on the Gold Coast and Nathan campuses. Instead, a modified protocol was used to measure carbon by including increasing independent spatial samples with woody plants measured in 28 10 m by 15 m quadrats with one quadrat per vegetation block (Figure 6). In each quadrat, the **Diameter at Breast Height (DBH), height and type of vegetation were recorded**. These values were then converted into estimates of Above Ground Biomass and carbon using wood-specific gravity measures, along with density and area of the block to provide a final value.

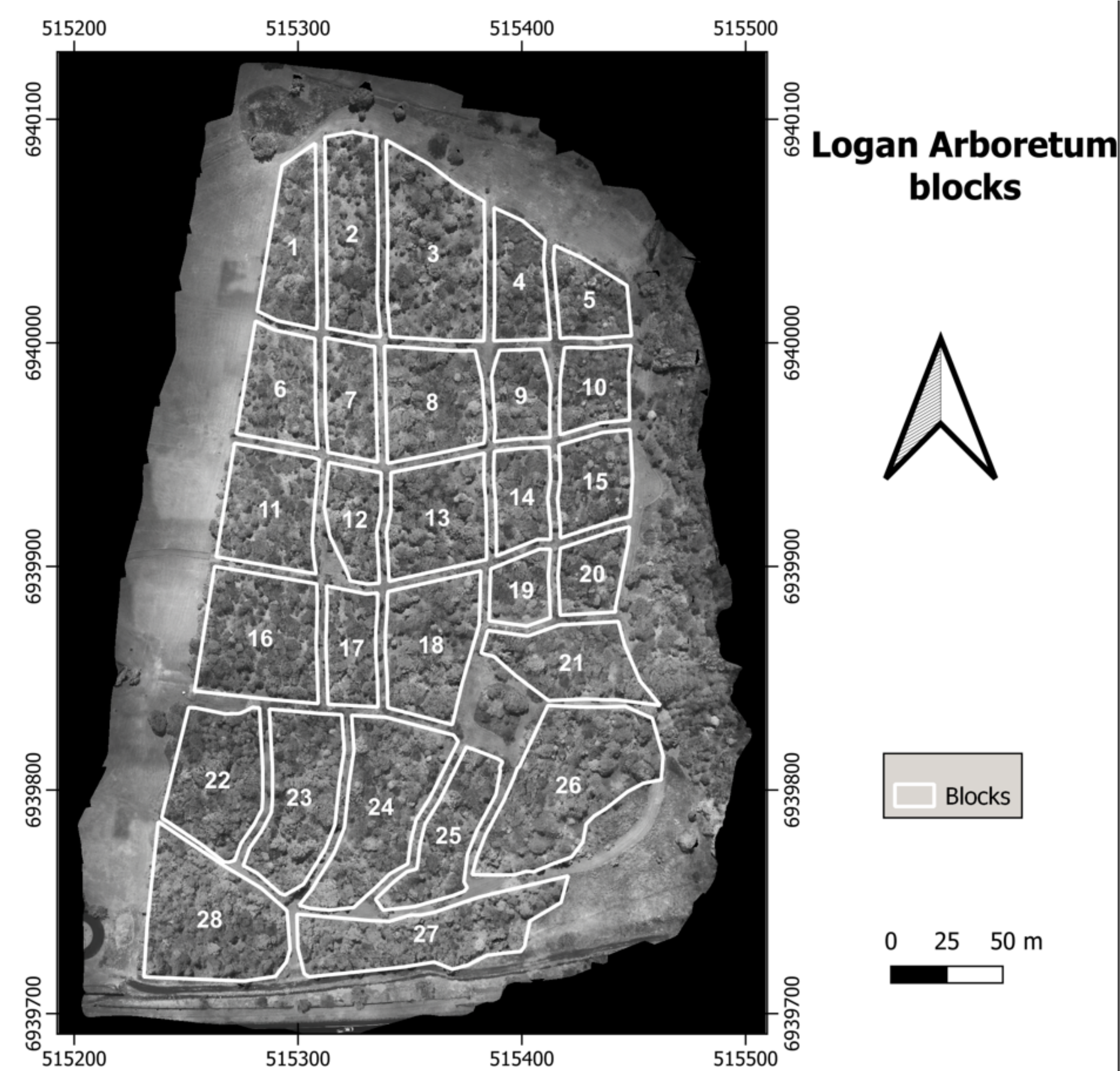

Figure 6. Details of the 28 blocks of vegetation in the Arboretum at the Logan Campus in September 2023 calculated based on drone multispectral image (Jigme Thinley pers. com. 2023).

Table 2. Location and size of the 28 blocks of trees in the Arboretum on the Logan campus with the latitude and longitude referring to the bottom east corner (latitude and Longitude) of the 10m by 15 m quadrats.

Block	Vegetation type	Size (ha)	Latitude	Longitude
1	Open Forest	0.16	-27.66366	153.6637
2	Open Forest	0.20	-27.66349	153.1554
3	Dry Rainforest	0.33	-27.66375	153.1557
4	Dry Rainforest	0.12	-27.66382	153.1561
5	Riparian Rainforest	0.11	-27.6639	153.1564
6	Open Forest	0.16	-27.66419	153.155
7	Open Forest	0.12	-27.66421	153.1554
8	Dry Rainforest	0.20	-27.6643	153.1558
9	Dry Rainforest	0.10	-27.66423	153.1561

10	Riparian Rainforest	0.11	-27.66427	153.1564
11	Open Forest	0.21	-27.66464	153.1441
12	Open Forest	0.11	-27.66473	153.1554
13	Dry Rainforest	0.21	-27.66471	153.1557
14	Dry Rainforest	0.11	-27.66469	153.1561
15	Riparian Rainforest	0.13	-27.66461	153.1565
16	Open Forest	0.28	-27.66536	153.155
17	Open Forest	0.12	-27.66527	153.1553
18	Dry Rainforest	0.23	-27.66528	153.1558
19	Dry Rainforest	0.08	-27.66510	153.1561
20	Riparian Rainforest	0.10	-27.66495	153.1564
21	Subtropical Rainforest Timbers	0.19	-27.66533	153.1564
22	Subtropical Rainforest Timbers	0.23	-27.66576	153.1549
23	Subtropical Rainforest Timbers	0.24	-27.66585	153.1553
24	Subtropical Rainforest Timbers	0.30	-27.66606	153.1555
25	Subtropical Rainforest Timbers	0.17	-27.66607	153.1558
26	Subtropical Rainforest Timbers	0.37	-27.66592	183.1564
27	Open Forest	0.28	-27.66634	153.1548
28	Open Forest	0.32	-27.66653	153.1558

Fieldwork for the Arboretum occurred in October 2023 by a team of four consisting of Prof. Catherine Pickering, Jesse Range, Joel Irwin and Jigme Thinley from Griffith University, with sampling taking around 11 person days to sample all 28 blocks.

