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Inventorying University of North Carolina Asheville's Forested Properties to Assess Carbon Stock

Anna-Lisa Keller
Department of Biology
University of North Carolina Asheville
One University Heights
Asheville, North Carolina 28804 USA

Faculty Advisors: Dr. Jonathan Horton and Dr. Alison Ormsby

Abstract

Trees are a precious ecological, aesthetic, economic and educational asset to institutions of higher education. The University of North Carolina Asheville has signed the nationwide Carbon Commitment and is now committed to becoming net carbon neutral by the year 2050. The goal of this research was to assess the current carbon stock of campus trees and predict future carbon sequestration. In collaboration with the NC Forest Service, a plot-sampled inventory was taken of two satellite forested properties of UNC Asheville: the Urban Forest (23 ha) and Sandy Bottom Preserve (12 ha). Each surveyed tree was identified to species and the diameter at breast height was recorded. The inventory procedures followed those developed for the i-Tree Eco tool, which was used to calculate carbon storage and to forecast future carbon sequestration. It was found that the Urban Forest stores around 3,450 metric tons of carbon and sequesters 75.5 metric tons of carbon annually, while the Sandy Bottom Preserve stores 946.2 tons of carbon and sequesters 65.1 metric tons each year. To enhance the services provided by these trees, it is recommended that invasive species removal take place in addition to selective tree removal, both standard forestry practices. The information collected from this project determined that about 0.78% of the university's annual carbon emissions are currently being offset by the sampled urban forests. Two additional forested properties owned by the university remain to be surveyed and once they are analyzed for carbon sequestration, they will contribute to a greater offset of emissions. Additionally, this study contributes to the campus Climate Action Plan by providing land management recommendations to increase carbon storage potential in the University's forests.

1. Introduction

Atmospheric carbon dioxide (CO_2) emissions are predicted to double in the next century which will continue to accelerate climate change, posing human health and safety risks[1,2]. Carbon dioxide is the primary greenhouse gas emitted anthropogenically and it contributes greatly to global warming by trapping and reflecting heat back to Earth[3]. Sources of anthropogenic carbon dioxide emissions include, but are not limited to, transportation, power generation, and agriculture[4]. In addition to the use of fossil fuels, deforestation is another major factor that advances climate change. As tree biomass is removed and destroyed, the carbon stored within the vegetation and soil is released into the atmosphere[5]. Furthermore, deforestation for urban development results in the loss of a carbon sink, as vegetation is unable to regrow and capture carbon. In the United Nations' 2021 Report on Global Forest Goals, it was stated that we lose 10 million hectares (ha) of the world's forests each year, and global deforestation is expected to accelerate with urban expansion[6].

Increasing concerns about the effects of climate change have prompted researchers to study forest composition and estimate ecosystem services provided by urban trees. More than half of the world's population lives in urban areas, making urban forests a major target for carbon sequestration research, especially considering most anthropogenic CO_2 emissions come from urban areas[4,7]. The concentration of CO_2 in urban areas is higher due to human activities such as heating buildings and dense transportation via internal combustion engines[8]. Therefore, urban forests are important carbon mitigators because they capture atmospheric carbon from urban areas. Further, they reduce the need for heating and cooling energy through the process of transpiration and blocking cold wind gusts[9,10]. Urban forests are known to sequester carbon through vegetative growth. Essentially, plants use light energy from the sun to combine water and carbon dioxide to produce sugars and oxygen during photosynthesis[11]. Sugars are then used to form lignin, a structural component of plant secondary cell walls, explaining the mechanism by which plants store carbon in their biomass[11]. Sequestration refers to the annual uptake of CO_2 and the assimilation of it within the trees biomass, which is then referred to as carbon storage. Carbon stocks refer to a carbon pool that can still release and accumulate carbon. Carbon content in trees is widely accepted to be about 50% of tree biomass[12].

Evaluating the composition of urban forests can help highlight the ecosystem services they provide, promoting the prioritization of their management and conservation. Ecosystem services are various benefits to humans that are provided by the environment[7]. Examples of ecosystem services provided by trees include carbon storage and sequestration, air filtering, noise reduction, micro-climate regulation, reduction of stormwater runoff, and addition of cultural and aesthetic values[13]. Some of these services are involved in reducing the urban heat island effect[7]. The urban heat island effect describes how urban areas tend to be higher in temperature compared to surrounding rural areas because of human activities and infrastructure, such as buildings and roads, that absorb and re-emit heat energy[7]. Vegetation can absorb and retain heat, making urban trees useful in diminishing excess heat and carbon dioxide concentrations which, in turn, helps reduce the costs of heating and cooling. Through the process of transpiration, trees lose water vapor from their leaves, which has a cooling effect on trees and the surrounding air, similar to how humans perspire to cool down[10]. Trees can also help reduce or divert wind gusts, helping reduce heating costs[10].

Of all ecosystem services provided by urban forests, carbon storage and sequestration are arguably the most important for universities, especially considering that in the United States, colleges and universities are responsible for about 2% of the nation's carbon emissions[14]. Colleges and universities across the United States have signed carbon commitments with the hopes of promoting sustainability and lowering their environmental footprint[14]. The University of North Carolina Asheville (UNCA) signed the Second Nature Carbon Commitment in March 2021, pledging to become net carbon neutral by the year 2050. As part of the Commitment, the university is developing a Climate Action Plan, which outlines how the university will use short, medium, and long-term goals to lower and offset its greenhouse gas emissions. Many universities around the United States have signed similar carbon commitments as a way to promote sustainability and lower their environmental footprint[14]. Inventorying the trees on college campuses to determine carbon offset potential is one way to help universities come closer to achieving their carbon neutrality goals. The information collected through these inventories can help inform land management actions that maximize carbon stock potential and create optimal conditions for growth.

The University of Georgia carried out a complete inventory of the trees on their main campus to quantify carbon stocks (stored and annually sequestered)[14]. Tree species, height, and diameter at breast height (DBH) were recorded for all live trees and i-Tree Eco V6 was used to quantify carbon stock[14]. The results showed that carbon sequestered in the main campus trees offset 0.11% of emissions released annually by the university in 2018[14]. A similar study conducted at the Auburn University campus quantified carbon stock in trees located on the main campus[15]. This study found that areas with larger trees and protected forests provide the most ecosystem services[15]. The urban forest inventory at UNCA will contribute to the already existing studies that evaluate the environmental impacts of universities and how urban trees help mitigate these impacts. It will also bring the University closer to its goal of becoming net carbon neutral by the year 2050.

My study assessed the carbon stocks of two urban forests owned by the University of North Carolina Asheville contribute to offsetting carbon emissions released by the University. These forests were inventoried to better understand their structure and composition. The information collected through this study will inform the University how much of its carbon emissions are currently being offset by these properties and will advise land management plans to help maximize the ecosystem services provided by the forests. This work can be expanded to include other ancillary forested properties owned by the University.

