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Quantifying carbon stocks of trees on the main campus of the University of North Carolina Asheville

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Abstract

Trees are an invaluable ecological resource in urban environments, providing vital ecosystem services such as carbon storage and sequestration. These services are especially important in urban areas which are hotspots for greenhouse gas emissions. This study aimed to quantify the total carbon storage and future sequestration rates of trees on the main campus of the University of North Carolina Asheville. This study was comprised of three sampling efforts in different parts of campus: a complete inventory of the University Heights Loop area (17.2 ha), a complete inventory of the Big Meadow area (1.9 ha), and a plot-based subsample of the remaining area of main campus (90.9 ha). Each surveyed tree (DBH >2.5 cm) was identified to species (genus at minimum) and diameter at breast height (1.4 m) was measured. Sampling protocols developed for the i-Tree Eco tool were employed to calculate current carbon storage and future sequestration. It was found that University Heights Loop area stores 352.4 metric tonnes (T) of carbon valued at $60,100 and annually sequesters 8.2 T ($1,420). Big Meadow stores 48.3 T of carbon ($9,800) and annually sequesters 1.1 T ($210). The remaining area of campus considered for plot based sub-sampling stores 4,098 T of carbon ($699,000) and annually sequester 108.7 T ($18,500). The results of this study indicate that only 0.66% of the university's carbon emissions are currently being offset by these areas. To meet the goals of the Second Nature Carbon Commitment that UNC Asheville signed to become net carbon neutral by 2050, action needs to be taken to reduce greenhouse gas emissions.

1. Introduction

Anthropogenically influenced climate change is a threat to human health, biodiversity, and ecosystem functions. These climate shifts are the result of human activities and increased emissions of greenhouse gases, especially carbon dioxide[1,2]. Atmospheric carbon dioxide (CO_2) levels have increased by over 100 ppm from pre-industrial era levels and are predicted to double within the next century, likely resulting in an increase in average global temperature between 0.95 and 1.20 degrees Celsius[3,4,5]. Anthropogenically induced climate change is attributed to the extraction and combustion of fossil fuels used for energy production [4]. The extent and magnitude the impacts of climate change are larger than previous estimated assessments[5]. To mitigate the ecological, social, economic, and public health impacts of the increasing concentration of atmospheric greenhouse gases and anthropogenically influenced climate change, understanding and quantifying carbon sequestration and storage by trees is imperative.

The biotic fixation of atmospheric carbon dioxide into plant tissue by photosynthesis is the largest flux in the carbon cycle between the atmosphere and terrestrial ecosystems[6]. This metabolic pathway biologically transforms carbon dioxide and water into carbohydrates and oxygen. Plants then use carbohydrates to form other molecules. Much of this photosynthetically fixed carbon is stored long-term in structural compounds cellulose and lignin in vascular tissues

[1]. Carbon sequestration is the measure of the annual uptake of carbon into plant tissue for long-term storage. In terrestrial ecosystems (urban and forested) trees are a major carbon sink, storing and sequestering a vast majority of total carbon stored in all plant tissue across the landscape [7]. As a tree grows more carbon is accumulated in its biomass, and this storage is a reflection of the amount of carbon than can return to the atmosphere if the tree dies and decays[8]. Trees with DBH measurements less than 15.2 centimeters, have not been found to greatly enhance carbon storage of a landscape[9]. The carbon content of trees is widely accepted to be approximately 50% of total tree biomass[10].

Carbon stocks of trees can be quantified using the i-Tree Eco software program[11]. This software package was developed by the United States Forest Service, Northern Research Station. This program uses back-ended species specific allometric equations based on tree species, size, health, and canopy exposure to light to quantify carbon sequestration[12]. The minimum metrics necessary for estimates are tree species (genus at minimum) and DBH. Tree metrics are coupled with meteorological data to quantify ecosystem services at a landscape scale. With this program, complete inventory or *a priori* plot-based sampling can be used. For plot-based sampling, 0.04 hectare (0.1 acre) plots are typical to use at a 10 % standard deviation sampling intensity for forest inventories[13].

In the United States, universities are responsible for about 2% of total carbon emissions[14]. In 2021 the University of North Carolina Asheville (UNCA) signed the Second Nature Carbon Commitment, committing to achieve net carbon neutrality by 2050. In response to this commitment the University is developing a Climate Action Plan, comprised of short, medium, and long-term goals to lower, and offset greenhouse gas emissions. As of fall 2020, the campus possesses 70% tree canopy coverage and is a designated "Tree Campus USA" by the Arbor Day Foundation. Quantifying current carbon stocks of campus trees could inform land management practices for UNCA to maximize carbon sequestration and storage and aid the University to reach their carbon net neutrality goals.

Universities from around the world have accounted carbon stock in trees on their campuses. Fox et al (2020) quantified the carbon stock of the main campus of the University of Georgia, Athens, GA[15]. Bassett (2015) estimated the environmental benefits of trees in the heart of the University of Pennsylvania's campus[16]. Martin et al. (2013) quantified the ecosystem services of trees on both managed and unmanaged land stewarded by Auburn University[17]. De Villiers et al. (2014) quantified the carbon stock of trees on the campus of the University of Waikato in New Zealand[18]. Nandini et al (2009) reported the total carbon stored in above and below ground tree biomass on the Jnanabharathi Campus of Bangalore University, India[19].

This study contributes to a growing body of work quantifying current carbon stocks and future annual sequestration of trees on university campuses worldwide. The information gathered here will inform the management of campus trees to maximize ecosystem services and highlight how the University's green spaces contribute to offset greenhouse gas emissions. This work, combined with the efforts of fellow student Anna-Lisa Keller, whose work estimates the carbon stocks of UNC Asheville's forested ancillary properties, will provide a more accurate estimate of the University's total carbon stocks.

2. Methods

2.1 Study Area

The University of North Carolina Asheville is a public liberal arts institution founded in 1927 in Asheville, North Carolina. The campus occupies 147 hectares and supports 3,600 students and 1,120 faculty and staff. To quantify carbon stocks of trees on the main campus of UNCA, three sampling efforts were performed. A complete inventory for both the University Heights Loop and the Big Meadow areas of campus (Fig. 1), and an *a priori* sub-sampling survey for the remainder of campus (Fig. 2). A sub-sampling method was chosen over a complete inventory for the remainder of campus due to the time constraint of the field season.

2.2 University Heights Loop

The area of UNCA's main campus within the loop of University Heights and Edgewood Rd is 10.2 hectares in area, which constitutes 15.6% of the main campus (Fig. 1). A complete inventory of trees with a DBH greater than 2.5 cm was performed to quantify carbon stocks. These data were taken by a combination of Campus Operations staff between the years 2004 and 2016, by students enrolled in ENVR 373: Urban Ecology in the Environmental Studies Department in 2017, and by students in the Environmental Studies Department for an independent research course in 2018.

Surveyed trees within University Heights were identified to species or genus at minimum, and DBH measurement was taken at 1.4 m. These data were imported into i-Tree Eco software program for ecosystem service analysis.

