Field Based Forest Carbon Assessment Griffith University, Nathan Campus

Large tree being used for nesting of Powerful Owls at Nathan campus (Kate Leopold)

Catherine Pickering and Jaiden Johnston-Bates, Biodiversity Working Group, Griffith University; Kate Leopold and Mark Runkovski, Natura Pacific, September 2023.

Contents

Summary 2
Background 3
Methods 5
Results 10
Conclusions 24
References 24

Summary

The native forests of Griffith University contribute a range of important ecosystem services and functions including sequestering carbon, and hence are an important component of Griffith University's Sustainability Goals including in relation to the United Nations Sustainable Development Goals SDG13: Climate Action as well as SDG15: Life on Land. To estimate the carbon currently stored within the native forests on the Nathan campus of Griffith University (~135.9 ha), and potential for future carbon sequestration, field estimation of the carbon in the forests was undertaken along 14 transects across 7 of the 12 Regional Ecosystems (RE) on the campus in 2023. Specifically, Above Ground Biomass was estimated by converting measurements of the height and width of all wood plants and standing dead trees with a Diameter at Breast Height of 5cm along 14 10m * 50m transects (two per RE, randomly located) using standard allometric calculations. These field values were then converted to tons of Above Ground Carbon per ha (12.5.3a = 98.1, 12.9-10.17c = 155.2, 12.9-10.26 = 168.2, 12.9-10.4 = 141.3 12.11.24 = 177.2, 12.11.25 = 106.8, 12.11.26 = 94.4, weighted average across RE = 150 t C ha^{-1}) which when combined with the area of each sampled RE and other RE on campus **(144.6 ha)** to give a final estimate of the amount of Above Ground Carbon **(20,398 t carbon)** (living and standing dead) as well as both Above and Below (in roots) Carbon in woody plants (living and standing dead) **(25,497 t carbon)**. There were lots of dead standing trees in the forest (20.9% of wood plants). When they were removed from the calculations the carbon values were slightly lower per RE (12.5.3a = 85.1, 12.9-10.17c = 144.2, 12.9-10.26 = 161.3, 12.9-10.4 = 132.3 12.11.24 = 158.5, 12.11.25 = 102.4, 12.11.26 = 64.0, weighted average across RE = 139.4 t C ha^{-1}) while the total Above Ground Carbon in living wood plants was estimated as **18,938 t carbon** and both Above and Below (in roots) Carbon in living woody plants was estimated as **23,673 t carbon.** These values are broadly similar to those for a range of wet open forests in subtropical Queensland and reflect the generally high BioCondition of the forests at Nathan. It is also possible to estimate carbon flux for the forests on campus based on a rate of 2.92 t ha^{-1} y^{-1} given for similar forests in the region. Using this value, the Nathan forests may be sequestering carbon from the atmosphere at the rate of **423 t per year.** However, too frequent/hot bushfires, further clearing, drought conditions and the spread of weeds will reduce biodiversity in the forests and their capacity as carbon stores and carbon sinks.

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. 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.

Nathan Field Sampling

Of the 12 REs on the Nathan campus, seven are large enough to satisfied criteria for BioCondition and hence were sampled (Tables 1 and 2). For each of the seven RE's, two transects were randomly allocated using GIS mapping. These were assessed on the ground and in some cases moved slightly, to ensure they met a number of ranked criteria which included no incursion by access trails such as roads and paths as a priority, with the full 100 m transect located parallel to contours as much as practicable (given the constraint of trail incursion). Transects were also generally located away from edges of the forest and other types of disturbances including clearing as well as away from ponds and waterways, to ensure the area within the transect was representative of the desired RE type. The start and end points were permanently marked with star pickets labelled with the site number (Figure 2). Field work measuring BioCondition and Carbon in the forests for the Nathan occurred in June to September 2023 by a team consisting of Jaiden Johnston-Bates from Griffith University, and Kate Leopold from Natura Pacific, with sampling taking just over one day per transect.