Starting in the corner of the 10 m by 15 m quadrat (long side parallel with creek/campus), all trees above 2 m in height in m and DBH of 5 cm or great at 1.3 m from the ground were measured (Figure 7). The DBH was measured using a tape, while 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 at 1.3 m from the ground, the diameter and height of all trunks were recorded. The trees were allocated to a general tree types (Acacia 25.6% trees planted), Rainforest (42% trees planted), Eucalypts (20.2% planted), Sheoak (6.8% planted), Bottlebrush (5.2% planted) or dead)(Table 1). Location data for each tree was also collated using a phone GPS system (e.g. Vivo 1935 Android version using the KoboCollect App giving an average GPS precision was 4.6m), along with the location of the bottom right-hand (south-east) corner of each quadrat. The width of the trails within the Arboretum were also measured at 10 random points giving an average width of 4.35 m. The area of each block within the Arboretum was calculated using multispectral drone image data collected in September 2023, with colour bands combined to produce a false color composite image, with data then entered into R studio to calculate the area of each block (Figure 6, Table 2) (Jigme Thinley pers. com. 2023).

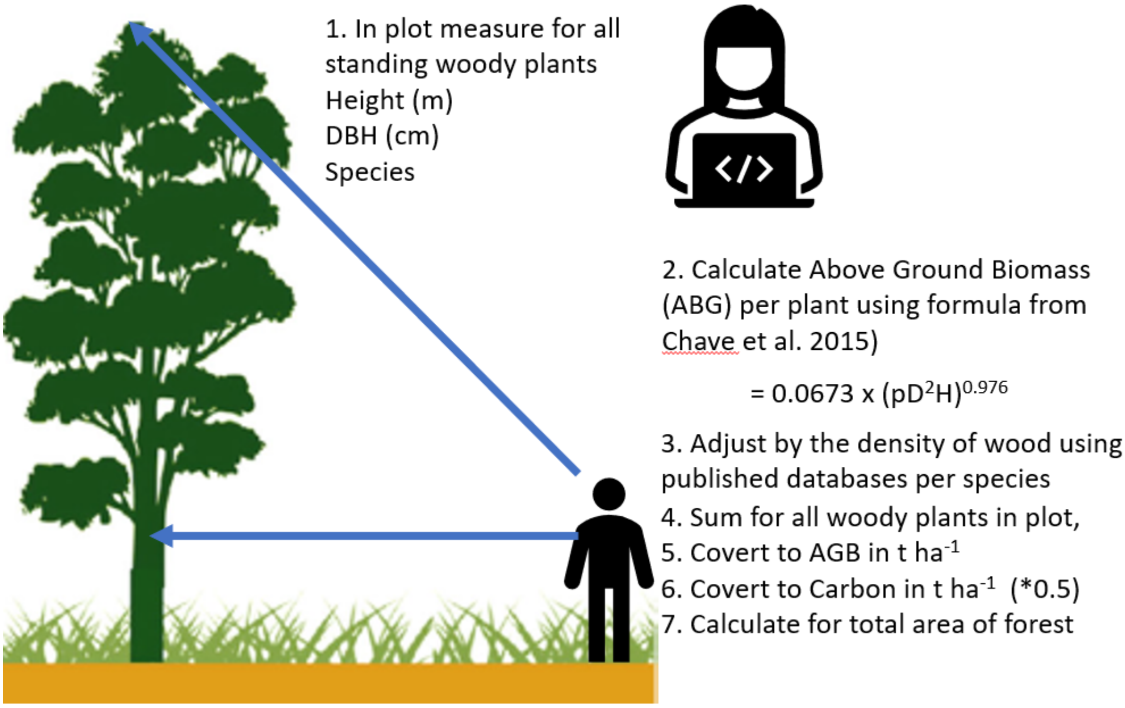

Figure 7. Schematic showing each stage in calculating carbon for the forests at Griffith University.

Results

There were 287 trees and 10 standing dead trunks with 5 cm or greater DBH across the 28 quadrats (one per block) within the Arboretum giving a tree density of 707 trees per ha (Table 3). The most common types of trees across the 28 quadrats in 2023 were Acacia (36.7% trees), Rainforest trees (30%), Eucalypts (17.2%), Sheaoaks (7.1% woody plants), Bottlebrush (5.7%) and dead trees (3%). When these values where adjusted by the area of each block, it is estimated that the Arboretum currently contains around 3,565 trees including 1,350 Acacia, 1,114 Rainforest trees, 631 Eucalypts, 260 Sheaoaks, 210 Bottlebrush and 114 dead trees. This suggests a survival rate of around 75% for the trees planted in 2014 although there have been some additional small scale plantings in Phase 2 and 3. The total number of all trees (including standing dead) in September 2023 is estimated at 3,679 trees across the 5.2 ha core of the Arboretum.

Calculating Biomass and Carbon per ha in the Arboretum

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

Table 3. The number of trees (≥5 cm DBH, ≥2 m height, living and standing dead trees) and the Above Ground Biomass (AGB in kg) and Carbon (kg) (using allometric formula from Chave et al., (2015)) per quadrat and ha for 28 blocks of trees in the Arboretum at the Logan campus of Griffith University.