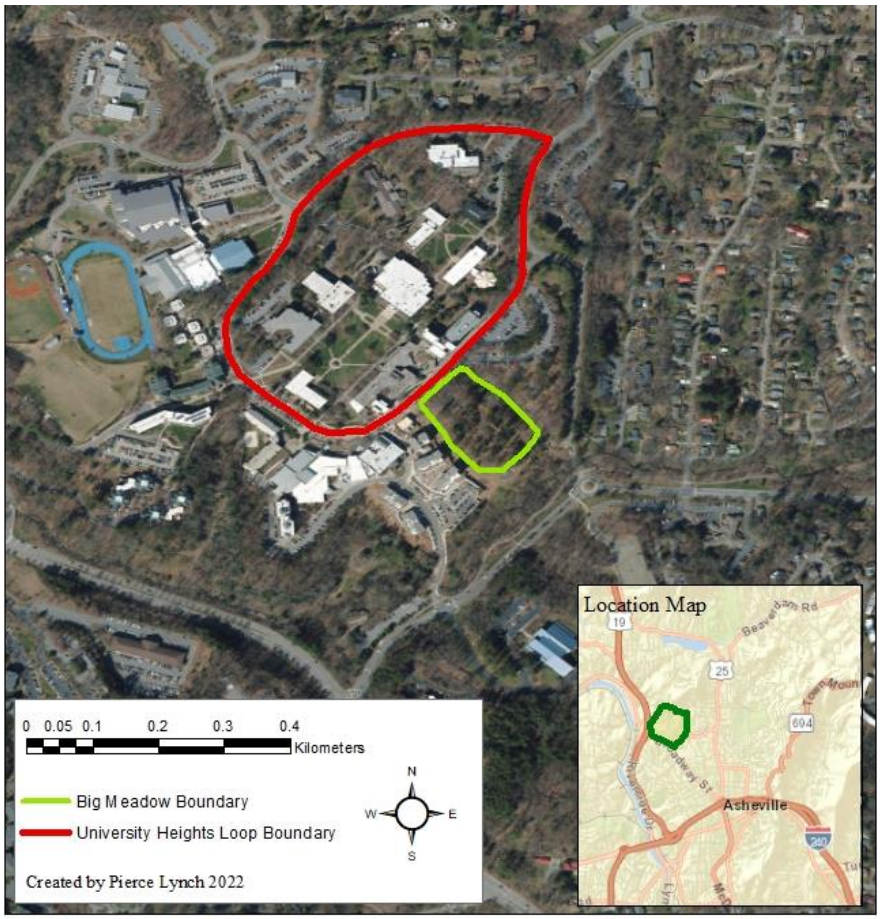

Figure 1**.** Map depicting the University Heights Loop (17.2 ha in red) and Big Meadow (1.9 ha in green) areas of the main campus of the university of North Carolina Asheville.

2.3 Big Meadow

The Big Meadow area of UNCA is categorized as a unique short leaf pine (*Pinus echinata* L.) savannah ecosystem that is of management interest to the University. Prescribed fire has been introduced to promote ecosystem function and health, including tree growth. Our data were collected prior to burning.

In the Big Meadow area, a complete inventory was conducted. For this survey, all trees with a DBH greater than 2.5 cm, within the 1.9 hectares of Big Meadow area (Fig. 1) of the University of North Carolina Campus were identified to genus or species and the DBH measurement at 1.4 m was taken per i-Tree Eco protocol. These data were collected in May and June of 2021 and analyzed using the i-Tree Eco software program.

2.4 Main campus sub-sampling

A combination of LiDAR infrared data and traditional orthoimagery were employed to select for areas of main campus with significant tree cover within which to locate plots (Fig. 2). Plot Hound (NCX, San Francisco, CA) was then used to randomly locate plots within these areas of main campus with high tree density. These actions were performed by North Carolina Forest Service, Service Forester Jordan Luff. Areas with high tree density were selected because trees

store 97% of total carbon in plant biomass across the landscape[7]. A total of 57, 0.04-hectare circular plots, accounting for an area of 2.28 hectares were generated. These plots were imported into the Gaia GPS software, mobile phone application (Trailbehind Inc, Boulder, CO) for field location. All trees within each plot with a DBH greater than 2.5 cm were identified to species, genus at minimum, and DBH was measured. For each plot, percent canopy cover was estimated in the field and percent of trees measured within each plot was reported. These data were collected summer and fall of 2021 and analyzed using the i-Tree Eco software program.