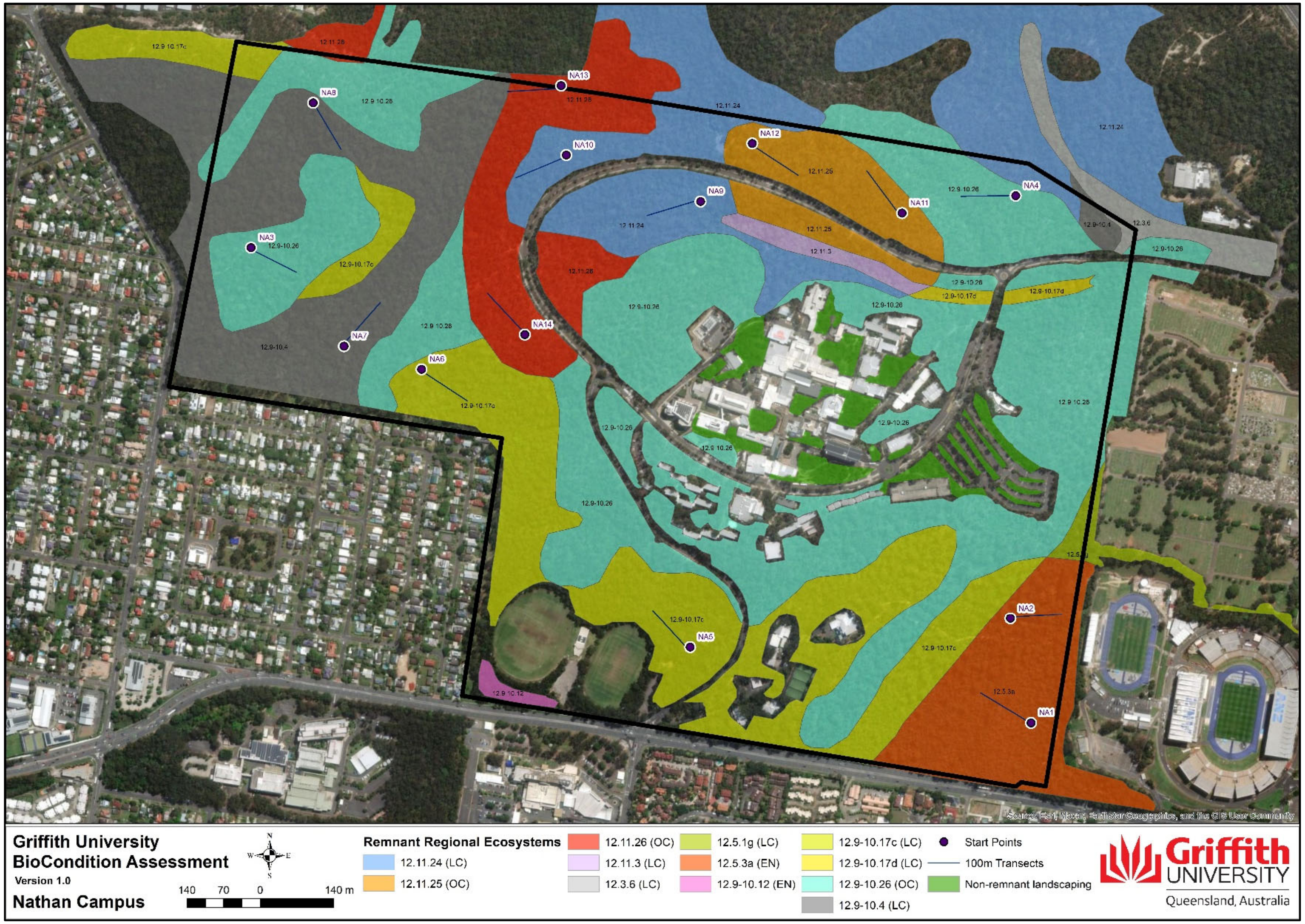

Figure 2. Map of Regional Ecosystems at the Nathan campus of Griffith University, including the location of the 14 BioCondition transects.

Table 2. Location details of the 14 BioCondition transects on the Nathan campus of Griffith University.

Transect number	RE	Plot Origin (+/- 10m)		Plot Centre (+/- 10m)		Plot end	
		Lat	Lon	Lat	Lon	Lat	Lon
NA1	12.5.3a	-27.558547	153.058337	-27.558319	153.057865	-27.55809	153.05741
NA2	12.5.3a	-27.556738	153.057861	-27.556723	153.058255	-27.55658	153.05888
NA3	12.9-10.26	-27.550266	153.043206	-27.550503	153.04363	-27.55072	153.04409
NA4	12.9-10.26	-27.55005	153.058472	-27.549913	153.058015	-27.54987	153.05766
NA5	12.9-10.17c	-27.557216	153.051735	-27.556962	153.051505	-27.5566	153.05097
NA6	12.9-10.17c	-27.552389	153.046509	-27.552661	153.046906	-27.55291	153.0473
NA7	12.9-10.4	-27.552031	153.044989	-27.551718	153.045326	-27.55137	153.04562
NA8	12.9-10.4	-27.547814	153.044358	-27.54822	153.044654	-27.54864	153.0449
NA9	12.11.24	-27.549464	153.051857	-27.549623	153.051373	-27.54968	153.05087
NA10	12.11.24	-27.548664	153.049299	-27.548855	153.048887	-27.54913	153.04844
NA11	12.11.25	-27.549706	153.0558	-27.549358	153.055469	-27.54903	153.05515
NA12	12.11.25	-27.548533	153.052903	-27.548732	153.053323	-27.549	153.05375
NA13	12.11.26	-27.547513	153.04924	-27.547443	153.048755	-27.54757	153.04829
NA14	12.11.26	-27.551758	153.048453	-27.551429	153.048082	-27.55112	153.04778

Because there were more 14 transects for the Nathan campus, the Diameter at Breast Height (DBH) and height of all woody plants (living and standing dead wood) was recorded in only half of the 20 m x 50 m central plot that is also used to estimate course woody debris for BioCondition (Figure 3). Specifically, for consistency, tree data was collected in the 10 m x 50 m plot to the right hand side of the transect also used for recording species richness and non-native plant cover for the BioCondition assessment. This is different to the Gold Coast where the full 20 m x 50 m plot was sampled in both of the two transects.