		Per 10 m by 15 m						quadrat per Ha			Total
Block	Vegetation type	#trees	#trunks	Av. Height (m)	Av. DBH (cm)	Total AGB (kg)	Av. ABG(Kg) per trunk	AGB (kg)	AGB t	C t	#trees
Block 3	Dry Rainforest	8	14	10.4	14.5	1062.0	75.9	70796.7	70.8	35.4	175
Block 4	Dry Rainforest	14	26	8.6	13.8	1878.3	72.2	125217.4	125.2	62.6	115
Block 8	Dry Rainforest	9	18	11.4	18.5	2511.8	139.5	167451.4	167.5	83.7	121
Block 9	Dry Rainforest	9	13	9.5	14.0	910.5	70.0	60698.8	60.7	30.3	58
Block 13	Dry Rainforest	11	24	9.4	13.2	1480.0	61.7	98665.4	98.7	49.3	152
Block 14	Dry Rainforest	9	24	9.4	11.6	1068.5	44.5	71232.6	71.2	35.6	64
Block 18	Dry Rainforest	6	17	10.1	13.1	835.4	49.1	55691.3	55.7	27.8	91
Block 19	Dry Rainforest	12	22	9.7	12.7	1340.9	61.0	89394.8	89.4	44.7	62
Block 1	Open Forest	9	20	8.7	11.6	679.0	34.0	45269.5	45.3	22.6	94
Block 2	Open Forest	7	12	8.2	11.1	495.0	41.2	32998.6	33.0	16.5	95
Block 6	Open Forest	12	15	8.2	12.6	799.8	53.3	53323.1	53.3	26.7	125
Block 7	Open Forest	8	16	10.9	16.1	1841.5	115.1	122764.8	122.8	61.4	62
Block 11	Open Forest	9	10	9.7	16.5	1206.2	120.6	80410.2	80.4	40.2	125
Block 12	Open Forest	16	25	10.3	14.4	2096.1	83.8	139737.0	139.7	69.9	116
Block 16	Open Forest	7	16	9.4	10.2	924.3	57.8	61619.3	61.6	30.8	130
Block 17	Open Forest	14	17	10.0	12.3	1307.1	76.9	87138.2	87.1	43.6	107
Block 27	Open Forest	15	17	9.0	11.8	1138.6	67.0	75907.3	75.9	38.0	280
Block 28	Open Forest	9	13	8.3	11.0	600.0	46.2	40002.8	40.0	20.0	192
Block 5	Riparian Rainforest	14	24	7.3	11.6	1036.1	43.2	69075.3	69.1	34.5	99
Block 10	Riparian Rainforest	16	26	9.2	12.0	1332.7	51.3	88847.2	88.8	44.4	115

Block 15	Riparian Rainforest	9	17	7.8	11.6	690.9	40.6	46061.2	46.1	23.0	79
Block 20	Riparian Rainforest	12	26	7.9	9.8	791.6	30.4	52773.3	52.8	26.4	77
Block 21	Subtropical Rainforest	5	8	9.4	15.9	1198.0	149.7	79863.8	79.9	39.9	62
Block 22	Subtropical Rainforest	16	30	7.6	9.5	927.0	30.9	61802.3	61.8	30.9	246
Block 23	Subtropical Rainforest	9	14	9.6	14.5	1093.6	78.1	72908.5	72.9	36.5	143
Block 24	Subtropical Rainforest	9	15	8.1	12.9	871.7	58.1	58114.2	58.1	29.1	179
Block 25	Subtropical Rainforest	13	17	7.9	15.2	1915.2	112.7	127682.5	127.7	63.8	145
Block 26	Subtropical Rainforest	10	15	9.8	11.9	657.9	43.9	43857.8	43.9	21.9	250
Totals or Av. (Average)		297	511	Av. 9.1	Av. 12.8	32689.6	Av. 64.0	77813.0	Av.77.8	Av.38.9	3,557

The density of wood for different species uses data from Llic et al. (2000) (Table 1). The estimates of biomass were Basic Density (g cm^{-3}) values were available for 29 of the 34 most commonly planted species in the Arboretum, accounting for 58.5% of all the trees in Phase 1 planting (Table 1). These were used to calculate weighted average wood densities for Acacia (0.614 g cm^{-3}), Rainforest trees (0.527), Eucalypts (0.788), Sheaoaks (0.570), Bottlebrush (0.760) and for standing dead trunks (0.657) (Table 1). As many trees in 2023 had more than one stem (42%) the values for individual stems were combined to give a total value per tree.