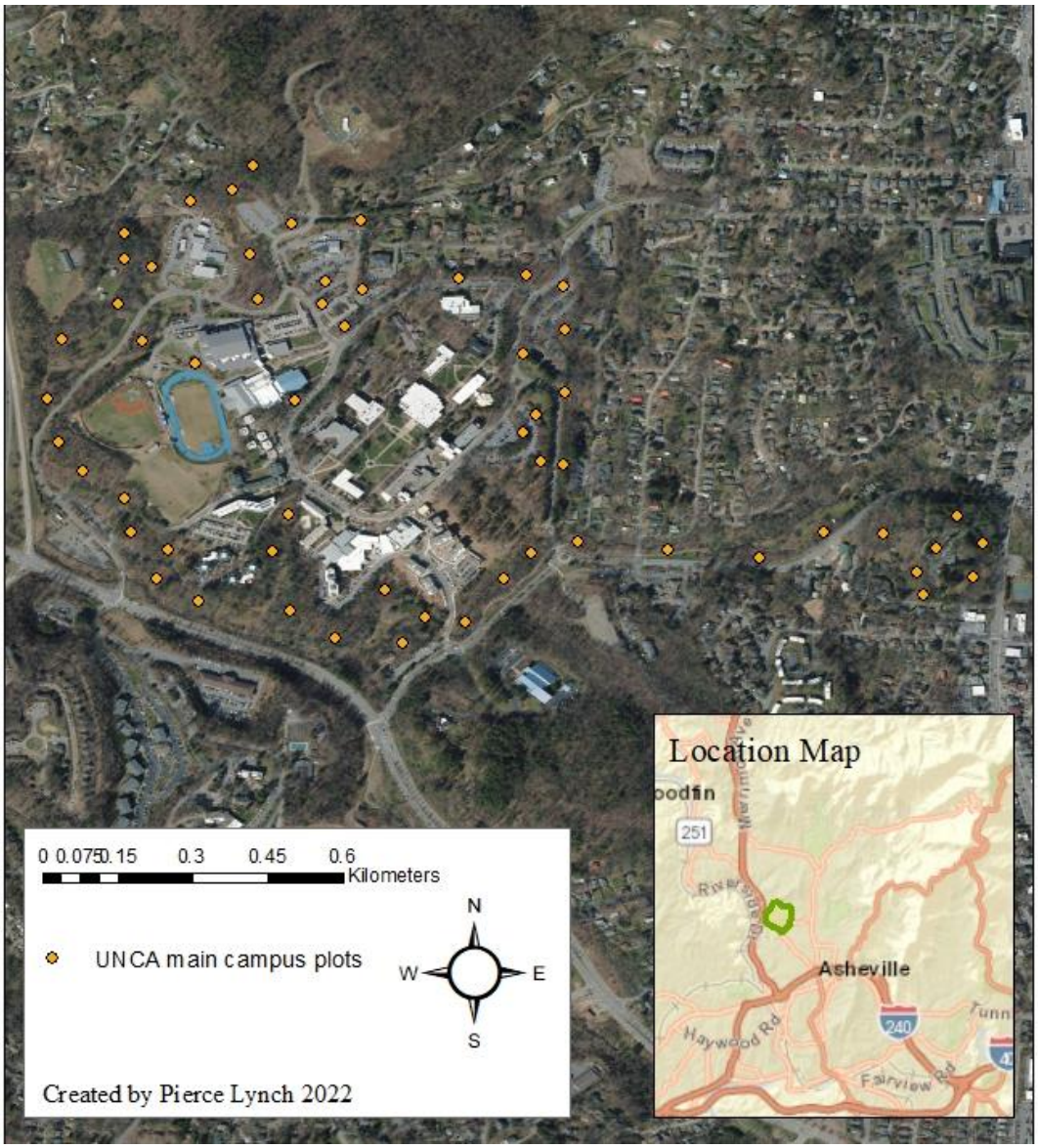

Figure 2. Map depicting the plots (orange) used for the subsampling on the main campus of the University of North Carolina Asheville

3. Results

3.1 University Heights Loop

A total of 1,510 trees were measured within the University Heights Loop area of UNCA's main campus. The species with the highest importance values were white oak (*Quercus alba* L.), flowering dogwood (*Cornus florida* L.), eastern hemlock (*Tsuga canadensis* L. Carriére) indicating that these species were the most dominant in University Heights (Table 1). The importance values here are calculated based on population percentage and leaf area, indicating prevalence within landscape. These results do not necessarily indicate which trees should be preserved. Trees with a DBH measurement of less than 15.2 centimeters comprised 51% of the trees sampled(Fig. 3)

The trees within University Heights store a total of 319.7 T of carbon valued at $60.1 thousand (Fig. 4) and sequester 7.6 T of carbon per year valuing $1,420 per year (Fig. 5). The white oak (*Q. alba*) trees in the University Heights Loop store 66.2 T of carbon, with southern red oak (*Quercus falcata* Michx.) trees storing 25.7 T, and black oak (*Quercus velutin*a Lam.) trees storing 20.0 T. The white oak (*Q. alba*) trees in University Heights Loop sequester 0.80 T annually, while the southern red oak (*Q. falcata*) trees sequester 0.44 T annually, and black oak (*Q. velutina*) annually sequestering 0.38 T of carbon. The monetary value of carbon storage and sequestration is projected by an integrated assessment model which estimated the net present value of climate change impacts over the next 100 years of one additional metric tonne of carbon emitted into the atmosphere today[5]. Seventy-five percent of the trees within University Heights are native species to North America, with 67% being native to North Carolina. Twenty-five percent of the trees within University Heights are exotic species, with a majority (19% of total) of those species from Asia.

Table 1. Species found within University Heights Loop area of UNCA's main campus with highest importance values

Species name	Percent Population	Percent Leaf Area	Importance Value
White oak (*Quercus alba*)	5.0	15.7	20.7
Flowering dogwood (*Cornus florida*)	12.4	1.6	14.0
Eastern hemlock (*Tsuga canadensis*)	5.9	6.5	12.3
Southern red oak (*Quercus falcata*)	2.8	7.8	10.6
Eastern white pine (*Pinus strobus*)	3.3	7.0	10.4
Shortleaf pine (*Pinus echinata*)	3.5	5.0	8.5
Tulip poplar (*Liriodendron tulipifera*)	1.9	6.0	7.8
Sugar maple (*Acer rubrum*)	2.3	4.6	6.9
Kousa dogwood (*Cornus kousa*)	6.1	0.8	6.9
American holly (*Ilex opaca*)	3.2	1.5	4.8

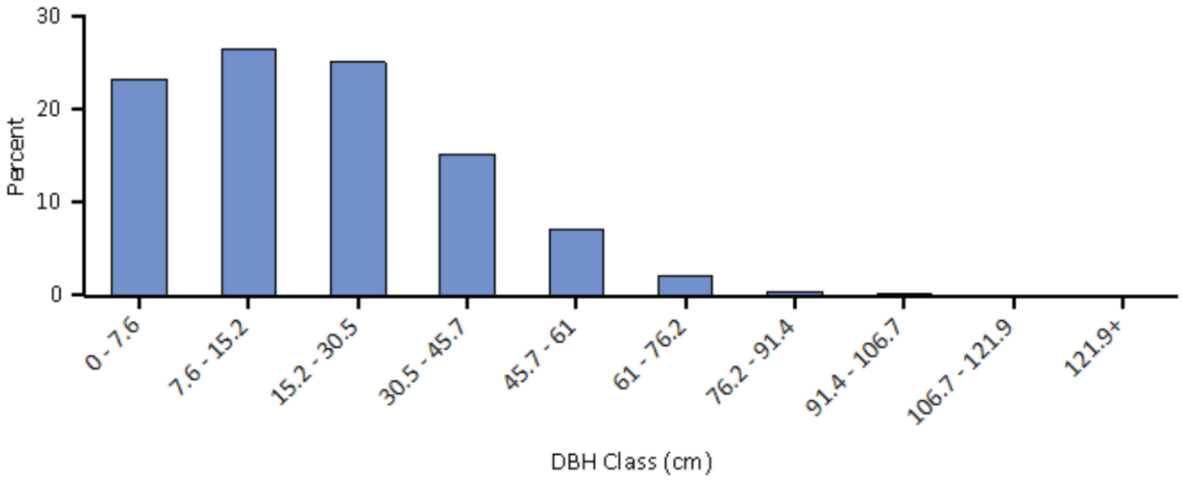

Figure 3. Percent of tree population by diameter class (DBH 1.4 m) in the University Heights Loop area of UNCA's main campus