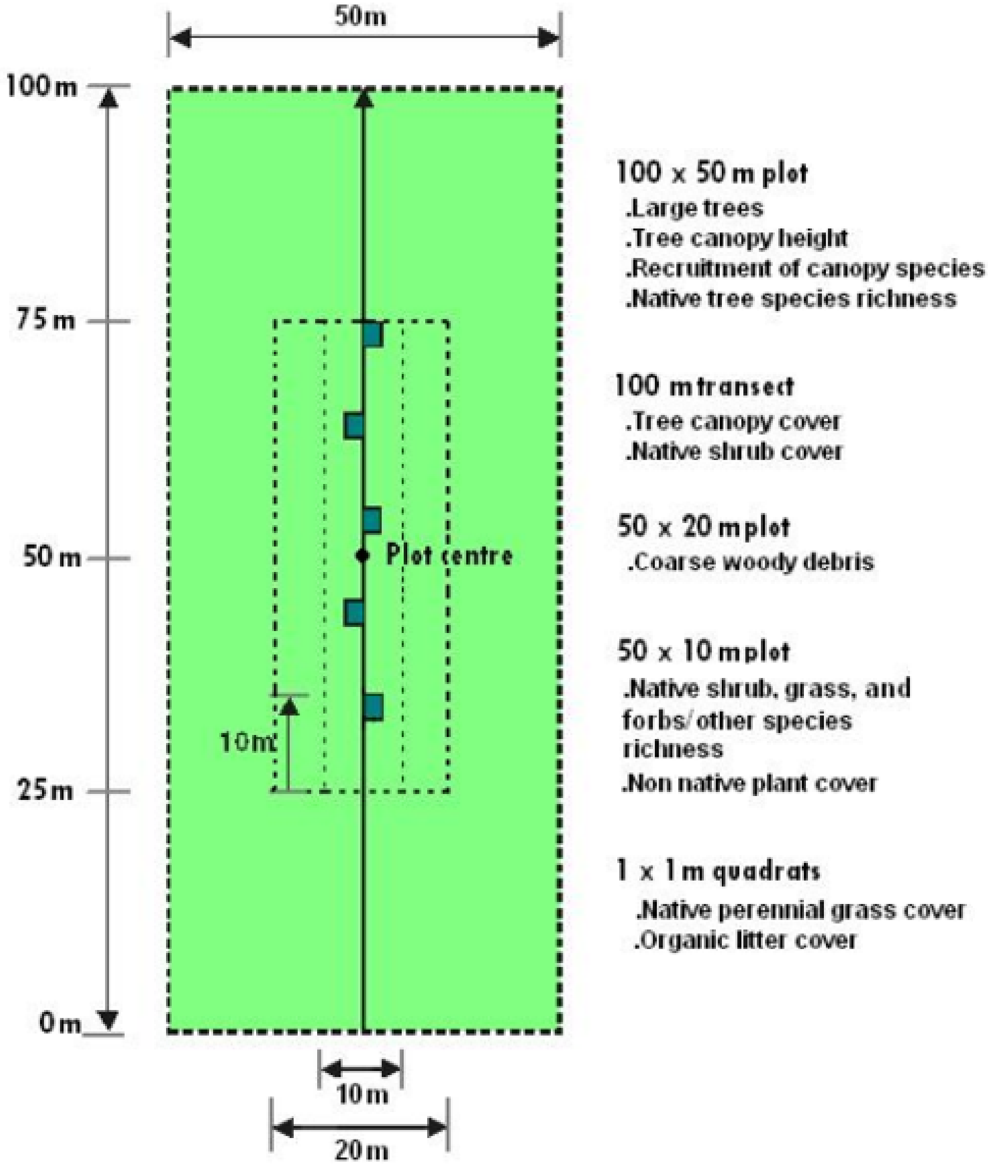

Figure 3. Layout of BioCondition transects, plots and quadrats modified from Queensland Government BioCondition Assessment Manual (Neldner et al. 2020).

Starting in the corner of the 20 x 50 m plot, woody vegetation above 2 m in height and 5 cm in Diameter at Breast Height (DBH) in the plot was measured. One person identified the species of woody plant, and measured 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 m. If there were multiple trunks or stems at the DBH measurement height, the diameter of all stems equal to or greater than 5 cm DBH was recorded.

