University of North Carolina Asheville
Journal of Undergraduate Research
Asheville, North Carolina
December 2022

Carbon Sequestration in the Face of Invasion: Invasive Species as a Threat to UNC Asheville's Carbon Stock

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Abstract

Anthropogenic climate change is one of the greatest threats to this generation and is caused by increased levels of greenhouse gases in the atmosphere particularly carbon dioxide (CO_2). Excess CO_2 is emitted through human activity involving the combustion of fossil fuels such as industrial manufacturing and vehicle use. The best defense mechanism against these heightened levels of greenhouse gases are trees and forests which take in CO_2 from the air and convert it into breathable oxygen through photosynthesis. The additional carbon left over from this process will then be stored as biomass, so the longer a tree lives, the more carbon it can store. Unfortunately, the lives of many trees are being cut short due to the presence of exotic invasive plant species. The invasion of healthy native forests leads to an increase in tree deaths, which then releases any and all stored carbon back into the atmosphere. Thus, invasive plant species are indirectly contributing to climate change. The goal of this study was to determine how the presence of invasive species is threatening the trees of the campus of the University of North Carolina Asheville and likewise, its carbon stock. To do this, five plots were selected in UNC Asheville's South Campus Forest area. Each tree with a diameter at breast height of greater than 2.5 centimeters was measured as well as their geographic coordinates, which invasive species were growing nearby, and what percentage of the tree was covered in invasives. Trees were individually treated and invasive plants were removed throughout this project. Using the i-Tree Eco v6.0.29 software, current and future carbon storage and sequestration for each tree were calculated. It was found that these plots store a total of 26.27 metric tons of carbon and sequesters 0.895 metric tons of carbon annually. The trees measured in South Campus forest were most threatened by Oriental Bittersweet (*Celastrus orbiculatus*), English Ivy (*Hedera helix*), Poison Ivy (*Toxicodendron radicans*), and Chinese Privet (*Ligustrum sinense*). Additionally, it was found that invasive plants showed no discernable preference for smaller versus larger trees, so all trees are at equal risk of being invaded.

1. Introduction

Humankind has entered into a period known as the *Anthropocene*, categorized by the mass extinction and environmental degradation caused by human activity[1]. Human energy production through fossil fuel combustion is the primary source of greenhouse gas emissions which have significantly contributed to the warming effect on Earth's surface[2]. In response to the growing body of information on the issue, the 1990 and 1992 Assessments by the

Intergovernmental Panel on Climate Change (IPCC) sought to provide context to policymakers based on their (at the time) current understanding of climate change. These assessments explained that human activity, particularly the depletion of fossil fuels, is contributing to a phenomenon known as the *Greenhouse Effect*. This is a naturally occurring phenomenon, yet the greenhouse gases being added in excess to the atmosphere is exacerbating its effects. Gases such as methane and ozone can contribute to this phenomenon, yet in this case, carbon dioxide will be the primary focus. The Greenhouse Effect takes when greenhouse gases form a barrier around the surface of the earth which then absorbs heat from the sun. While some of the sun's heat may be reflected from the earth's surface and back into space, much of it is trapped and re-emitted into the atmosphere, warming the surface of the earth and contributing substantially to the widespread environmental degradation seen today[3].

Among the suggestions by the IPCC to mitigate the disastrous effects of climate change are an improved system of forest management and where possible, expansion of forested areas[4]. Not only are trees some of the best protection available against the climate crisis, research suggests forests themselves store more carbon than the sum of their individual trees, which further emphasizes the importance of their preservation and management[5]. In this way, forests act as *carbon sinks*, absorbing and storing carbon dioxide from the atmosphere for a sustained period of time. Through the process of photosynthesis, trees absorb carbon dioxide from the atmosphere and convert it into breathable oxygen, of which humans reap the benefits[6]. The excess carbon will then be stored and used to build up a tree's biomass[6]. Higher amounts of atmospheric carbon dioxide have been shown to increase rates of photosynthesis and subsequently increase biomass[6]. This research has thus operated under the assumption that there is a direct link between levels of atmospheric carbon, photosynthetic rates, and tree biomass. Throughout this paper, the total amount of carbon held within these trees will be referred to as *carbon storage*. Carbon storage may be influenced by several variables including differing tree species, their relative growth rates, and their allocation of carbon to different parts of the tree[7]. Despite this variability, it is understood that the majority of aboveground biomass and thus, stored carbon, is located in the trunk of the tree[7]. It is with these understandings that Diameter at Breast Height (DBH) is recognized as a relative indicator of how much carbon a tree may store.