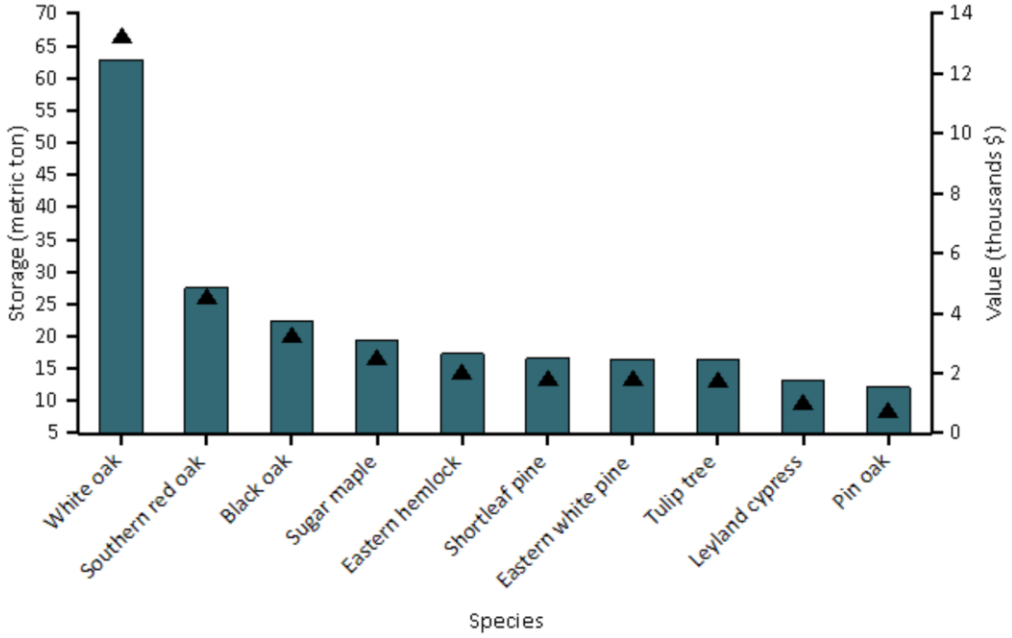

Figure 4**.** Estimated carbon storage (points) and value (bars) for tree species with the greatest storage in the University Heights Loop area of UNCA's main campus

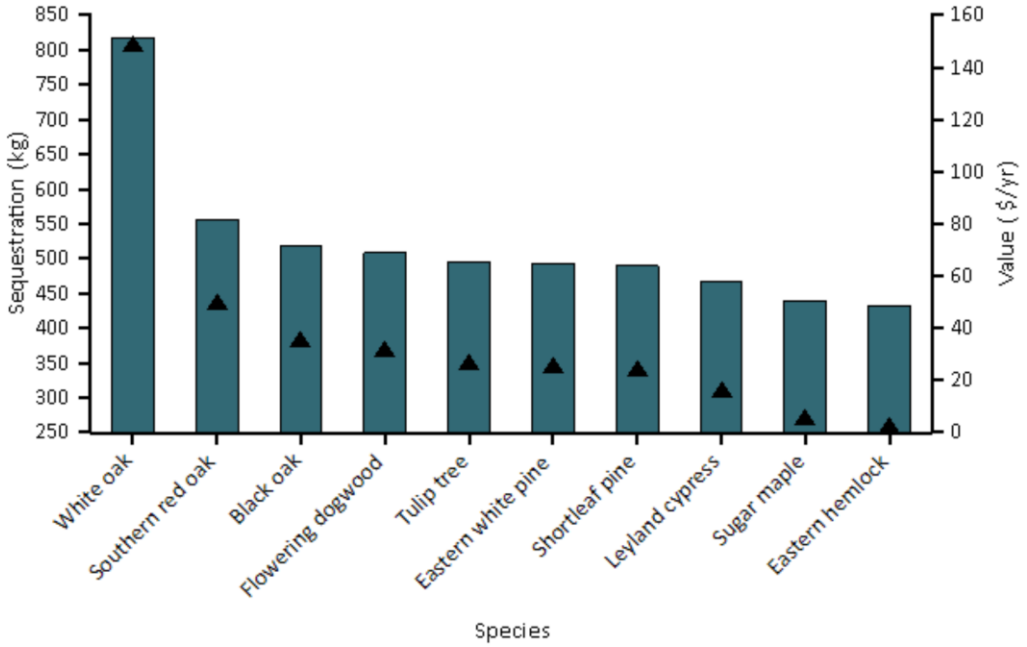

Figure 5. Estimated annual gross carbon sequestration (points) and value (bars) for tree species with the greatest sequestration, University Heights area of UNCA's main campus

3.2 Big Meadow

A total of 279 trees were sampled in Big Meadow. The species with the highest importance values were shortleaf pine (*P. echinata* L.), southern red oak (*Q. falcata*), and red maple (*Acer rubrum* L.) signifying these species are presently the most dominant in this area (Table 2). Trees with a DBH measurement less than 15.2 centimeters comprised 61% of total trees surveyed.

The trees in Big Meadow store 48.31 T valued at $9,800 (Fig. 4) and annually sequester 1.115 T of carbon valuing $210 per year (Fig. 5). The southern red oak (*Q. falcata*) trees in Big Meadow store 14.8 T of carbon, with shortleaf pine (*P. echinata*) storing 10.7 T, and red maple storing 7.3 T. The shortleaf pine (*P. echinata*) trees in Big Meadow sequester 0.25 T per year, while the southern red oak (*Q. falcata* L.) trees sequester 0.21 T per year, and red maple (*A. rubrum*) sequester 0.18 T per year. One hundred percent of the tree species in Big Meadow are native to North Carolina.

Table 2. Species found in Big Meadow of UNCA's main campus with the highest importance values

Species name	Percent Population	Percent Leaf Area	Importance Value
Shortleaf pine (*Pinus echinata*)	17.6	27.3	44.8
Southern red oak (*Quercus falcata*)	12.2	24.0	36.2
Red maple (*Acer rubrum*)	8.6	12.3	20.9
Virginia pine (*Pinus virginiana*)	10.8	9.9	20.6
Flowering dogwood (*Cornus florida*)	15.1	2.4	17.4
Southern crabapple (*Malus angustifolia)*	11.8	1.3	13.1
Tulip poplar (Liriodendron tulipifera)	2.9	7.0	9.8

White oak (*Quercus alba*)	3.9	5.8	9.7
Black cherry (*Prunus serotina*)	6.5	1.8	8.3
Post oak (*Quercus stellata*)	4.7	1.4	6.1

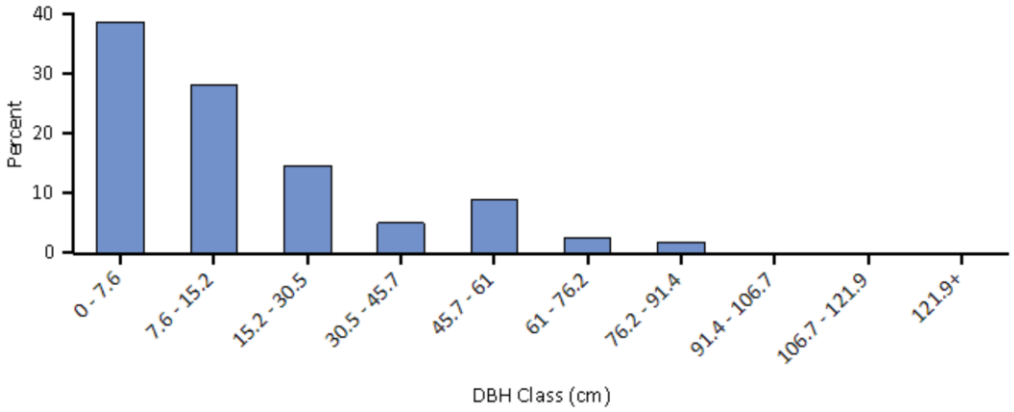

Figure 6. Percent of tree population by diameter class (1.4 m) in the Big Meadow area of UNCA's main campus