This study aimed to answer the following questions:

1. What are current carbon stocks in the University of North Carolina Asheville's Urban Forest and Sandy Bottom Preserve?
2. What is the future carbon sequestration potential of the University of North Carolina Asheville's forests and how might this contribute to the University's carbon neutrality goals?
3. What land management practices can be used to create conditions for optimal growth and maximize carbon storage potential in UNC Asheville's forests?

2. Methods

The University of North Carolina Asheville collaborated with the North Carolina Forest Service (NCFS) for this project in the Summer of 2021. The NCFS is familiar with conducting tree inventories, estimating ecosystem services, and developing management plans. The NCFS was able to gain insight into the composition of UNC Asheville's forests and the ecosystem services they provide while developing a collaborative relationship with students and faculty at the University. As part of this collaborative partnership, Management Forester Jordan Luff generated random plot locations throughout UNCA's forests using Plot Hound (NCX, San Francisco, CA)[16]. Sixty permanent 0.04 ha (0.1 acre) plots were placed in the Urban Forest (Fig. 1), a 23 ha (56.6 acre) parcel across W.T. Weaver Boulevard from south campus and 30 plots were established at Sandy Bottom Preserve, an 12 ha (30-acre) parcel near Bent Creek Experimental Forest in Buncombe County. Plot shapefiles were then downloaded onto the Gaia GPS software (Trailbehind Inc, Boulder, CO) for locating and establishing plot centers in the field. This *a priori* randomization of the location of plots allowed for the estimation of forest stand characteristics with a 10% standard deviation, a sampling intensity often used for forest inventories[17].

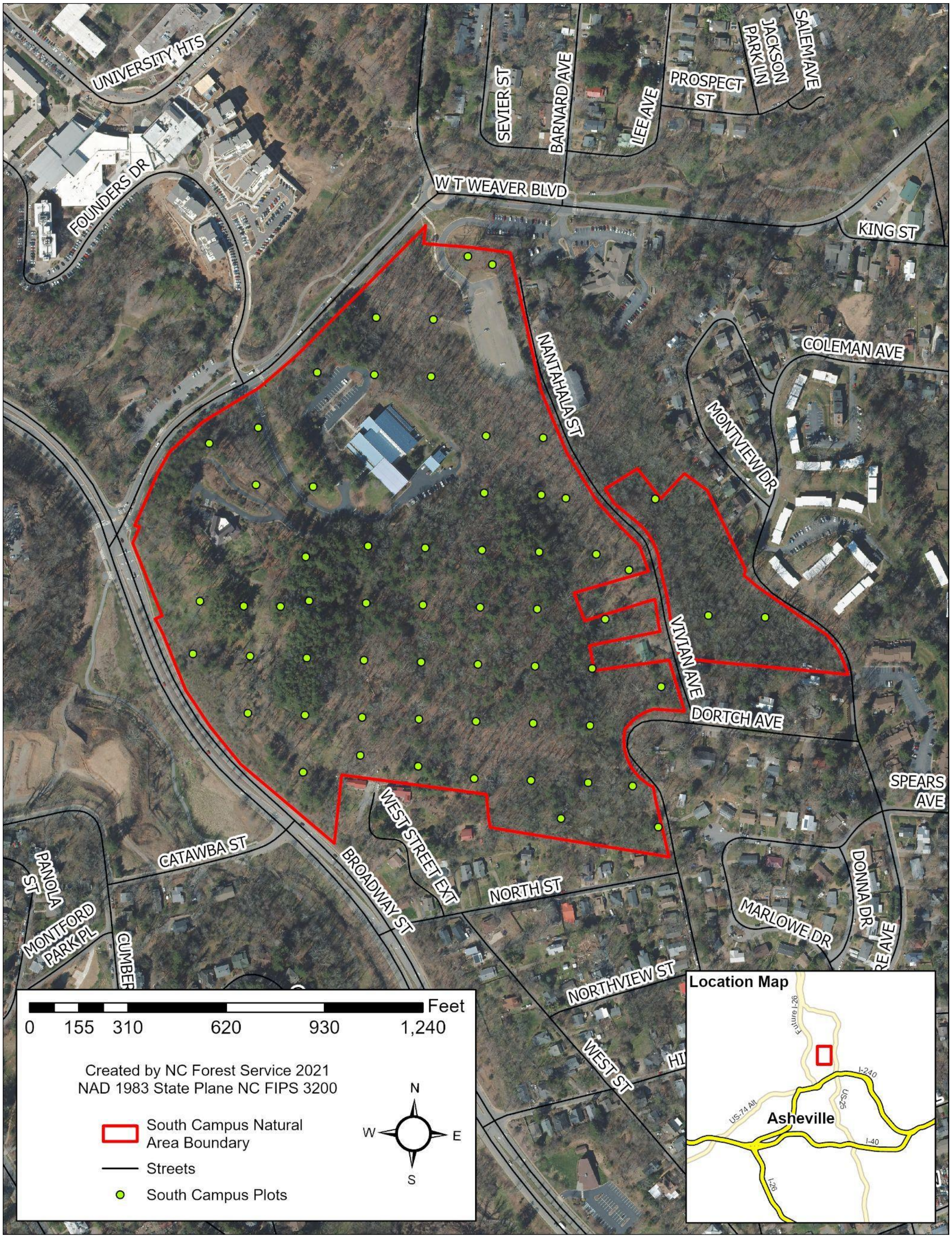

Figure 1. Map depicting the South Campus/Urban Forest property (23 ha) owned by UNC Asheville. Green dots represent the plot centers.

Data collection began in May 2021 in the Urban Forest and July for Sandy Bottom Preserve. Plot centers were located and marked with capped rebar for future resampling. Meter tapes were extended 22.6 m from N-S and E-W to discern the size of the plot (22.6 m diameter = 0.01 ha circular plot). Plots were inventoried by quartile. Within each plot, all trees with a DBH (measured at 1.3 m) > 2.5-cm were identified to species and their DBH was recorded as described in the i-Tree Eco user's manual[8,18]. If identification was not possible in the field, leaf and branch samples were collected for later identification. Additionally, the initial proposal of this project included measuring the following parameters: tree height, live canopy height and width, canopy dieback, and canopy crown exposure to allow for more accurate carbon sequestration forecasting. However, due to time constraints, the scope of this project was narrowed after about a month of sampling. To complete an inventory over a larger area, the minimum required parameters (species, DBH and percent canopy cover) were measured. Percent canopy cover estimates the percentage (in 5% increments) of each plot covered by the tree canopy[19].

Data were compiled and entered into the i-Tree Eco V6 software for the calculation of carbon stocks and annual sequestration. The i-Tree Eco tool is designed to use field data from complete inventories of trees and sampled plots along with local hourly air pollution and meteorological data to quantify urban forest structure, environmental effects, and value to communities[19]. Following data processing, the estimated carbon stocks made by i-Tree Eco were compared with annual carbon emissions released from UNCA. Using the data collected for this study, a forest management plan was developed in collaboration with the NCFS to identify optimal conditions for tree growth and to maximize the amount of carbon stored in vegetation, therefore helping with the University's carbon accounting as it moves towards its carbon neutral goal.