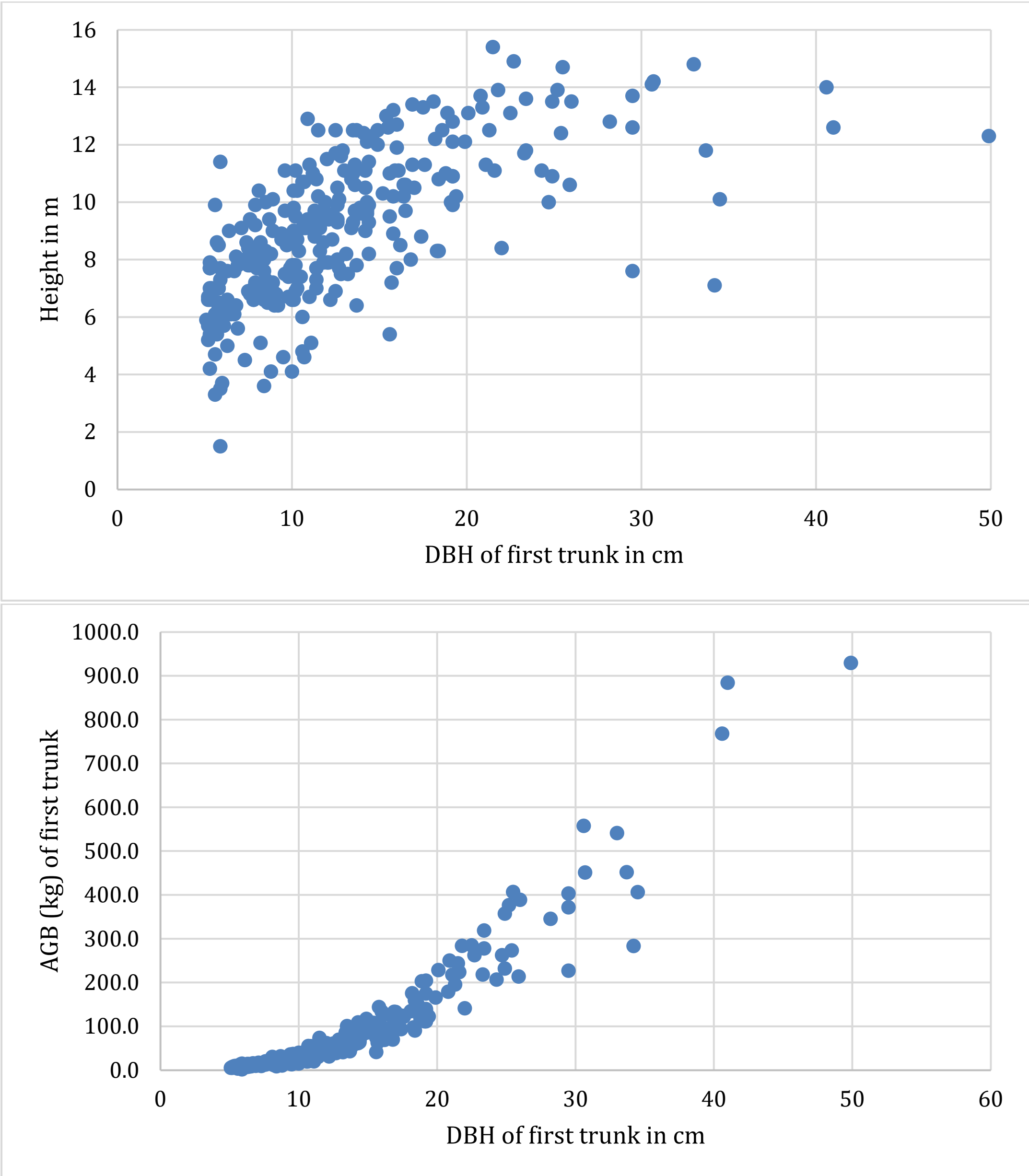

Figure 8. Size distribution of the 297 trees measure across the 0.42 ha sampled (28 10 m by 15 m quadrats) showing the relationship between DBH, height and AGB, and how there are some very large trees, of which only two were not planted as part of the Arboretum.

The values per tree were summed within each quadrat to give AGB values each 28 quadrats, and these were then coveted into per ha values. The per ha values for AGB per ha were then converted into carbon by multiplying the AGB by 0.5 which is a standard conversion value (Keith et al., 2014). Finally, the C t per ha values were multiplied by the area (size of blocks) for each type of vegetation and summed to give a final value for woody biomass in the Arboretum of 192.5 t C in woody biomass. When the below ground values are included, the total for the Arboretum is 240.5 t C.

Differences in AGB and growth among types of trees and types of forest

Although trees were planted at a similar time (95% in 2014), there have been differences in their growth within and among species with the tallest planted tree a Eucalypt at 41 cm DBH, 12.6 m in height and 889 kg ABG, and the smallest rainforest tree of 5.9cm DBH, 1.5 m in height and 1.8 kg of ABG (Figure 8).

Only two trees were identified in the quadrats that were likely to pre-date the planting a large Sheoak in the quadrant in Block 25 (1 trunk, DBH 49.9, cm, height 12.3 cm, AGB in kg of 929.4) and a large Acacia in Block 24, (1 trunk, DBH 33.7 cm, height 11.8 m, AGB in kg of 446).

Using the field data it is possible to compare the growth of the different types of trees and vegetation types in the Arboretum. There were significant differences among the different types of trees using the non-parametric Kruskal-Wallis statistical test for DBH, Height and AGB (Table 4, Figures 9, 10 and 11). In general Acacia and Eucalypts were wider (larger DBH), than other types of trees (Figure 9), while Eucalypts were taller than all other types of trees (Figure 10). Eucalypts also had greater AGB than all other trees apart from Acacia, while Acacia were taller than rainforest and bottlebrush trees (Figure 11).

Table 4. Size measures of different types of trees within the Arboretum. Data consists of Mean ± Standard Error for the different types of trees, and the results of Kruskal-Wallis tests.

	# trunks	DBH (cm)	Height (m)	Tree AGB(kg)
Acacia	2.0±0.1	13.7±0.7	9.3±0.2	132.3±14.2
Bottlebrush	1.5±0.1	7.8±0.5	7.0±0.4	34.3±4.8
Dead	1.9±0.3	8.5±0.8	6.4±0.4	42.4±10.7
Eucalypt	1.2±0.1	16.2±1.0	10.7±0.3	173.6±23.3
Rainforest	1.6±0.1	11.3±0.5	8.6±0.3	62.1±5.8
Sheoak	2.3±0.3	13.0±2.2	8.6±0.4	121.8±43.0
Total	1.7±0.1	12.8±0.4	9.1±0.1	109.0±7.9
Kruskal-Wallis test		<0.001	<0.001	<0.001

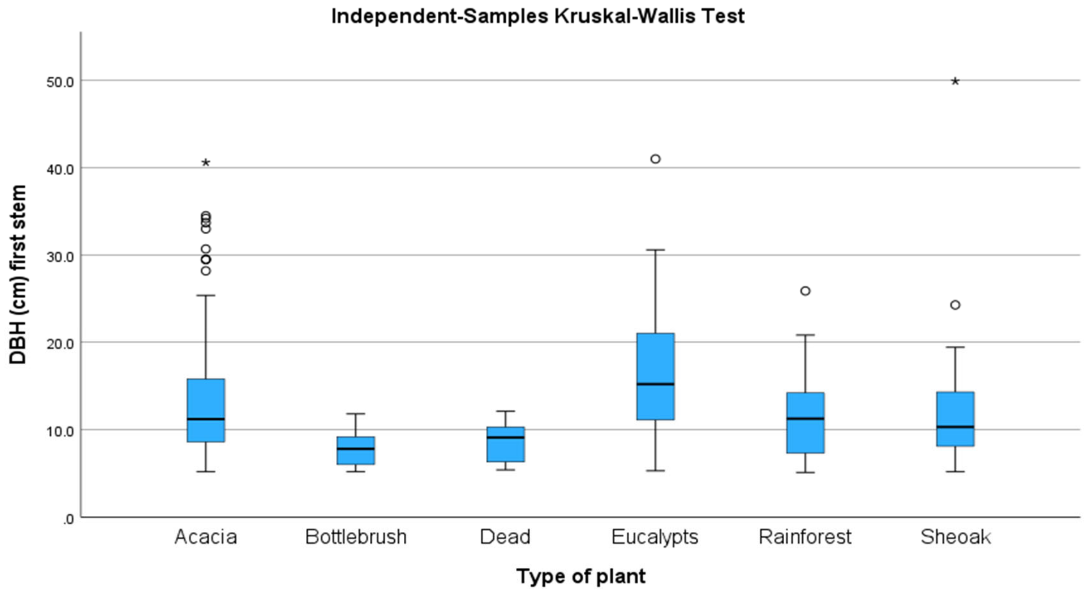

Figure 9. Boxplots showing the mean (dark line) and distribution of DBH (cm) for the first stem of trees from different types of plants.