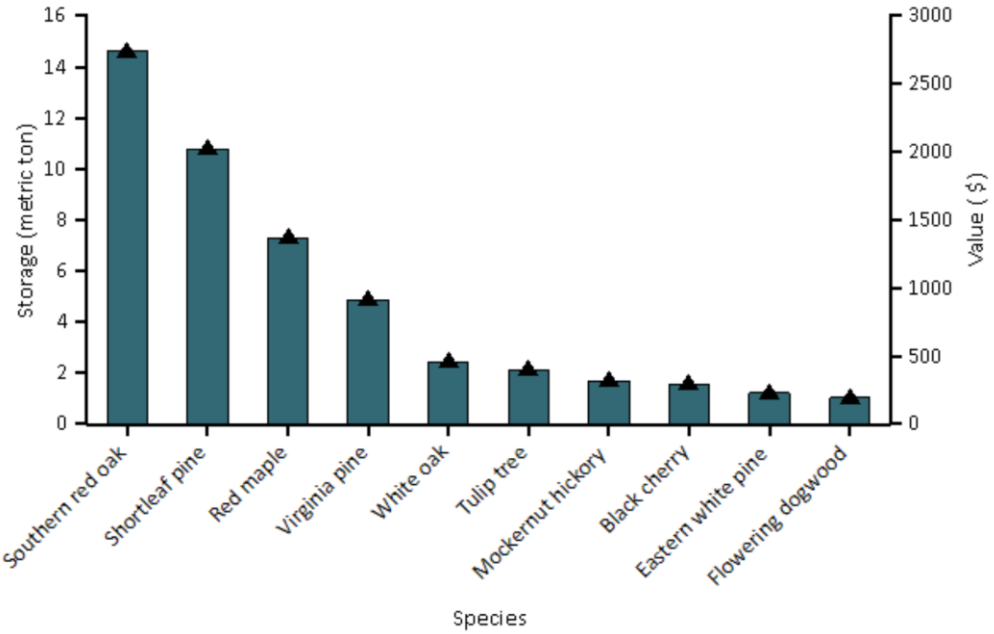

Figure 7**.** Estimated carbon storage (points) and value (bars) for tree species with the greatest storage in the Big Meadow of UNCA's main campus

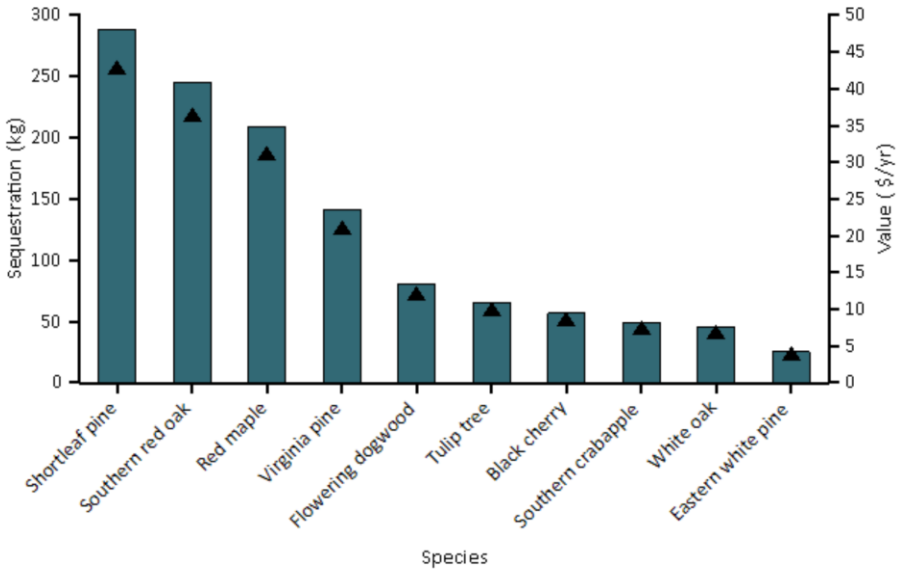

Figure 8. Estimated annual gross carbon sequestration (points) and value (bars) for tree species with the greatest sequestration, Big Meadow area of UNCA's main campus

3.3 Main campus sub-sampling

A total of 2,259 trees were measured in the area considered for plot based sub-sampling. I-Tree Eco estimates that there are 26,710 trees within this area. The species with the highest importance values are tulip tree (*Liriodendron tulipifera* L.), white oak (*Q. alba*), and red maple (*A. rubrum*) denoting these species are currently dominant in these areas of campus (Table 3). Trees with a DBH measurement of less than 15.2 centimeters totaled to 66.1% of all surveyed trees.

Ninety-five percent of tree species present in the forested areas of UNCA's main campus are native to North America with 94% native to North Carolina. Five percent of species present were exotic to North America with 2% originating in Asia. The areas of UNCA's main campus considered for plot based sub-sampling store 3,720 T of carbon valued at $699 thousand (Fig. 6) and sequesters 98.57 T of carbon annually valuing $18.5 thousand per year (Fig. 7). The white oak (*Q. alba*) trees in the forested areas of main campus store 615.0 T of carbon, the tulip trees (*L. tulipifera*) store 476.4 T of carbon, and the southern red oak (*Q. falcata*) trees store 387.3 T of carbon (Figure 5). The tulip trees (*L. tulipifera*) in the forested areas of main campus sequester 14.41 T annually, the black cherry (*Prunus serotina* Ehrh.) trees sequester 11.00 T per year, and the red maple trees annually sequester 9.38 T of carbon (Figure 6).

Table 3. Tree species found in the areas of UNCA's main campus considered for plot based sub-sampling with the highest importance values

Species name	Percent Population	Percent Leaf Area	Importance Value
Tulip tree (*Liriodendron tulipifera)*	6.5	18.3	24.8
White oak (*Quercus alba*)	7.3	12.9	20.3
Red maple (*Acer rubrum*)	8.1	5.3	13.4
Black cherry (*Prunus serotina*)	7.3	6.1	13.4
Eastern white pine (*Pinus strobus*)	5.1	7.0	12.1
Southern red oak (*Quercus falcata*)	2.9	7.8	10.7

Black haw (*Viburnum prunifolium*)	8.7	0.5	9.2
Northern red oak (*Quercus rubra*)	2.2	4.6	6.9
Eastern hemlock (*Tsuga canadensis*)	5.0	1.6	6.7
Black tupelo (*Nyssa sylvatica*)	5.3	1.1	6.5