3. Results

3.1 The Urban Forest

A total of 2,105 trees were measured in the Urban Forest property and i-Tree Eco estimated for a total of 19,850 trees in the property. The species with the highest importance values were eastern white pine (*P. strobus* L.), tulip tree (*Liriodendron tulipifera* L.), and black cherry (*Prunus serotina* Ehrh.), meaning these species were the most dominant in the Urban Forest (Table 1). Importance value is calculated in i-Tree Eco using the sum of percent species population and percent leaf area[18]. Trees that had a DBH of less than 15.2 centimeters (6 inches) accounted for 65.2% of the total trees measured. The estimated tree density of the Urban Forest based on this plot measurement is about 863 trees per ha (351 per acre).

Table 1. Species found in UNC Asheville's Urban Forest with Highest Importance Value. Importance value is calculated by summing the percent population and percent leaf area. Percent leaf area is calculated by using estimated crown measurements and percent canopy missing[18].

Species name	Percent Population	Percent Leaf Area	Importance Value
Eastern white pine (*Pinus strobus*)	20.5	30.6	51.1
Tulip tree (*Liriodendron tulipifera*)	10.5	28.5	38.9
Black cherry (*Prunus serotina*)	8.3	10.3	18.6
Southern red oak (*Quercus falcata*)	2.8	7.5	10.2
White oak (*Quercus alba*)	5.8	3.8	9.7

Mockernut hickory (*Carya tomentosa*)	4.0	1.9	5.9
Norway maple (*Acer platanoides*)	4.5	1.3	5.8
Black haw (*Viburnum prunifolium*)	5.2	0.2	5.4
Sourwood (*Oxydendrum arboreum*)	3.7	1.4	5.0
Red maple (*Acer rubrum*)	4.2	0.6	4.9

In the sampled inventory of the Urban Forest, 90% of the trees measured are native to North America and 86% of the trees measured are native to North Carolina. Exotic species made up about 10% of the trees measured in this study. The gross annual carbon sequestration of the Urban Forest is 75.51 metric tons, a value of about $12.9 thousand per year (Fig. 2). Carbon sequestration value is calculated by estimating the economic damages that are associated with increases in carbon dioxide emissions[18,20]. In the Urban Forest, an estimated 3,450 metric tons of carbon is stored with an associated value of $589 thousand (Fig. 3). Out of all the trees measured, tulip trees appear to store the most carbon (24%) while eastern white pine trees sequester the most (26.2%) on an annual basis.

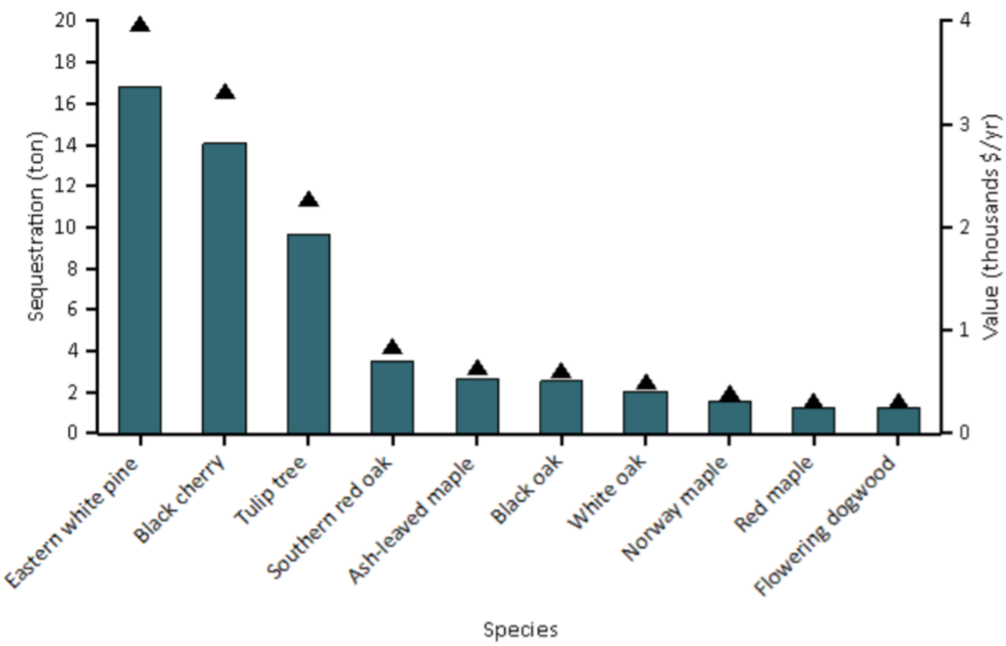

Figure 2. Estimated annual gross carbon sequestration (points) and value (bars) for urban tree species with the greatest carbon sequestration at the Urban Forest. Dollar values are calculated based on the estimated economic damages correlated with increases in atmospheric carbon dioxide emissions.

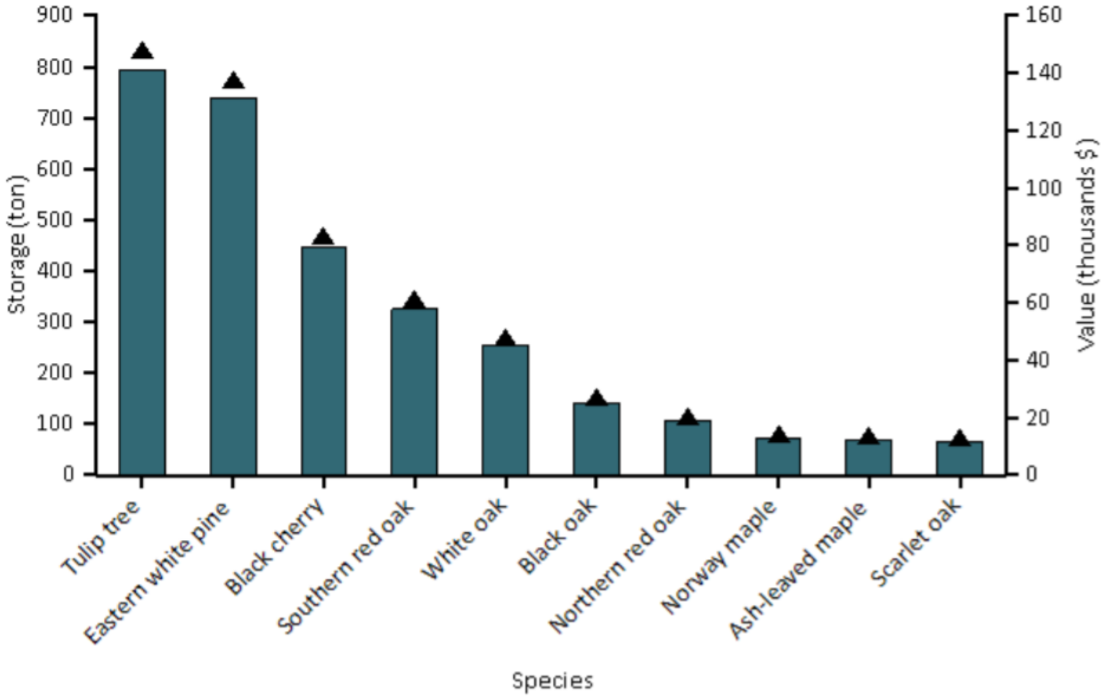

Figure 3. Estimated carbon storage (points) and values (bars) for urban tree species with the greatest carbon storage at the Urban Forest. Dollar values are calculated based on the estimated economic damages correlated with increases in atmospheric carbon dioxide emissions.