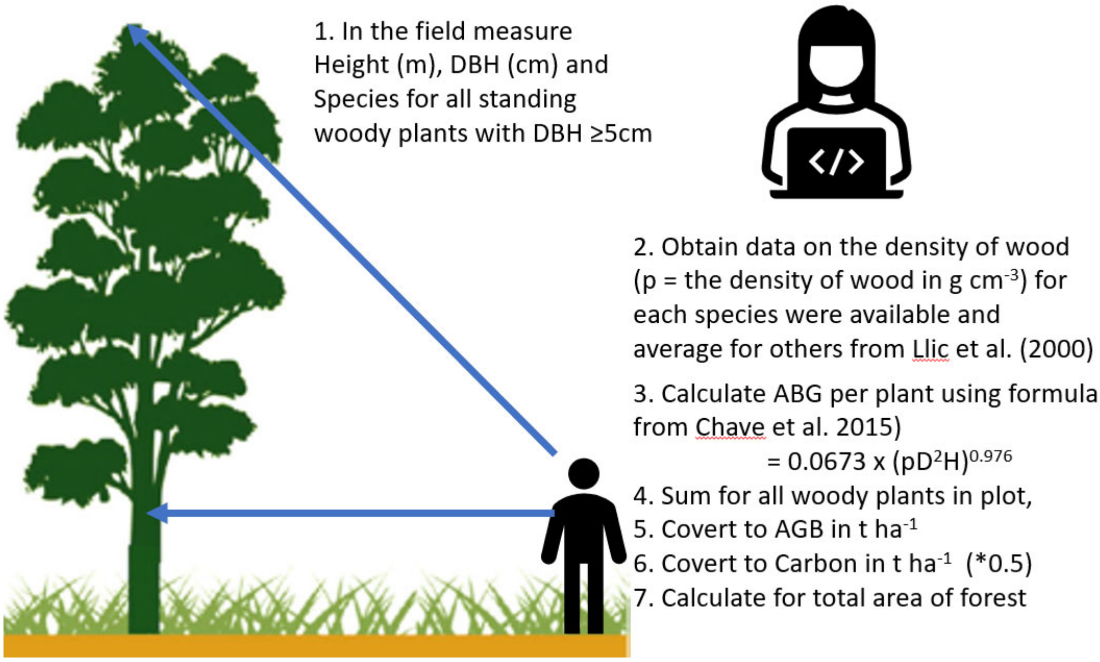

Figure 4. Schematic showing each stage in calculating carbon for the forests at Griffith University.

Results

A total of 1,114 woody plants with DBH of 5 cm or more were measured across the 14 transects at Nathan which accounted for a total of 0.7 ha of forest out of the 145 ha of native forest on the campus (Table 3). There was considerable variation in the diversity and density of trees per transect and RE (Table 3, Figure 5). The most common living woody plants in the Nathan forests were *Angophora woodsiana* (13.2%), *Allocasuarina littoralis* (8.3%), *Acacia leiocalyx* (8.3%) and *Lophostemon confertus* (7.6%) with a total of 32 tree species recorded across the 14 transects. There were also many standing dead trees (233 = 20.9% of all trees)(Table 3). The density of trees (expressed as per ha) ranged from 840 per ha in NA12 to 3,500 per ha in NA13 (Table 3, Figure 5). The total estimated number of trees across all the forests at Nathan campus was 201,809. There was also variation in species among the transects, with a minimum of 9 species and a maximum of 15 recorded per transect, with standing dead trees the only ‘type’ of tree that occurred in all 14 transects (Table 3).

Table 5. Number of trees (woody plant) per species for each of the 14 transects from seven Regional Ecosys

	12.5.3a		12.9-10.26		12.9-10.17c		12.9-10.4		12.11.24		12.11.2	
Species	**NA1**	**NA2**	**NA3**	**NA4**	**NA5**	**NA6**	**NA7**	**NA8**	**NA9**	**NA10**	**NA11**	**NA**
Unidentified	2						2					
Acacia concurrens			2		2							
Acacia disparrima			9					12	2	2		
Acacia leiocalyx	16	4	3	3	7	12		3		19	1	
Allocasuarina littoralis	6			7	6	1	1		11	2		
Allocasuarina torulosa							2	1				
Alphitonia excelsa			4		2	2	7	11	16	3		
Angophora leiocarpa	9	24						1				
Angophora woodsiana		1	17	8	2	4		19	1	14	41	
Corymbia gummifera			1	2	2							
Corymbia henryi											1	
Corymbia intermedia			1		1		2	1		2		
Corymbia trachyphloia		4	1	4	10	4	15	2				
Standing dead trees	**32**	**11**	**11**	**21**	**15**	**6**	**35**	**10**	**25**	**19**	**12**	
Dendrocnide excelsa									1			
Eucalyptus acmenoides			4	15		1	3	4		6	2	
Eucalyptus baileyana			6	4		1	1	1		1	3	
Eucalyptus carnea				6		3		6	1		6	
Eucalyptus crebra												
Eucalyptus helidonica					1							
Eucalyptus microcorys			1		5	1	2		2	1		
Eucalyptus planchoniana				3							1	
Eucalyptus psammitica								1		1	8	

Eucalyptus racemosa		2								1					3
Eucalyptus resinifera	4	1	1	1	3			1	2	1	3		1		18
Eucalyptus seeana	1										1				2
Eucalyptus siderophloia												4	11		15
Eucalyptus tereticornis		1													1
Eucalyptus tindaliae											12	7			19
Glochidion ferdinandi									25						25
Lophostemon confertus	1	2	7		6	18	20	5		13		1	12		85
Lophostemon suaveolens	1	7			2				12						22
Melaleuca nodosa	2														2
***Persoonia* sp.**						1		3							4
Xanthorrhoea johnsonii				7										1	8
Grand Total	10	10	14	12	14	12	11	16	11	14	12	11	16	10	35

Transect NA1 (RE 12.5.3a)

Transect NA2 (RE 12.5.3a)

Transect NA3 (RE 12.9-10.26)

Transect NA4 (RE 12.9-10.26)

Transect NA5 (RE 12.9-10.17c)

Transect NA6 (RE 12.9-10.17c)

Transect NA7 (RE 12.9-10.4)

Transect NA8 (RE 12.9-10.4)

Transect NA9 (RE 12.11.24)

Transect NA10 (RE 12.11.24)

Transect NA11 (RE 12.11.25)

Transect NA12 (RE 12.11.25)

		
Transect NA13 (RE 12.11.26)	**Transect NA14 (RE 12.11.26)**	

Figure 5. Characteristics of the different transects and Regional Ecosystems at the Nathan campus of Griffith University.