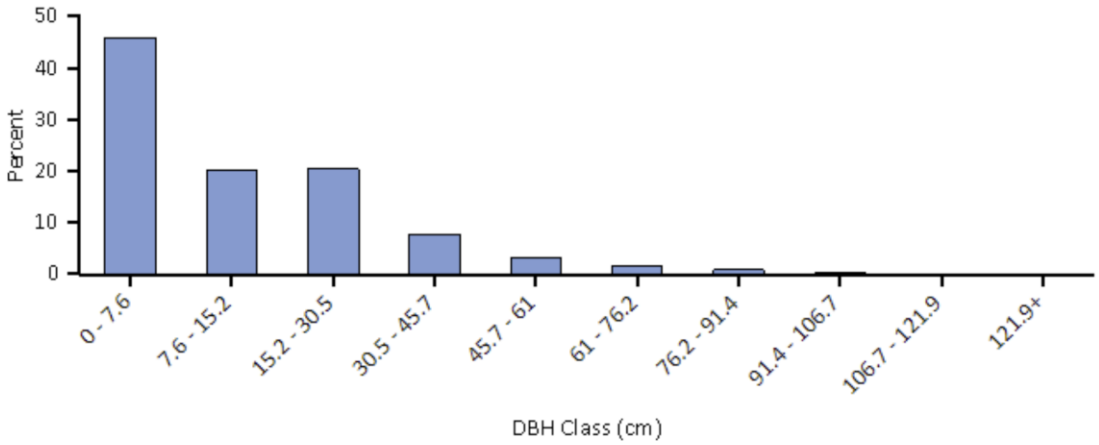

Figure 9. Percent of tree population by diameter class (1.4m) in the areas of UNCA's main campus considered for plot based sub-sampling

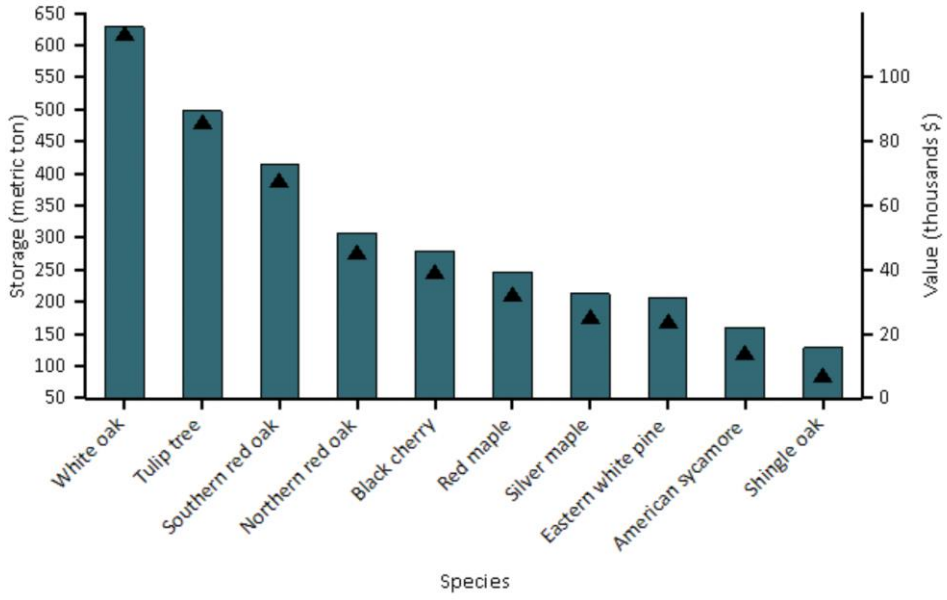

Figure 10. Estimated carbon storage (points) and value (bars) for tree species with the greatest storage in area of UNCA's main campus considered for plot based sub-sampling

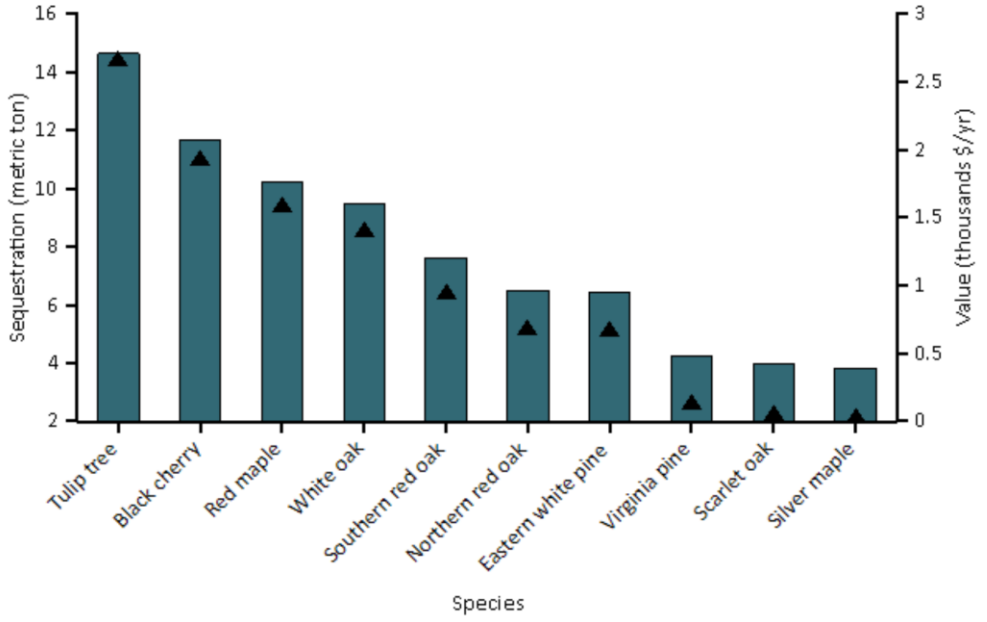

Figure 11. Estimated annual gross carbon sequestration (points) and value (bars) for tree species with the greatest sequestration in the area of UNCA's main campus considered for plot based sub-sampling

4. Discussion

This research builds on a growing body of literature assessing carbon stocks on university campuses. These assessments aid in promoting and achieving sustainability goals set by universities by quantifying carbon sequestration against carbon emissions. The results here compare well with the carbon stock assessments of the University of Georgia[15] and University of Pennsylvania[16] (Table 4). The trees on the main campus of the University of North Carolina Asheville store and sequester more carbon than both the University of Georgia and University of Pennsylvania (Table 4). Both Basset and Fox et al. used a complete inventory method to assess carbon stocks, while the study performed at UNCA used a combination of complete inventory and plot based sub-sampling.

Table 4**.** Comparison of area and carbon stocks between UNC Asheville, University of Georgia, and University of Pennsylvania

	University of North Carolina Asheville	**University of Georgia (Fox et al. 2020)**	**University of Pennsylvania (Basset 2015)**
Area (ha)	110.0	94.1	64.7
Carbon Sequestration (T/year)	118	64.9	37.8
Carbon Storage (T/ha)	40.9	36.6	11

Table 5. Comparison of area, tree density, carbon sequestration, carbon storage and carbon storage per hectare of the surveyed areas of UNCA's main campus

	University Heights	Big Meadow	Main Campus Subsampling	Total
Area (ha)	17.2	1.9	90.9	110
Tree density (trees/ha)	87	146	293	258
Carbon storage (T)	352.4	48.3	4098	4498.7
Carbon Sequestration (T/year)	8.2	1.1	108.7	118
Sequestration dollar value	$1,400	$210	$18,500	$20,110
Carbon Storage per hectare (T/ha)	20.5	25.4	45.1	40.9
Storage dollar value	$60,100	$9,080	$699,000	$768,180

The most important factors in determining the capacity of carbon sequestration and storage in urban trees is species and DBH distribution[20]. Large trees can provide up to 44% more benefits than small trees and small trees store potentially 1000 times less carbon than large trees[21,22]. In other words, large healthy trees yield the highest quantity and quality of ecosystem services, in regard to carbon storage and carbon sequestration. Trees with a DBH measurement of less than 15.2 cm comprised over half of all surveyed trees. With most trees measured here not being large enough to contribute greatly to the carbon storage and sequestration, selection for individual trees can be prioritized for optimization of future carbon storage and sequestration.