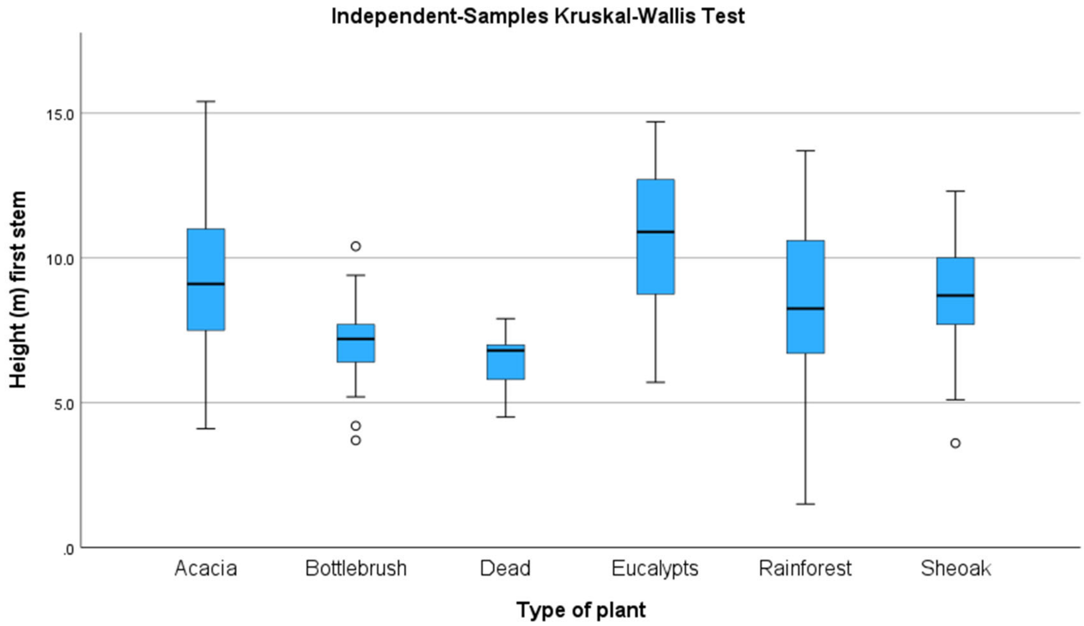

Figure 10. Boxplots showing the mean (dark line) and distribution of heights (m) for the first stem of trees from different types of plants.

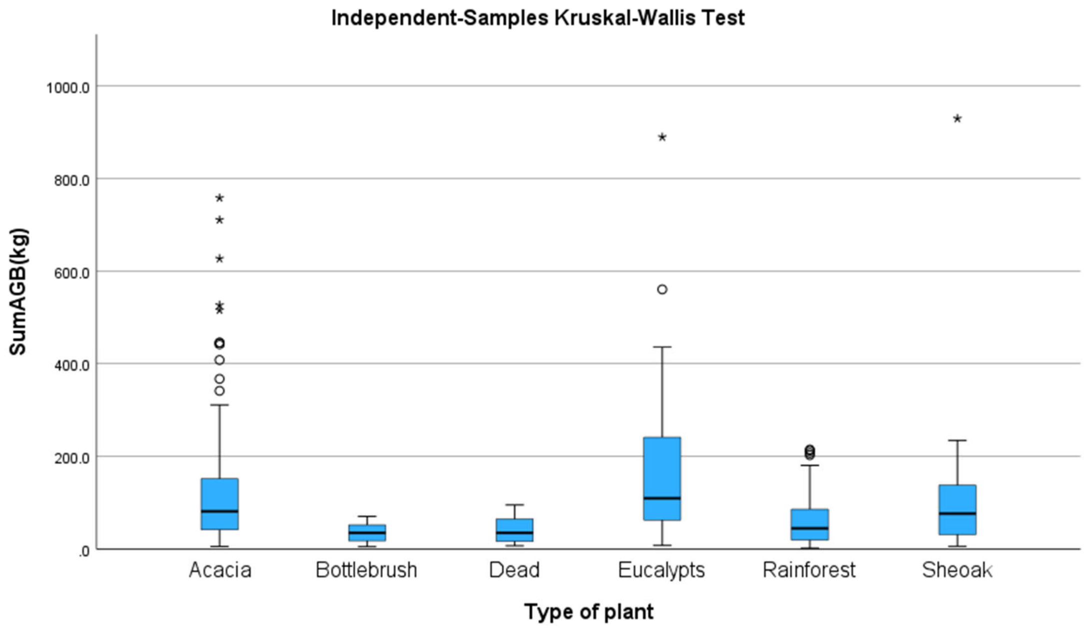

Figure 11. Boxplots showing the mean (dark line) and distribution of ABG biomass for trees from different types of plants.

There were also some differences among the types of forests in growth per block. There was no difference in the average DBH of trees or AGB for average trees among the forest blocks, but there were significant differences in height (Table 5, Figures 12, 13 and 14). The Dry Rainforest had taller trees than the Riparian Rainforest (Figure 13).

Table 5. Size measures of different types of vegetation within the Arboretum. Data consists of mean and standard error for the different types of trees, and results of Kruskal-Wallis tests.