Calculating Biomass and Carbon per ha in the forest

Values for Above Ground Biomass (AGB, which here is equivalent to LAC + standing dead trees) were used to calculate the amount of carbon held for all woody plants and standing dead trees using an allometric formula from Chave et al. (2015) that is often used for tropical trees. 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:

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 was obtained from Llic et al. (2000) with Basic Density (g cm^{-3}) with values available for 16 of the 32 species of trees in the forest. These values ranged from 0.51 g cm^{-3} (*Corymbia gummifera*) to 0.913 0. 51 g cm^{-3} (*Eucalyptus siderophloia*) with an average of 0.73 g cm^{-3}. Where data was not available per species, the average wood density (0.73 g cm^{-3}) was used including for standing dead wood (Table 4).

Table 4. Details of trees including percentage of all trees, density of wood (g cm^{-3}) from Llic et al. (2000), Above Ground Biomass (AGB kg), total carbon and average carbon per tree (kg) for the 32 species of trees and standing dead trees across the 14 transects sampled at the Nathan campus.

Species	% all trees	Density wood (g cm^{-3})	AGB (kg)	Total carbon (kg)	C (kg) per tree
Other/unidentified	0.1		70.7	35.2	-
Dendrocnide excelsa	0.1		51.1	25.5	51.1
Eucalyptus helidonica	0.1		1033.0	516.5	1033.0
Eucalyptus tereticornis	0.1	0.778	10.1	5.0	10.1
Eucalyptus crebra	0.1		726.9	363.4	363.4
Eucalyptus seeana	0.2		261.6	130.8	130.8
Melaleuca nodosa	0.2		31.9	16.0	16.0
Allocasuarina torulosa	0.2		65.7	32.9	21.9
Eucalyptus racemosa	0.2	0.940	11671.3	5835.7	3890.4
Acacia concurrens	0.3		108.5	54.3	27.1
***Persoonia* sp.**	0.3		32.2	16.1	8.1
Corymbia gummifera	0.4	0.510	580.0	290.0	96.7
Eucalyptus planchoniana	0.4	0.719	4915.6	2457.8	614.4
Xanthorrhoea johnsonii	0.5		280.5	140.2	35.1
Corymbia intermedia	0.7	0.752	1113.0	556.5	92.7
Eucalyptus psammitica	0.7	0.719	4153.2	2076.6	276.9
Eucalyptus siderophloia	1.1	0.913	1605.6	802.8	107.0
Corymbia henryi	1.3		7131.5	3565.7	445.7

Eucalyptus resinifera	1.3	0.792	9370.3	4685.1	520.6
Eucalyptus tindaliae	1.4		6053.9	3026.9	318.6
Eucalyptus microcorys	1.6	0.811	30259.7	15129.9	1440.9
Lophostemon suaveolens	1.7	0.600	1611.7	805.8	73.3
Eucalyptus baileyana	1.9	0.752	24982.6	12491.3	1086.2
Glochidion ferdinandi	2.0	0.557	2675.0	1338.0	107.0
Acacia disparrima	2.1		593.0	296.5	22.8
Eucalyptus carnea	2.2		11867.8	5933.9	370.9
Angophora leiocarpa	2.3		816.0	408.0	22.7
Corymbia trachyphloia	2.9	0.846	8815.7	4407.8	220.4
Eucalyptus acmenoides	3.2		12323.0	6161.5	293.4
Alphitonia excelsa	3.6	0.562	979.4	489.7	18.8
Lophostemon confertus	3.8		11238.0	5619.0	132.2
Acacia leiocalyx	4.7		1409.5	704.8	15.2
Allocasuarina littoralis	7.6	0.57	3444.3	1722.2	37.0
Angophora woodsiana	8.3		9273.6	4636.8	63.1
Dead	8.3		18668.4	9334.2	80.1
Total	13.2	0.730	191941.8	95970.9	