4.2 Sandy Bottom

Overall, 1,697 trees were measured in the Sandy Bottom Preserve. The i-Tree Eco tool estimated a total of 15,380 trees within the entire property. The estimation made by i-Tree Eco of tree density in Sandy Bottom is 1,398 trees per ha (566 per acre). This estimation is made based on tree density in measured sample plots. The tree species with the highest importance values include red maple (*Acer rubrum* L.), sourwood (*Oxydendrum arboreum* DC.), and American hornbeam (*Carpinus caroliniana* Walter), meaning that these species currently dominate the property (Table 2).

Table 2. Species found in UNC Asheville's Sandy Bottom Preserve with Highest Importance Value. Importance value is calculated by summing the percent population and percent leaf area. Percent leaf area is calculated by using estimated crown measurements and percent canopy missing[18].

Species name	Percent Population	Percent Leaf Area	Importance Value
Red maple (*Acer rubrum*)	24.2	22.5	46.7
River birch (*Betula nigra*)	9.8	18.2	28.1
Tulip tree (*Liriodendron tulipifera*)	5.8	11.2	17.1
Sourwood	10.6	3.6	14.2

(*Oxydendrum arboreum*)			
American hornbeam (*Carpinus caroliniana*)	10.1	2.9	13.0
Eastern white pine (*Pinus strobus)*	4.8	6.7	11.5
Virginia pine (*Pinus virginiana*)	2.8	5.5	8.2
Black tupelo (*Nyssa sylvatica*)	6.1	1.6	7.7
Pitch pine (*Pinus rigida*)	1.6	5.5	7.2
Shortleaf pine (*Pinus echinata*)	2.1	3.8	5.9

About 71.9% of the total trees measured had a DBH of less than 15.2 centimeters. At the Sandy Bottom property (Fig. 4), 100% of the trees measured are native to North America and 99% of the trees measured are native to North Carolina, with exotic species making up none of the trees measured. Gross annually sequestered carbon in the Sandy Bottom preserve is estimated to be about 65.1 metric tons, valuing about $11.1 thousand per year (Fig. 5). An estimated 946 metric tons of carbon is stored with an associated value of $161 thousand (Fig. 6).

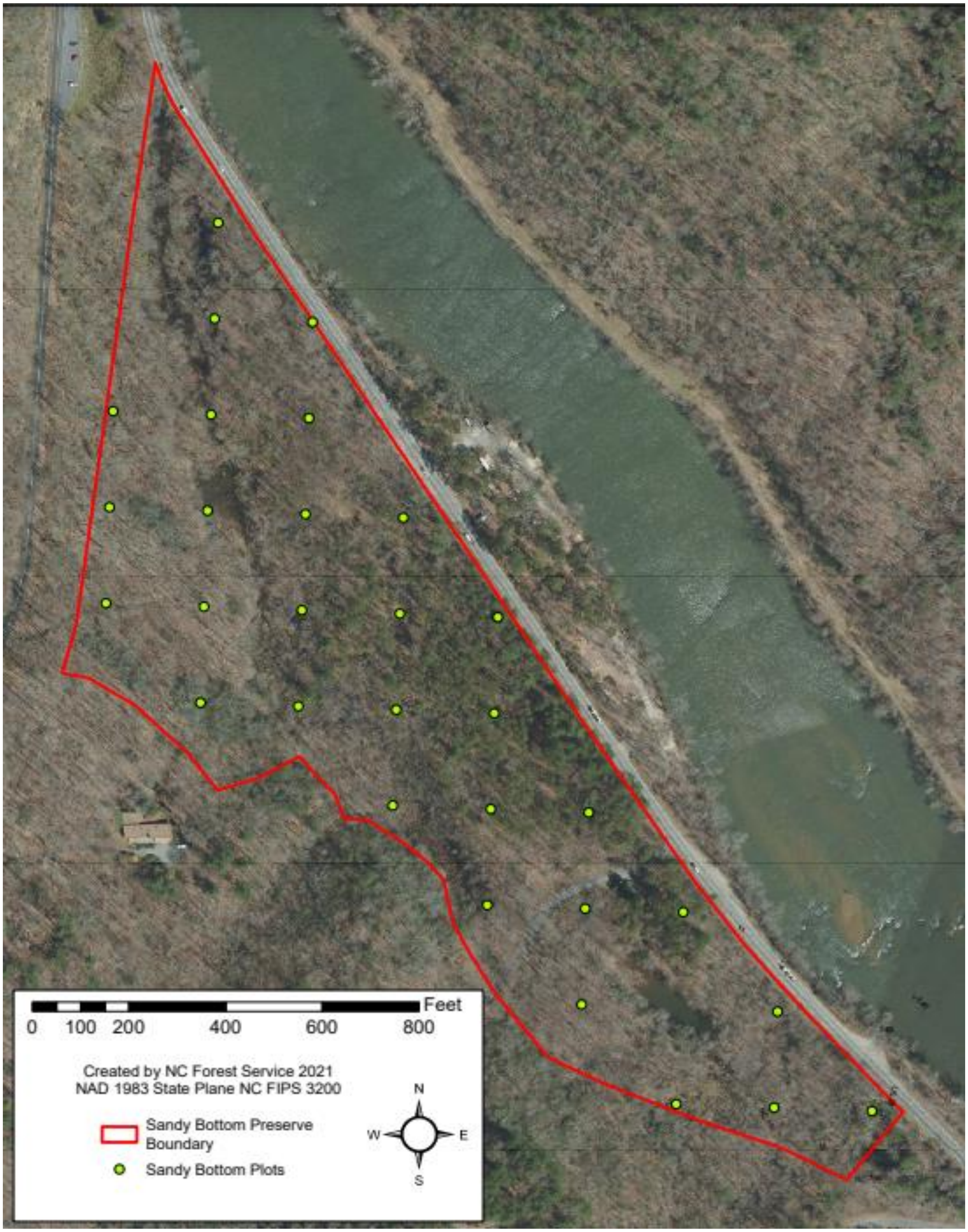

Figure 4. Map depicting the Sandy Bottom Preserve property (12 ha) owned by UNC Asheville's Endowment Fund Board. Green dots represent the plot centers. The road names and locator map on this figure are not included to keep the location of the property private.