4.1 University Heights Loop

The area of UNC Asheville's main campus within University Heights Loop (Fig 1) houses most buildings used for instruction and administration, as well as outdoor spaces for the University community to gather. This area of campus is landscaped and intensely managed, indicating that specific recommendations and preservation of individual trees can be prioritized.

The trees in University Heights Loop store 7.8 % of the total carbon stored in trees on the main campus of UNCA, and annually sequester 7.0 % of all carbon sequestered by main campus trees (Table 5). The University Heights Loop area of main campus has the lowest value for tree density. This area of campus is dominated by flowering dogwood (*C. florida),* kousa dogwood (*C.* kousa) and eastern hemlock (*T. canadensis).* White oak (*Q. alba*) comprises only 5% of the tree population in University Heights Loop area while storing 20% of the total carbon stored in trees here and sequester 10.7% of all sequestered carbon in University Heights Loop. These results indicate prioritizing the health of these trees is vital for the carbon storage and sequestration in this area. Additionally, white oak had the greatest leaf area percentage. Environmental benefits yielded by trees are a direct result of leaf surface area, these benefits include but are not limited to oxygen production, pollution removal, and rainwater interception (Bassett 2015). The data used for the University Heights Loop area of campus were taken between the years 2004 and 2018, by Campus Operations and students. i-Tree claims that to have reliable estimates, trees should be resurveyed every 10 years. Since the data used here has been taken sporadically and by various individuals, this area should be resurveyed to have a more accurate estimate of carbon stocks on the main campus of UNCA.

4.2 Big Meadow

The Big Meadow area of campus is a 1.9-hectare shortleaf pine savannah located on UNC Asheville's main campus (Fig. 1). Savannah ecosystems are considered a transitional landscape, with sparse overstory and a prominent herbaceous understory[23]. This area is used for recreation as well as an outdoor classroom for the Biology and Environmental Studies departments for interest of its plant and bird communities and the recent introduction of prescribed fire on ecosystem dynamics.

Big Meadow stores 1 % of total carbon stored on UNCA's main campus. This can be attributed to the low tree density, as well as this area being dominated by evergreen trees (Table 5). Evergreen tree species tend to store less carbon than winter-deciduous tree species[24]. This notion is supported by our results here with southern red oak (*Q. falcata)* tree storing more carbon than the shortleaf pine (*P. echinata*) trees (Fig 4, Fig 5), even though the shortleaf pine population outnumbers the southern red oak population (Table 2).

4.3 Main campus sub-sampling

The area considered for plot-based subsampling includes land for various uses. The soccer and baseball fields, dormitories, the Asheville Botanical Garden, a greenway, various student-run gardens, and other campus buildings. This area of campus stores 91.2% of total carbon stored on UNCA's main campus. Much of this surveyed area can be categorized as "unmanaged." Carbon stocks in these unmanaged areas of campus can be increased using silvicultural techniques such as crop tree release, removal of invasive species, and tree planting initiatives with trees that store and sequester more carbon can encourage greater carbon storage and sequestration across the landscape[25].

In the area considered for plot bases sub-sampling, tulip trees (*L.* tulipifera) and white oak (*Q. alba)* had the highest importance values (Table 3). White oak (*Q. alba)* make up a higher percentage of the population than tulip trees (*L. tulipifera)* but due to the tulip trees life history traits of having fast and aggressive growth, they can sequester carbon at a faster rate than slow-growing white oaks.

4.4 UNC Asheville Emissions

The University of North Carolina Asheville is designated as Tree Campus USA by the Arbor Day Foundation. This designation is reserved for higher education institutions who promote the health of trees and encourage student involvement[26]. Since the early 2000's the University has utilized wood harvested from trees that are removed once deemed unhealthy or hazardous. The lumber from this program has been incorporated into various construction projects around campus; eastern white pine was used to construct various outdoor structures on campus and black walnut was used for the interior paneling in the observatory, and other wood has been used by the STEAM studio to produce art.

UNC Asheville emits an estimated 18,000 T of greenhouse gases annually (Fig. 12). Based on the estimates returned by i-Tree Eco, the trees on UNCA's main campus mitigate about 0.66% of annual emissions. Prioritizing the health of existing trees and setting goals for higher tree coverage could optimize the carbon storage across the landscape of UNCA's main campus. Though, UNCA boasts a 70% tree coverage of campus, only a fraction of emissions are mitigated highlighting the need to reduce emissions to meet carbon net neutrality goals.

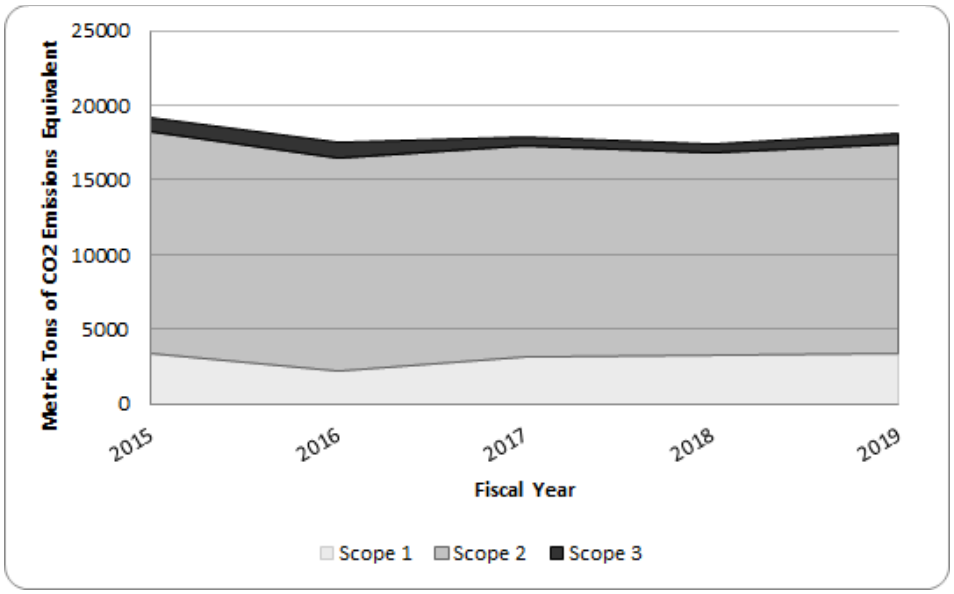

Figure 12. Estimated greenhouse gas emissions released by the University of North Carolina Asheville. Scope 1 emissions include on-campus mobile and stationary operations. Scope 2 emissions are purchased energy, while Scope 3 emissions include off-campus university-related activities including travel for athletics, field trips and study abroad.