	# blocks	# trunks	DBH (cm)	Height (m)	Tree AGB(kg)
Dry Rainforest	8	2.0±0.1	13.9±0.8	9.7±0.3	140.7±16.6
Open Forest	10	1.5±0.1	12.8±0.6	9.3±0.2	103.9±12.4
Riparian Rainforest	4	1.8±0.2	11.3±0.8	8.1±0.4	74.5±12.2
Subtrop. Rainfor. Timb.	6	1.6±0.1	12.8±1.0	8.5±0.3	106.320.3
Total	28	1.7±0.1	12.8±0.4	9.1±0.1	109.0±7.9
One-Way ANOVA			0.222	0.023	0.501

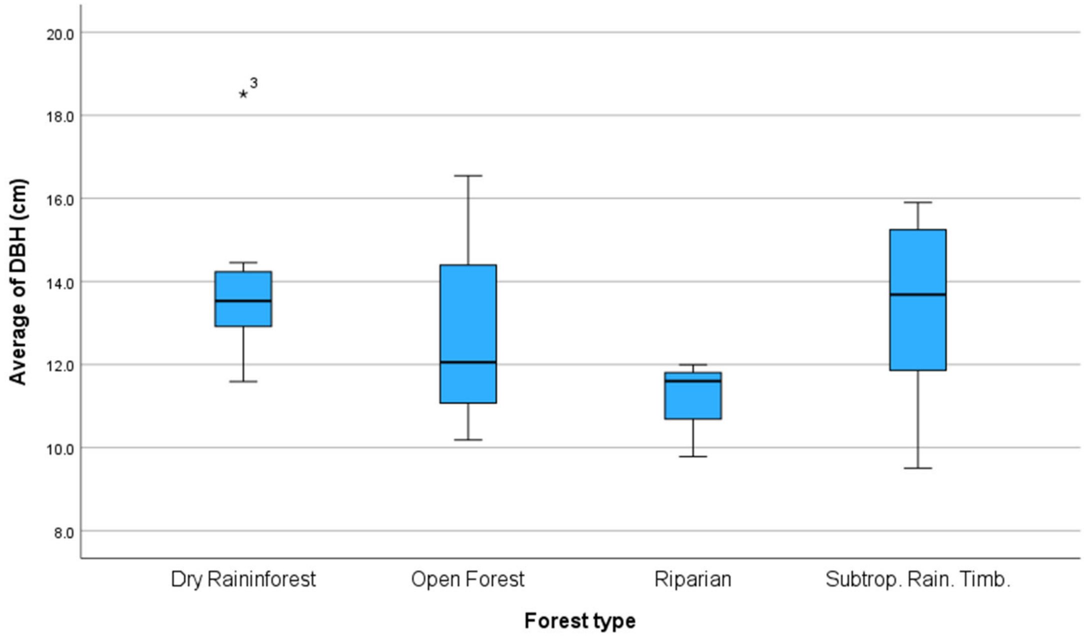

Figure 12. Boxplots showing the mean (dark line) and distribution of DBH (cm) for the first stem trees from in different types of forest within the Arboretum.

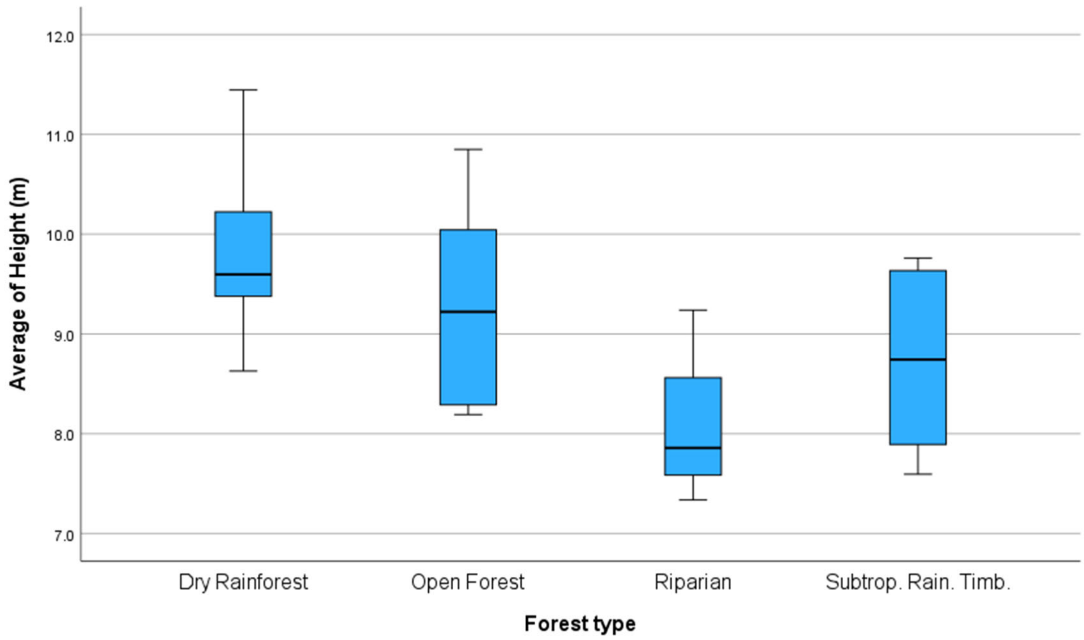

Figure 13. Boxplots showing the mean (dark line) and distribution of Height (m) per block for the different types of forest within the Arboretum.