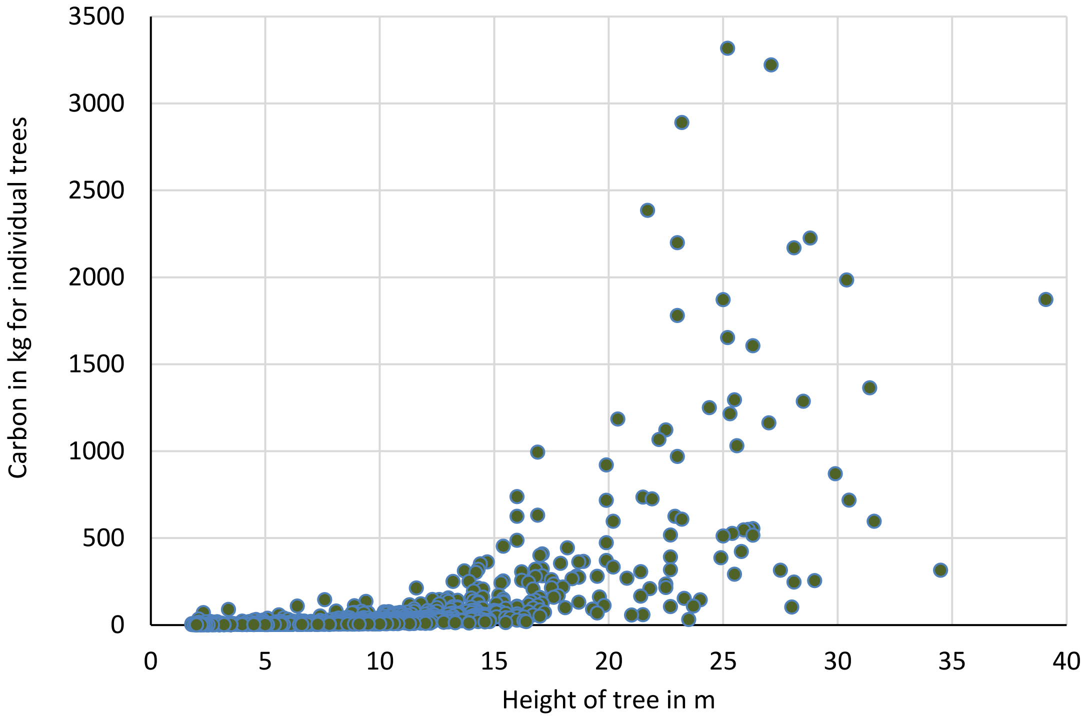

Figure 6. Relationship between the height (m) and estimated total carbon (kg) for 1,114 trees measured (including 233 standing dead trees) across the 14 transects sampled at the Nathan campus.

The results highlighted that while there are many trees in the forest, most biomass and hence carbon is accounted for by a few big old trees. For instance, in terms of size (AGB) and hence Carbon, just twenty individuals representing 1.8% of the trees in the forest accounted for 40.3% of the carbon recorded (Table 5, Figure 6). These trees were from a range of species and were spread out across nine of the 14 transects.

Table 5. The twenty biggest trees recorded across the 14 transects sampled at the Nathan campus.

Transect	Species	DBH (cm)	Height	AGB (kg)	Carbon (kg)
NA10	*Eucalyptus microcorys*	80	25.2	6635	3317
NA7	*Eucalyptus microcorys*	76	27.1	6444	3222
NA1	*Lophostemon confertus*	29	23.2	5780	2890
NA8	*Eucalyptus baileyana*	75.6	21.7	4769	2385
NA3	*Eucalyptus microcorys*	61	28.8	4452	2226
NA2	*Eucalyptus racemosa*	63	23	4397	2198
NA3	*Eucalyptus baileyana*	52	28.1	4339	2170
NA10	*Eucalyptus racemosa*	52	30.4	3969	1985
NA9	*Eucalyptus carnea*	50.5	39.1	3745	1872
NA5	*Eucalyptus microcorys*	59.9	25	3742	1871
NA4	*Eucalyptus planchoniana*	63.3	23	3560	1780
NA2	*Eucalyptus racemosa*	52	25.2	3305	1653
NA5	*Eucalyptus microcorys*	54	26.3	3212	1606
NA9	*Eucalyptus resinifera*	46	31.4	2728	1364
NA3	*Eucalyptus baileyana*	51	25.5	2589	1295
NA5	*Eucalyptus microcorys*	43.5	28.5	2574	1287
NA3	*Eucalyptus baileyana*	51.2	24.4	2499	1250
NA11	*Eucalyptus tindaliae*	50.3	25.3	2430	1215
NA7	*Eucalyptus acmenoides*	55.3	20.4	2369	1185
NA5	*Eucalyptus resinifera*	45.7	27	2325	1162

There was a range of Carbon estimates among the transects and RE with a minimum estimate of 94.4 t C ha^{-1} in NA13 which was in RE 12.11.26 (Table 6). In contrast the highest estimate was 177.2 t C ha^{-1} NA9 in RE 12.11.24. The values also ranged from some much lower that the Gold Coast RE 12.11.23 Blackbutt forest (e.g. 126 t C ha^{-1}) while others were higher (Table 6).

The values for tons of carbon per ha per REs at Nathan where often high in comparison to those estimated for Broad Vegetation Groups in sub-tropical Queensland (Ngugi et al., 2014). However, Ngugi et al. (2014) field measurements did not include standing dead trees, which accounted for 20.9% of all trees on the Nathan campus, and 7.15% of all the carbon in the forests at Nathan. When standing dead trees were removed from the transect data the estimates of tons of carbon per ha for living wood plants were lower ranging from 64.0 t C ha^{-1} in 12.11.26 to 161.3 t C ha^{-1} in 12.9-10.26, with a weighted average by area of 139 t C ha^{-1} (Table 7). These values are broadly consistent with the field based estimates for Broad Vegetation Groups (BVG) from (Ngugi et al., 2014) for taller open forests but higher than those for dry open forests and woodlands (Figure 7). More specifically the values for the forests at Nathan are broadly similar to those of tall open forest dominated by species such as *Eucalyptus grandis* or E*. saligna, E. resinifera, Syncarpia hillii, E. sphaerocarpa* on uplands and alluvia (BGV 8a, 146 t C ha^{-1}), Moist open forests to tall open forests mostly dominated by *E. pilularis* on coastal sands, sub-coastal sandstones and basalt ranges (BGV 8b, 136 t C ha^{-1}) and Moist to dry eucalypt open forests to woodlands, dominated by variety of species including *E. acmenoides, E. racemosa, E. cloeziana, E. siderophloia*, on coastal lowlands and ranges (BGV 9a, 111.5 t C ha^{-1})(Figure 7).