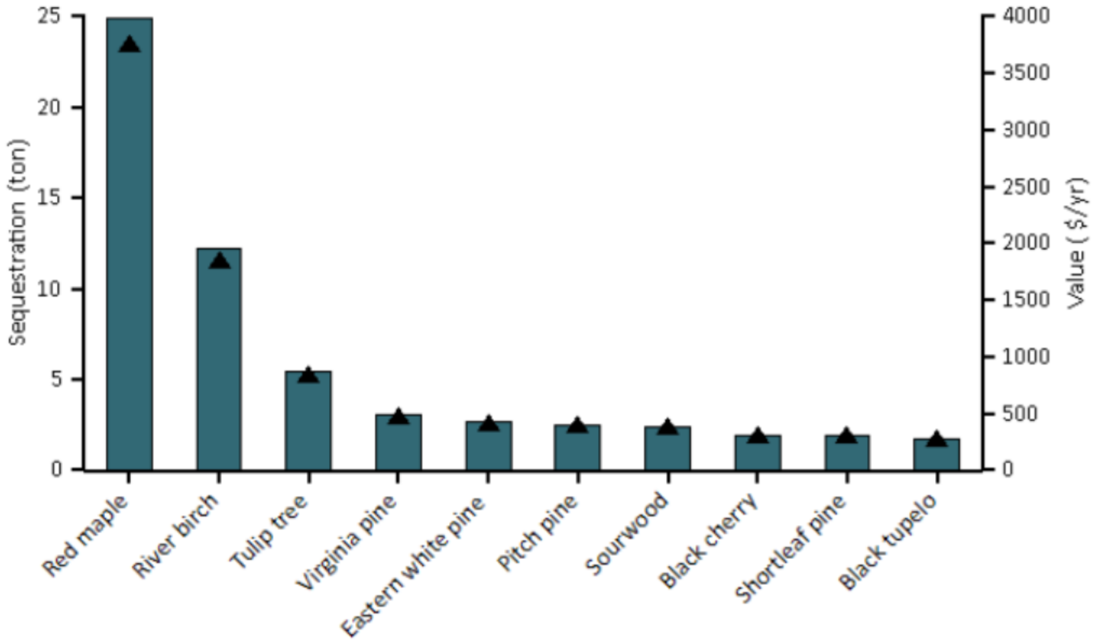

Figure 5. Estimated annual gross carbon sequestration (points) and value (bars) for urban tree species with the greatest carbon sequestration at Sandy Bottom Preserve.

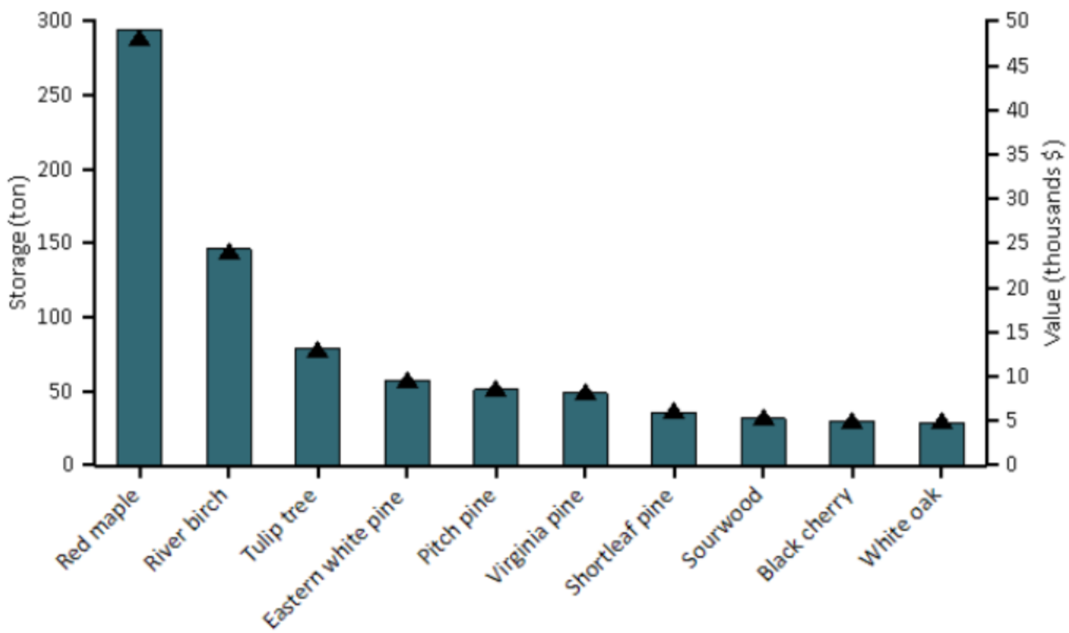

Figure 6. Estimated carbon storage (points) and values (bars) for urban tree species with the greatest carbon storage at Sandy Bottom Preserve.

4. Discussion

This research contributes to the body of literature assessing carbon stocks on lands owned by universities. These efforts have had the goal of quantifying carbon sequestration against annual carbon emissions to promote sustainability at universities. Several similar studies have been carried out at universities across the United States and are exemplified by the research done at the University of Georgia by Fox et al. (2020), and the University of Pennsylvania by Bassett

(2015). The measured forested properties at UNC Asheville are higher in carbon stocks compared to these other two universities. In the complete inventory of the University of Georgia's 94.1 ha main campus, a total of 6,915 trees were measured (Table 3). These trees were estimated to store 3450 metric tons of carbon. A complete inventory of the University of Pennsylvania's core campus trees showed an estimated 715.2 metric tons of carbon storage in 4,086 trees that were measured over a span of 64.7 ha. In the plot sampled inventory done in UNCA's 23 ha urban forest, a total of 2,105 trees were sampled and there was an estimated total of 3,452 metric tons of carbon storage. Meanwhile, Sandy Bottom Preserve's 11 ha forest had a total of 1,697 trees sampled with an estimated 946 metric tons of carbon storage. Carbon storage per hectare in the two UNCA forested properties (125.6 mt/ha) was higher compared to the University of Georgia (36.6 mt/ha) and the University of Pennsylvania (11 mt/ha). Carbon sequestration was also highest in the two sampled forests at UNC Asheville (140.6 mt) despite the smaller size of area sampled, compared to the University of Georgia (64.9 mt) and the University of Pennsylvania (37.8 mt). Considering that the studies done at the University of Georgia and Pennsylvania were done on their central campuses that included buildings, parking, and other non-forested areas, this result may be attributed to a higher tree density in UNC Asheville's undeveloped urban forests that likely have a larger number of more sizable, older trees. Trees help reduce the amount of atmospheric carbon content by sequestering carbon in new growth. The amount of annually sequestered carbon increases with the health and size of trees.