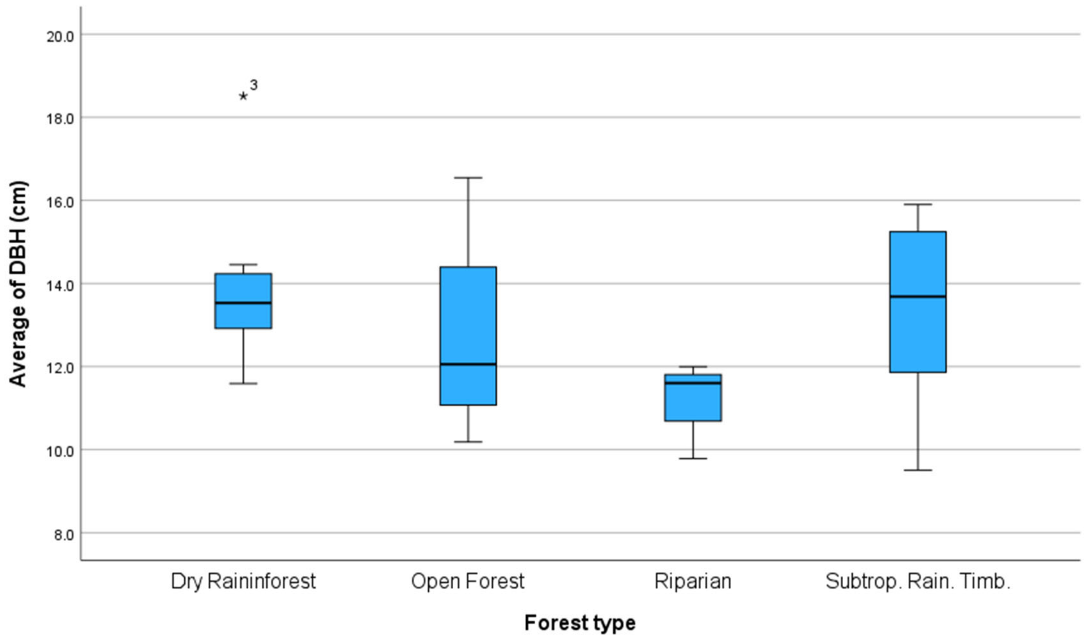

Figure 14. Boxplots showing the mean (dark line) and distribution of AGB for trees from in different types of forest within the Arboretum.

It is possible to compare the carbon values (t c per ha-1) among the different types of forest, and the Arboretum overall with that from natural forests using estimates for Broad Vegetation Groups in sub-tropical Queensland (Ngugi et al., 2014) (Figure 15) and for the native forest at the Gold Coast (Pickering et al. 2023a) and Nathan campus (Pickering et al., 2023b). Doing so highlights how within around nine years, the forests making up the Arboretum at Logan have sequestered significant amounts of carbon, around in a relatively short period, with the standing values for carbon equivalent to some Broad Vegetation Groups in drier areas in the region. The Arboretum after nine years already contains about 29% (Gold Coast) and 27% (Nathan) of the carbon in the native forests on the other campuses with around 4 t c per ha-1 (27 t for the whole Arboretum) sequestered on average per year over the last nine years, although the actual values would vary as the trees grew.

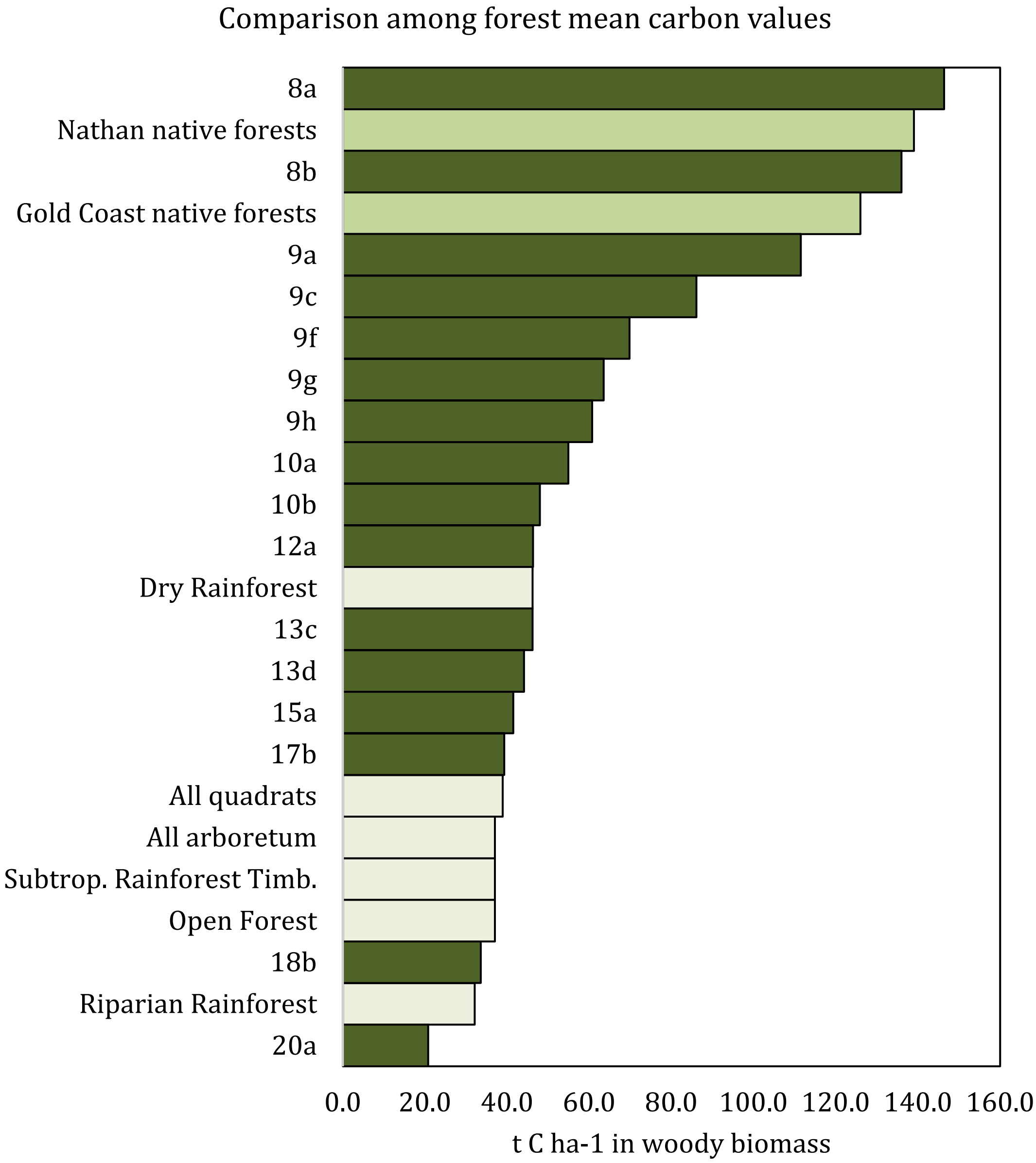

Figure 15. Comparison of AGB in woody biomass from different forest types in the Arboretum including standing dead trees, with that for living trees for different subtropical forest types as reflected by Broad Vegetation Groups (BGV) in Queensland (Ngugi et al., 2014) and estimates for the Gold Coast (Pickering et al., 2023a) and Nathan (Pickering et al., 2023b) native forests.