To calculate the total carbon in tons in woody plants (living and standing dead trees) on the Nathan campus, the per ha values for each RE were multiplied by the area of the RE, with a weighted average of the tons of carbon per ha used for the six RE with small areas (0.2 to 1.3 ha) on the campus (Table 6) to give an overall total of **20,398 t of carbon** in the native forest at Nathan. Then Above and Below ground living biomass (and standing dead trees) was calculated by adding another 25% based on an average shoot to root ratio of 0.25 for *Eucalyptus* species (Keith et al. 2014) giving a value of **25,497 t of carbon**.

If instead just the living wood plants were included, then the values for the campus forest are **18,938 t of carbon for the above ground biomass, and 23,673 including roots** (Table 7).

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 7). The estimated carbon flux for that forest type is 2.92 t ha^{-1} y^{-1}. Using this value, the Nathan forests may be sequestering carbon from the atmosphere at the rate of **423 t y^{-1}**. However, it may be much less than this, and the forests could even become a carbon source if there is clearing, too frequent/hot fires and damage/loss of large old trees coupled with increasingly dry conditions.

Table 6. Total Above Ground Biomass (AGB) and Carbon per ha based on wood plants **(living and standing dead trees)** across transects, and REs in the forests at the Nathan campus of Griffith University. AG = Above Ground

RE	Area (ha) RE	Transect	# trees	Total tree AGB (kg)	Total Carbon (kg)	# trees	AGB in t ha^{-1}	AG C in t per ha^{-1}	Ave AG C in t per ha^{-1}	Total Carbon per RE in t
12.5.3a	9	NA1	74	9848	4924	1480	197.0	98.5	98.1	883.2
12.5.3a		NA2	57	9779	4890	1140	195.6	97.8		
12.9-10.26	55.5	NA3	68	21266	10633	1360	425.3	212.7	168.2	9333.2
12.9-10.26		NA4	81	12367	6184	1620	247.3	123.7		
12.9-10.17c	24.9	NA5	64	18539	9269	1280	370.8	185.4	155.2	3863.7
12.9-10.17c		NA6	54	12495	6247	1080	249.9	124.9		
12.9-10.4	17.5	NA7	90	17613	8806	1800	352.3	176.1	141.3	2472.4
12.9-10.4		NA8	81	10643	5321	1620	212.9	106.4		
12.11.24	10.2	NA9	98	17668	8834	1960	353.4	176.7	177.2	1807.7
12.11.24		NA10	85	17776	8888	1700	355.5	177.8		
12.11.25	6.4	NA11	91	10302	5151	1820	206.0	103.0	106.8	683.4
12.11.25		NA12	42	11054	5527	840	221.1	110.5		
12.11.26	9.1	NA13	175	6337	3168	3500	126.7	63.4	94.4	858.8
12.11.26		NA14	54	12538	6269	1080	250.8	125.4		
All other REs	3.3								150.1	
		Total	1114	191942	95971	1423	281	141		**20,398**

Table 7. Total Above Ground Biomass (AGB) and Carbon per ha based on **just living wood plants** across transects, and RE in the forests at the Nathan campus of Griffith University. AG = Above Ground

RE	Area (ha) RE	Transect	# trees	Total tree AGB (kg)	Total Carbon (kg)	# trees	AGB in t ha^{-1}	AG C in t per ha^{-1}	Ave AG C in t per ha^{-1}	Total Carbon per RE in t
12.5.3a	9	NA1	42	7878	3939	840	158	79	85	766
12.5.3a		NA2	46	9142	4571	920	183	91		
12.9-10.26	55.5	NA3	57	20565	10283	1140	411	206	161	8953
12.9-10.26		NA4	60	11697	5848	1200	234	117		
12.9-10.17c	24.9	NA5	49	16807	8404	980	336	168	144	3590
12.9-10.17c		NA6	48	12032	6016	960	241	120		
12.9-10.4	17.5	NA7	55	16247	8124	1100	325	162	132	2315
12.9-10.4		NA8	71	10213	5107	1420	204	102		
12.11.24	10.2	NA9	73	15044	7522	1460	301	150	158	1616
12.11.24		NA10	66	16649	8325	1320	333	166		
12.11.25	6.4	NA11	79	10113	5056	1580	202	101	102	655
12.11.25		NA12	40	10362	5181	800	207	104		
12.11.26	9.1	NA13	166	5964	2982	3320	119	60	64	583
12.11.26		NA14	29	6841	3421	580	137	68		766
All other RE	3.3								139.4	
Total	135.9		881	169,555	84,777	1,070	261	131		**18,938**