5. Future Research Needs

This project was performed in collaboration with student researcher Anna-Lisa Keller who quantified carbon stocks of trees for two forested properties owned by the university, the Urban Forest, and Sandy Bottom Preserve. Together, these projects will provide a more complete assessment of carbon stocks at UNC Asheville. Future studies should consider including more parameters such as tree crown assessments (health, volume, sun-light exposure) to yield more precise results. Furthermore, future studies include the entire carbon cycle. Soil is a well known reservoir for long term carbon storage and contains more carbon than both the atmospheric and vegetation biomass pools[27]. Understanding carbon soil dynamics can serve as a tool to further mitigate anthropogenic carbon emissions[28].

6. Conclusions

Currently only a fraction of the University's emissions are annually mitigated by trees on the main campus of UNC Asheville. Even considering the forested ancillary properties stewarded by UNCA, likely only a fraction of greenhouse gas emissions will be offset. Protection of individual trees on UNCA's main campus can help to preserve current carbon stocks and can influence species selection for future tree plantings. This study highlighted the importance of white oak (*Q. alba*), shortleaf pine (*P. echinata),* southern red oak (*Q. falcata*), and tulip poplar (*L. tulipifera*) for their great contribution to the carbon stocks in trees on UNCA's main campus. Protecting the current trees will help preserve the carbon stored within them and promote increased sequestration. Nevertheless, the University must take additional action to lower greenhouse gas emissions in order to comply with the Climate Action Plan and reach the goal of the Second Nature Carbon Commitment to become net carbon neutral by 2050.

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8. References

1. Chapin, III FS, Matson, PA, Vitousek, PM. (2011) Carbon Inputs to Ecosystems. *Principles of Terrestrial Ecosystem Ecology*.Springer Science + Business Media, LLC
2. Pace R, Biber P, Pretzsch H, Grote R. 2018. Modeling ecosystem services for park trees: sensitivity of i-Tree Eco simulations to light exposure and tree species classification. Forests. 9(89): 1-18.
3. Rapp, D. (2014) Temperatures in the past century. *Assessing Climate Change.* Springer Science + Business Media, LLC.
4. Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M. M. B., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P. M. (2013). Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. 1535 p. https://www.ipcc.ch/site/assets/uploads/2017/09/WG1AR5_Frontmatter_FINAL.pdf
5. Pörtner HO, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K, Alegría A, Craig M, Langsdorf S, Löschke S, Möller V, Okem A, Rama B (eds.). 2022. IPCC, 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. In Press.
6. Lorenz, K. (2013). Ecosystem Carbon Sequestration. In: Lal, R., Lorenz, K., Hüttl, R., Schneider, B., von Braun, J. (eds) Ecosystem Services and Carbon Sequestration in the Biosphere. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-6455-2_3
7. Davies ZG, Edmundson JL, Heinemeyer A, Leake JR, Gaston KJ. 2011. Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. *Journal of Applied Ecology*. 48(5): 1125-1134.
8. Köhl, M, Neupane, PR, Lotfiomran N. (2017). The impact of tree age on biomass growth and carbon accumulation capacity: A retrospective analysis using tree ring data of three tropical tree species grown in natural forests of Suriname. *PLOS ONE*, *12*(8).
9. Parsa VA, Salehi E, Yavari AR, Bodegom RM. 2019. Evaluating the potential contribution of urban ecosystem service to climate change mitigation. *Urban Ecosystems*. 22(1): 989-1006.
10. Thomas SC, Martin AR. 2012. Carbon content of tree tissues: a synthesis. Forests. 3: 332-352
11. Dale, MJ. 2013. Evaluation of methods for quantifying carbon storage of urban trees in New Zealand. The University of Auckland. 1(1): 1-10.
12. i-Tree Eco user's manual. 2020. V6.0. USDA. US Forest Service
13. Nowak, D. J., Greenfield, E. J., Hoehn, R. E., & Lapoint, E. (2013). Carbon Storage and sequestration by trees in urban and community areas of the United States. *Environmental Pollution*, *178*, 229–236. https://doi.org/10.1016/j.envpol.2013.03.019
14. Sinha P, Schew WA, Sawant A, Kolwaite KJ, & Strode SA. 2010. Greenhouse gas emissions from U.S. institutions of higher education. *The Journal of the Air & Waste Management Association.* 60(5): 568-573.
15. Fox W, Dwivedi P, Lowe III RC, Welch S, Fuller M. 2020. Estimating carbon stock of live trees located on the main campus of the University of Georgia. Journal of Forestry. 118(5): 457-465.
16. Bassett CG. 2015. The environmental benefits of trees on an urban university campus. Scholarly Commons. 1-44.
17. Martin NA, Chappelka AH, Loewenstein EF, Keever GJ. 2012. Comparison of carbon storage, carbon sequestration, and air pollution removal by protected and maintained urban forests in Alabama, USA. International Journal of Biodiversity Science, Ecosystem Services & Management. 8(3): 265-272.

18. De Villiers C, Chen S, Jin C, Zhu, Y. 2014. Carbon sequestered in the trees on a Univerisyt Campus: A case study. *The Sustainability Accounting, Management and Policy Journal.* 5(2):149-171.
19. Nandini N, Kumar K, Tandon s. 2009. Assessment of carbon sequestration in trees of Jnanabharathi Campus- Bangalore University. *Ecology, Environment, and Conservation Journal.* 15(3):503-508.
20. Nowak DJ. 1993. Atmospheric carbon reduction in by urban trees. *Journal of Environmental Management.* 37: 207-217.
21. Armor T, Job M, Canavan R. *The benefits of large species trees in urban landscapes: a costing, design and management guide.* (London: CIRIA, 2012).
22. Nowak DJ. 1994. Air pollution removal by Chicago's urban Forest In: Chicago's urban Forest ecosystem: results of the Chicago urban Forest climate project.
23. Dyksterhuis, E. 1957. The savannah concept and its use. *Ecology*, 435-442. Retrieved from http://www.jstor.org/stable/1929887?seq=1#page_scan_tab_contents
24. Fajardo A, Piper FI, Hoch G. 2013. Similar variation in carbon storage between deciduous and evergreen treeline species across elevational gradients. *Annals of Botany*. 112:623-631.
25. Hackworth ZJ, Lhotka JM, Stringer JW. 2020. Midstory removal facilitates growth but reduces competitiveness of oak reproduction prior to and after shelterwood establishment cutting. Forest Science. 66 (3): 371–381.
26. Arbor Day Foundation. 2021. Lincoln (Nebraska): Tree campus higher education. [accessed 2021 October 5]. https://www.arborday.org/programs/tree-campus-higher-education/
27. Swift RS. 2001. Sequestration of carbon by soil. Soil Science. 166 (11): 858-871.
28. Lal R, Negassa W, Lorenz K. 2015. Carbon sequestration in soil. Current Opinion in Environmental Sustainability. 15(1): 79-86.