Table 3. Comparison of carbon stocks, area and tree density 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 (Bassett 2015)**
Area	35 ha	94.1 ha	64.7 ha
Tree density	1046 trees per ha	73.5 trees per ha	63.2 trees per ha
Sequestration	140.6 mt	64.9 mt	37.8 mt
Storage	125.6 mt/ha	36.6 mt/ha	11 mt/ha

Urban forests are typically composed of native and non-native plant species and therefore tend to have a higher tree diversity than surrounding native landscapes[19]. Although a high diversity of trees decreases the risk of insect or disease-related destruction, non-native species may out-compete and displace native species, having adverse effects for carbon sequestration[19,21]. Interestingly, in the study by Bassett (2015), a total of 228 tree species were recorded, while only 118 species were recorded across the Urban Forest and Sandy Bottom Preserve. Studies have shown that increased species richness can increase carbon stocks[21]. Despite the lower species diversity at UNC Asheville, it stores more carbon per ha, which may, in part, be attributed to the eastern white pine trees that were planted in the Urban Forest. Eastern white pines have a faster growth rate compared to other conifer and hardwood species in the Southern Appalachians and can therefore accumulate large quantities of carbon in their prime growth years[23]. The lower levels of diversity in the Urban Forest and Sandy Bottom Preserve is likely attributed to the fact that this is a relatively "natural" forest and will therefore have lower diversity compared to a horticulturally planted landscape, like those of the studies by Fox and others (2020) and Bassett (2015). Nevertheless, these findings may provide incentive for future management plans to plant tree species that will increase species richness and carbon stock potential.

4.1 The Urban Forest

The Urban Forest (Fig. 1), located on the south side of UNC Asheville's campus, was historically used as a dairy farm[24]. Native eastern white pine trees (*Pinus strobus* L.) were planted in the area in the 1930s after the farm was abandoned[24]. This forest is dominated by white pines in plantation areas, but generally, the forest is more heavily occupied by natural oak-hickory communities[25]. The forest has a thick understory that is dominated by non-native invasive species, including Chinese privet (*Ligustrum sinense* L.), oriental bittersweet (*Celastrus orbiculatus* Thunb.), multiflora rose (*Rosa multiflora* Thunb.), and tree-of-heaven (*Ailanthus altissima* S.).

The results from the Urban Forest inventory show the importance of eastern white pine and tulip trees, as they are the biggest contributors to carbon storage and sequestration in this forest. Furthermore, eastern white pine trees had the highest leaf area which could influence other ecosystem services including pollution filtration, water interception, and stormwater mitigation. The majority of the environmental benefits provided by trees come from the surface area of their leaves[9]. Most eastern white pines measured in this forest had a DBH of less than 7.6 cm (3 inches), which indicates that most of these trees are contributing more to carbon sequestration as they are still young and growing quickly. It should be noted that the i-Tree Eco tool does not take forest stand age into consideration. A portion of eastern white pines in the Urban Forest were planted in the 1930s, meaning they are past their growth prime and are likely contributing more to carbon storage rather than sequestration. Carbon storage in eastern white pines was noteworthy; the species stored the second most carbon out of all tree species on the property, behind tulip poplar trees (Fig. 3). About 20 percent of the eastern white pine trees measured in the Urban Forest had a DBH greater than 45.7-cm, while 24.2% of tulip trees had a DBH greater than 45.7-cm. As trees grow larger, they accumulate more carbon within their tissue which stores the carbon in their biomass. While both of these trees are fast growers and are important in the Urban Forest for their carbon stocks, their growth may be suppressed in the current stocking or forest stand age. Most of these trees are likely past their peak growth rate considering their age. Additionally, the Urban Forest has a dense understory that is presumably suppressing the growth of trees.

4.2 Sandy Bottom

The Sandy Bottom Preserve (Fig. 4) is bordered by the Blue Ridge Parkway, a neighborhood, Highway 191, and the French Broad River[26]. The area was recently classified as a Unique Wetland in 2020 which will provide more protection to the area and require development projects to thoroughly consider potential impacts to the wetland and the species it supports. Sandy Bottom is known for its rich biodiversity and is home to 22 species of fungi, 33 species of lichen, 354 plant species, and 178 animals species[26].

Originally, Sandy Bottom was a part of a 50,585.7 ha (125,000 acre) parcel of land owned by the Vanderbilt family held as part of the Biltmore Estate between the years 1900 and 1907[26]. The property has since been recognized as being a part of the Pisgah National Forest, used as a boy scouts campground, sold to land owners who developed a portion and donated the rest to protect floodplain communities[26]. UNC Asheville's Endowment Fund Board now owns Sandy Bottom and it has been used as a research site for several decades.

Red maple trees make up nearly a quarter of the total tree population at Sandy Bottom Preserve (24.2%) and contribute the most to carbon storage and sequestration. The size class of this species was relatively evenly distributed with 36.3% having a DBH of less than 7.6 cm, about 33.6% between 7.6 cm and 15.2 cm (3-6 inches), and 30.1% with a DBH greater than 15.2 cm. This explains their large contribution to both sequestration and storage; there are many smaller trees that are growing rapidly and sequestering large quantities of carbon in addition to several larger red maple trees that store a large amount of carbon. Despite the fact that this property is about half the size of the Urban Forest, it sequesters nearly the same amount of carbon on an annual basis. This is likely due to the Sandy Bottom Preserve having a younger forest composed of a high number of smaller, younger trees that are rapidly growing. It is also worth noting that the Sandy Bottom Preserve had a much higher tree density (566 per ha) compared to the Urban Forest (141 per ha). Smaller trees can stand closer together as they grow which allows for a higher density and higher rates of carbon sequestration at Sandy Bottom Preserve.

4.3 UNC Asheville Emissions

UNC Asheville is recognized by the Arbor Day Foundation as Tree Campus USA by promoting healthy trees and student involvement on campus[27]. Additionally, the university has implemented ways to preserve stored carbon in dead trees. The "Logs to Lumber" program has been used since the early 2000's, where dead, unhealthy and hazardous trees are removed and used as wood products (M. Acker, pers. comm., October 6, 2021). As trees die and decompose, the carbon stored within them is released back into the atmosphere. Using the wood from dead trees as long-term wood products is a way to help mitigate the amount of carbon released back into the atmosphere as wood decays. The program has used eastern white pine trees for outdoor structures (such as the building at Mullen Park), walnut trees have been incorporated into the interior paneling of the observatory, and other wood products have been donated to the STEAM studio to be used to produce art.

UNC Asheville releases an estimated 18,000 metric tons of greenhouse gasses annually (Fig. 7). Based on the estimates made by i-Tree, the trees in the Urban Forest and Sandy Bottom Preserve will together mitigate about 0.78% of annual emissions. The creation of forest management plans based on the composition of the Urban Forest and Sandy Bottom Preserve will improve forest health and may increase carbon stocks. It is important to note the value of carbon stocks in the sampled forests and should be emphasized that the removal or conversion of these forests to some other land use would increase the University's emissions drastically. The remaining forested properties (The Kellogg Center 16 ha, Chestnut Ridge 27 ha) owned by UNC Asheville that were not included in this study must be assessed to evaluate the current carbon sequestration in those forests and give the University a better understanding of how much of its greenhouse gas emissions are being offset by its trees. However, since only a fraction of the University's emissions are currently being offset by the Urban Forest and Sandy Bottom Preserve, UNC Asheville will need to take additional steps to reduce its greenhouse gas emissions and to meet its goal of becoming net carbon neutral by the year 2050.