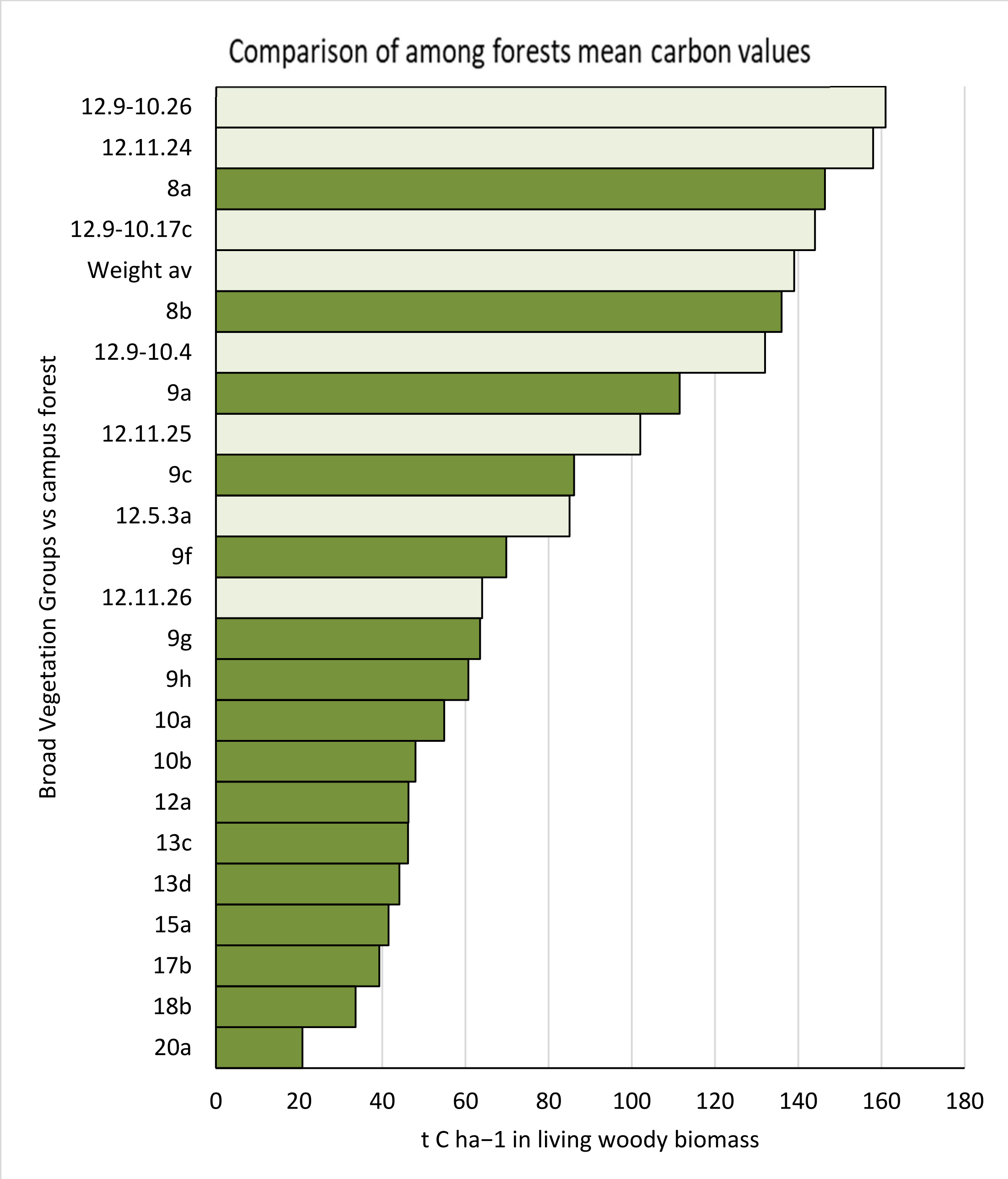

Figure 7. Comparison of the Landscape mean LAC stock (t C ha^{-1}) based only on living woody plants with a minimum DBH of 5 cm from field measurements of seven REs at the Nathan campus compared to field based estimates for Broad Vegetation Groups (BVG) from (Ngugi et al., 2014) for subtropical forests in Queensland.

Results in Comparison to Past Desktop Assessment

The estimates of total carbon based on measuring trees in the field with or without standing dead trees were 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 have been resulting in an underestimated value of 1,822 tons for the Gold Coast, and 10,440 for Nathan/Logan based on the type and area of RE's (Table 8).

Table 8. Summary values from desktop estimate of carbon in forests at Griffith University from Grieger and Mackey (2019) *** These values are incorrect as they are actually 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)
- Mis-identification of species (low)
- Errors in estimating area of REs on campus (low-moderate with changes in forest cover)

Conclusions

The forests on the campuses of Griffith University are important for the range of ecosystems services they provide including as stores of carbon and as carbon sinks as they recover from past logging. Damage to the forests including clearing reduces the extent of these ecosystems, 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 Universities commitments to sustainability and the UN Sustainable Development Goals including the aim of reaching net zero carbon emissions by 2029 (Griffith University, 2022b).

The current area of the 13 REs on the Nathan campus contains an estimated 21,749 tons of carbon in wood plants (living and standing dead), and 27,186 tons including roots in the forests. Of greatest importance are the large old trees in the forest which need to be conserved as a priority, not only due to their carbon values, but also as their cultural and habitat significance, which are an important natural asset to the University.

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