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 Arboretum, like that for the native forests on the Nathan and Gold Coast campuses of Griffith University (Pickering et al., 2023a,b) used 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 Arboretum (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 (low in the Arboretum as most of the same age)
- 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:

- Errors in estimating tree height using clinometer (moderate)
- Errors in measuring DBH (very low)
- Combining different species to types of trees (moderate)
- Errors in estimating size of the blocks (low-moderate with changes in forest cover)

Carbon Sequestration and future management of the Arboretum

The Arboretum is still relatively new and growing rapidly. Ongoing management of the Arboretum to enhance its biodiversity, soil protection and carbon sequestration values should include suppression of weeds particularly vines that can rapidly smother trees. The replacement of trees that have already died creating canopy gaps should be undertaken, as well as preparing for the larger task of replace many aging pioneer species such as *Acacia fimbriata* and *Macaranga tanarius* with more long-lived species. Suppression of fire also remains important, with heightened fire risks to forests associated with hotter and often drier conditions with a warming climate and more sever El Nino conditions.

Enhancing the connectivity of the Arboretum with the main buildings on campus is also important. This includes planting clusters of prominent shade trees intermittently along the path linking the Arboretum to the main buildings on campus (Figure 1). Such plantings would still allow the area to be used for major public event such as the Logan

EcoAction Festival and mowing of the grass area, but would increase the physical and psychological connectedness of these two zones.

The clearing of the mid story, and removal of some trees and branches in the blocks closest to the main part of the campus and introduction of informal seating close to the main entrance to the Arboretum is consistent with Crime Prevention Through Environmental Design (CPTED) principles and has been appreciated by staff working at Logan including those who value the wellbeing benefits of spending time among the trees (pers. Comm Sharon Paterson). However, maintaining a mid-story within the forest blocks close to Slacks Creek is recommended, as such structural complexity enhance the biodiversity values by providing habitat for species such as smaller birds and reptiles.

Increased use of signage on ground, guided walks, as well as communication via traditional methods and social media about the history, value and benefits of the Arboretum will enhance its value to staff, students and visitors to the Logan campus and is consistent with actions within Griffith University Biodiversity and Conservation Plan (Griffith University, 2022a).

Conclusions

The Arboretum at Logan along with the native forests on the campus of Griffith University are important for the range of ecosystems services they provide including functioning as stores of carbon and carbon sequestration. Maintaining their diverse values 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 total amount of carbon within the Arboretum (192.5 t of carbon above ground in trees, and) is small compared to that in the native forest on the Gold Coast (estimated 3,679 t of carbon in standing above ground wood vegetation, and 4,672 t including roots) and particularly compared to Nathan (21,749 t of carbon in wood plants (living and standing dead), and 27,186 t including roots in the forests). However, the rapid growth of the forest going from a few scattered remnant trees to over 3,500 trees averaging 9 m in heigh in around nine years is very impressive, reflecting the good growing conditions and management. Maintaining the Arboretum including weeding, education, and replacing pioneer species as they die off will be keep to its increasing value for a wide range of ecosystem services including carbon sequestration.

References

Chave, J., Rejou-Mechain, M., Burquez, A., Chidumayo, E. et al. (2015) Improved allometric models to estimate the aboveground biomass of tropical trees. Global Change Biology. 20, 3177-3190.

Eamus, D., McGuinness, K. and Burrows, W., (2000). Review of allometric relationships for estimating woody biomass for Queensland, the Northern

Territory and Western Australia. Australian Greenhouse Office, Commonwealth of Australia, Canberra.

Eyre, T.J., Kelly, A.L., Neldner, V.J., Wilson, B.A., Ferguson, D.J., Laidlaw, M.J. and Franks, A.J., (2015) *BioCondition: A condition assessment framework for terrestrial biodiversity in Queensland – assessment manual version 2.2.* Queensland Herbarium, Department of Environment and Science, Brisbane. Available online at: https://www.qld.gov.au/__data/assets/pdf_file/0029/68726/biocondition-assessment-manual.pdf. Accessed on 28 January 2021.

Griffith University (2014). Welcome to Griffith University Arboretum. PDF map produced by Griffith University.

Griffith University (2022a) Griffith University Biodiversity Conservation Plan 2022-25. Griffith University. Available at https://www.griffith.edu.au/__data/assets/pdf_file/0027/1672254/MC03340-Biodiversity-Conservation-Plan_FA-1.pdf

Griffith University (2022b) Griffith University climate action. Griffith University. Available at https://www.griffith.edu.au/sustainability/climate-action

Keith, H., Barrett, D. and Keenan, R., (2000). Review of allometric relationships for estimating woody biomass for New South Wales, the Australian Capital Territory, Victoria, Tasmania and South Australia. Australian Greenhouse Office, Commonwealth of Australia, Canberra.

Llic, J., Boland, D. McDonald, M., Downes, G, and Blackemore, P. (2000) Woody Density Phase 1 – State of Knowledge. National Carbon Accounting System Technical Report no. 18. Australian Government, Canberra.

Mackey, B.G., Keith, H., Berry, S.L. and Lindenmayer, D.B., (2008) *Green carbon – the role of natural forests in carbon storage*. The Australian National University Press, Canberra, Australia.

Ngugi, M.R., Doley, D., Botkin, D.B., Cant, M., Neldner, J.V. and Kelly, J. (2014) Long-term estimates of live above-ground tree carbon stocks and net change in managed uneven-aged mixed species forests of sub-tropical Queensland, Australia. Australian Forestry, 77: 3-4.

Pickering, C., Johnston-Bates, J., Leopold, K. and Runkovski, M. (2023b). Field-based Forest Carbon Assessment Griffith University Nathan Campus. School of Environment and Science, Griffith University. pp. 26.

Pickering, C., Leopold, K. and Runkovski, M. (2023a). Field-based Forest Carbon Assessment Griffith University Gold Coast Campus. School of Environment and Science, Griffith University. pp. 22.

Water and Carbon Group (2023). https://waterandcarbon.com/projects/griffith-university-environmental-arboretum-riparian-restoration-slacks-creek-restoration-project-scrp/ accessed October 2023.