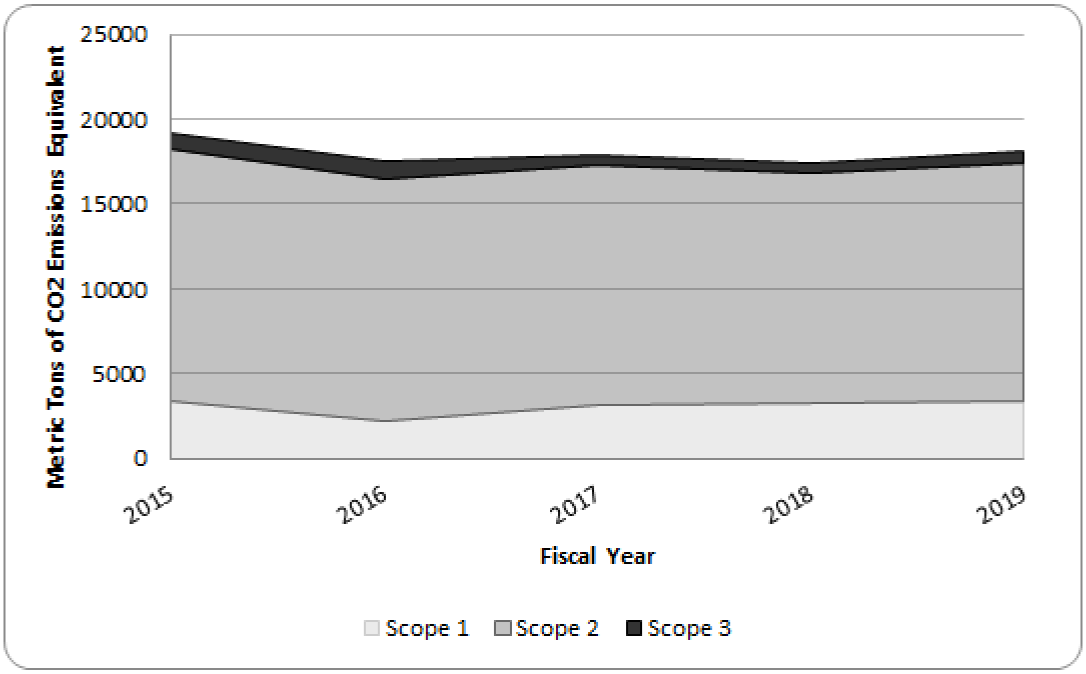

Figure 7. Estimated greenhouse gas emissions released by the University of North Carolina Asheville. Scope 1 emissions include on-campus mobile and stationary operations. Scope 2 emissions are purchased energy, while Scope 3 emissions include off-campus university-related activities including travel for athletics, field trips and study abroad[28].

4.4 Recommendations

Invasive plant species are known to have negative impacts on the health of forests by reducing native species richness and genetic variation, reducing forest productivity, and altering ecosystem functioning, including those that affect carbon sequestration[21,29,30]. This highlights the importance of site-specific forest management plans, where particular invasive species and other disturbances can be targeted to help improve forest health and increase carbon stock potential. Of the 70 tree species that were identified in the Urban Forest, seven of those species are considered invasive. The three most common invasive species measured were Norway maple (*Acer platanoides*), Chinese privet (*Ligustrum sinense*) and tree-of-heaven (*Ailanthus altissima*). Invasive species made up 8.3 percent of the tree population in the Urban Forest but the level of impact these invasives have on the health of the forest is difficult to determine. Additionally, other invasives including Japanese honeysuckle (*Lonicera japonica* Thunb.), oriental bittersweet (*Celastrus orbiculatus* Thunb.) and multiflora rose (*Rosa multiflora* Thunb.) were pervasive in the Urban Forest but were not quantified in this study.

At Sandy Bottom Preserve, only one invasive species was sampled in the forest: the Persian silk tree (*Albizia julibrissin* Durazz.). Invasive vegetation at Sandy Bottom Preserve was generally not as widespread compared to the Urban Forest. Most invasive vegetation was herbaceous, the most noteworthy species being Japanese stiltgrass (*Microstegium vimineum* A. Camus) which has the potential to act as an ecological filter by becoming a dominant species and reducing species richness and diversity[31]. As recommended by the NCFS, removing the invasive species within this forest would be useful in creating optimal conditions for growth and reducing competition between native and invasive species. Not only will this contribute to promoting biodiversity in the forest, but it will also allow native trees to increase growth and their carbon storage potential.

Crop tree release, either by selective tree removal or variable density thinning is a silvicultural technique that may be considered by the university. These strategies are designed to selectively remove trees in an aggregated fashion to manipulate sunlight and to stimulate the development of late-successional habitats[32]. Within sections of the Urban Forest, eastern white pines are overstocked, particularly in areas where they were planted following the abandonment of the farm in the 1930s[24]. In this case, implementing a crop-tree release strategy would be useful in maximizing carbon sequestration. By identifying healthy, but suppressed trees, surrounding trees of lesser value can be removed in order to allow the targeted tree to grow more quickly and therefore sequester more carbon[33]. Trees that are targeted for removal would be utilized as wood products so the carbon within them is not lost, as implemented by the "Logs to Lumber" program.

Another silvicultural strategy that could be implemented in either of the sampled forests is midstory removal. This method targets non-commercial midstory trees under a mature and dense canopy layer so that desirable tree species can be established in the regeneration layer[34]. Desirable tree species may include trees that promote ecological diversity or quickly sequester carbon. As recommended by the NCFS, eastern white pines and tulip trees may be planted to promote increased carbon sequestration. Trees that promote species diversity while still selecting for carbon sequestration include southern red oak, northern red oak, white oak, and boxelder, which should also be considered by the university as potential trees to plant.

4.5 Future Studies

This project was done in collaboration with student researcher Pierce Lynch who quantified carbon sequestration on UNCA's core-campus trees. Together, these projects will give a more complete carbon accounting for UNCA. Due to time limitations, only two of the four forested properties were analyzed in this paper. Future studies should complete inventories for the remaining properties to create a more conclusive quantification of the carbon stocks at UNC Asheville. Furthermore, future studies should consider including more parameters in their inventory, like the ones taken at the beginning of this study including tree height. More parameters measured means that the estimated carbon stocks and ecosystem services will be more precise. Additionally, the complete life cycle of carbon may also be considered in future studies. Soil serves as a large reservoir for carbon and contains more carbon than the atmosphere or vegetation, making it a major component of the carbon cycle[35]. Quantifying carbon storage and sequestration in soil and understanding ways in which sequestration can be enhanced has implications for further offsetting anthropogenic greenhouse gas emissions among other things[36]. Studies have shown that forest management driving the productivity in forest stands will increase the C input into the soil by modifying the stand quality by tree selection and a thinning regime, as well as stimulating decomposition on the forest floor[37]. This provides further incentive for the development and implementation of forest management plans.

5. Conclusion

Based on the composition of the Urban Forest and Sandy Bottom Preserve, only a fraction of UNC Asheville's emissions is currently being sequestered annually. Even considering the carbon stocks of core campus trees and the other remaining forested properties, all of the University's trees will still likely offset a fraction of annual carbon emissions. Implementing forest management plans is important in promoting carbon sequestration which can help increase mitigation of greenhouse gas emissions released by the University. Additionally, management of the University's forests will help keep currently stored carbon from being released into the atmosphere and utilizing removed trees as wood products will help minimize the amount of carbon released back into the atmosphere during removal. This study highlighted the importance of existing trees in the Urban Forest and Sandy Bottom Preserve, especially eastern white pines and red maple trees which contribute greatly to the carbon stocks in the forests. Protecting these trees will help preserve carbon stored within them and promote increased carbon sequestration. However, the University must also take steps to lower their emissions in order to comply with the Climate Action Plan and reach the goal of becoming net carbon neutral by the year 2050.

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7. References

1. 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
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. 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.
4. Zhao M, Kong ZH, Escobedo FJ, Gao J. 2009. Impacts of urban forests on offsetting carbon emissions from industrial energy use in Hangzhou, China. *Journal of Environmental Management*. 91(1): 807–813.
5. Goh JCJ. 2017. Carbon Accounting in Local-Scale Land Use and Land Cover Change. *The Journal of Sustainable Development*. 17(1): 46-74.
6. United Nations Department of Economic and Social Affairs, United Nations Forum on Forests Secretariat (2021). *The Global Forest Goals Report 2021.*
7. Dale, MJ. 2013. Evaluation of methods for quantifying carbon storage of urban trees in New Zealand. The University of Auckland. 1(1): 1-10.
8. Fares S, Paoletti E, Calfapietra C, Mikkelsen TN, Samson R, Thiec DL. 2017. Carbon sequestration by urban trees. The Urban Forest. 31-39.
9. Bassett CG. 2015. The environmental benefits of trees on an urban university campus. Scholarly Commons. 1-44.
10. Loughner CP, Allen DJ, Zhang DL, Pickering KE, Dickerson RR, Landry L. 2012. Roles of urban tree canopy and buildings in urban heat island effects: parameterization and preliminary results. American Meteorological Society. 51(1): 1775-1793.
11. Chapin, III FS, Matson, PA, Vitousek, PM. (2011) Carbon Inputs to Ecosystems. *Principles of Terrestrial Ecosystem Ecology.*Springer Science + Business Media, LLC
12. Thomas SC, Martin AR. 2012. Carbon content of tree tissues: a synthesis. Forests. 3: 332-352.
13. Prasad R. 2019. Carbon sequestration of the sac state arboretum. Sac State Sustainability. 1-10.
14. 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.
15. 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.
16. Bremer M, Frisa E, Maccarone R, Seif D. 2020. Campus forest carbon sequestration: an undergraduate project experience. Journal of Sustainability Education. 24: 1-15.
17. Nowak DJ, Greenfield EJ, Hoehn RE, Lapoint E. 2013. Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental Pollution. 178(1): 229-236.
18. i-Tree Eco user's manual. 2020. V6.0. USDA. US Forest Service
19. i-Tree Eco. c2020. Washington (DC): i-Tree Eco; [accessed 2021 September 21].
20. Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. 2016. Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 12866. 1-35.

21. Peltzer DA, Allen RB., Lovett GM Whitehead D, Wardle DA. 2010. Effects of biological invasions on forest carbon sequestration. Global Change Biology. 16(2): 732-746.
22. Liu X, Trogisch S, He JS, Niklaus PA, Bruelheide H, Tang Z, Erfmeier A, Lorenzen MS, Pietsch, KA, Yang B, Kühn P, Scholten T, Huang Y, Wang C, Staab M, Leppert KN, Wirth C, Schmid B, Ma K. 2018. Tree species richness increases ecosystem carbon storage in subtropical forests. Proceedings of the Royal Society B. 285: 1-9.
23. Burns, Russell M; Honkala, Barbara H.; [Technical coordinators] 1990. Silvics of North America: Volume 1. Conifers. United States Department of Agriculture (USDA), Forest Service, Agriculture Handbook 654
24. Farmer S, Ward JR, Horton JL, Clarke HD. 2016. Southern Appalachian urban forest response to three invasive plant removal treatments. Management of Biological Invasions.7(4): 329–342.
25. Heiman, K. 2005. Environmental assessment and finding of no significant impacts: Construction of Chancellor residence. Report to University of North Carolina Asheville. Consulting Biologist, Asheville, NC.
26. Graeter G, Hale R. 2020. Sandy Bottom conservation plan. Asheville, NC: University of North Carolina Asheville. 1-129.
27. Arbor Day Foundation. c2021. Lincoln (Nebraska): Tree campus higher education. [accessed 2021 October 5]. https://www.arborday.org/programs/tree-campus-higher-education/
28. Ormsby A, Hamstead J, Croisant D, Couzo E, Hall K, Appleton I, Fotus A, McVay C, Keller A, Nystrom L, Tesh M, Weber J, Zimmer J. 2021. Addressing Campus Greenhouse Gas Emissions: Climate Action Plan. UNC Asheville's Office of Sustainability. 1: 1-29.
29. Moser KW, Barnard EL, Billings RF, Crocker SJ, Dix ME, Gray AN, Ice GG, Kim MS, Reid R, Rodman SU, McWilliams WH. 2009. Impacts of Nonnative Invasive Species on US Forests and Recommendations for Policy and Management. Journal of Forestry. 107(6): 320–327.
30. Pyšek P, Jarošík V, Hulme PE, Pergl J, Hejda M, Schaffner U, Vilà M. 2012. A global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species' traits and environment. Global Change Biology. 18(1): 1725–1737.
31. Osland, Michael J. 2009. Managing invasive plants during wetland restoration: The role of disturbance, plant strategies, and environmental filters. Durham, NC: Duke University. 182 p. Dissertation.
32. Willis JL, Roberts SD, Harrington CA. 2018. Variable density thinning promotes variable structural responses 14 years after treatment in the Pacific Northwest. Forest Ecology and Management. 410: 114-125.
33. YiXiang W, ShouGong Z, YuanChang L, JingHui M, Ji Z. 2014. Initial effects of crop trees growth after crop tree release on *Pinus massoniana* plantation. Scientia Silvae Sinicae. 50 (10): 67-73.
34. 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.
35. Swift RS. 2001. Sequestration of carbon by soil. Soil Science. 166 (11): 858-871.
36. Lal R, Negassa W, Lorenz K. 2015. Carbon sequestration in soil. Current Opinion in Environmental Sustainability. 15(1): 79-86.
37. Jandl R, Lindner M, Vesterdal L, Bauwens B, Baritz R, Hagedorn F, Johnson DW, Minkkinen K, Byrne KA. 2007. How strongly can forest management influence soil carbon sequestration? Geoderma. 137: 253 – 268.