Unfortunately, atmospheric carbon levels are continuing to rise and showing no signs of slowing down. Trees and forests are being threatened by a number of the resulting factors as well as some more directly human-caused issues, namely the introduction and overgrowth of exotic invasive species. Exotic invasive species may have been introduced through a number of different means, primarily human travel and international trade[8]. Since these plants are not native to the areas to which they are introduced, they have no natural predators and do not face the same threats they would have faced in their original habitat and thus, are less inhibited in their growth[9]. Additionally, heightened levels of atmospheric carbon dioxide have proven to be advantageous for the photosynthetic rates invasive plant species[9]. The fitness of invasive plants in their new habitats has led to decreased abundance, diversity, and fitness of native plant species[10].

Invasive trees may outcompete native species through their tolerance to drought, shade, or disease, limiting factors which would otherwise impede the growth of native plants[11]. Most invasive plant species are *habitat generalists* and are known to grow in disturbed areas such as trails and roadsides regardless of the nutrients (or lack thereof) available to them[11]. These are areas with fewer available resources and are generally more hostile areas in which to grow, yet because invasive plants tend to be habitat generalists, they are able to successfully grow in such conditions. After successfully establishing themselves in their new habitat, these plants will begin to alter crucial environmental functions such as the cycling of nutrients through an ecosystem[11]. If these factors were not reason enough to recognize the success of invasive plants in establishing themselves, they also tend to have much faster growth rates than native plants[12]. Invasive plants may grow faster in their new environment due to their advantageous nature and the new resources available to them. The combination of a lack of predation, a lack of habitat preference, and the ability to grow quickly, ensures that exotic invasive plant species will be able to successfully take over even the healthiest of native forests.

Regardless of the tactics used, the growth and overgrowth of exotic invasive plant species is causing healthy native trees to die long before they reach the end of their natural lifespan. When a tree dies and decomposes, it releases all of its stored carbon back into the atmosphere through a process known as *heterotrophic respiration*[13]. The decomposition of dead carbon sinks such as trees allows all stored carbon to gradually be released into the atmosphere[13]. This is a naturally occurring process, yet when invasive species are introduced, they speed up how quickly trees are dying and releasing all of their carbon. In effect, exotic invasive plants are worsening the effects of climate change. Any tree lost before its time is a terrible loss in the ultimate fight against climate change, yet humans are not without solutions to this problem. One of the main causes of widespread tree death– the spread of exotic invasive plant species– is a very manageable issue.

This study aimed to answer the following questions:

1. How much carbon is stored in the plots designated in South Campus Forest?
2. How at risk are the trees in South Campus Forest for being threatened by invasive species?

2. Methods

Research began in Winter 2021. The i-Tree Eco v6.0.29 software was used to create a database of tree species, DBH, carbon storage, and carbon sequestration. i-Tree is a tool that provides analysis of collected field data and quantifies environmental benefits, in this case, carbon *sequestration*, a tree's annual carbon uptake, and carbon storage[14]. A list was compiled of the trees with the highest abundance on the University of North Carolina Asheville's campus. A theoretical plot was then entered into i-Tree for each tree species listed. Individual trees of each species were entered into the database starting with a DBH of 2 inches, then adding more trees increasing in increments of 2 until their highest possible DBH was reached. Plot data was exported through i-Tree to the United States Forest Service to be processed. After receiving results, graphs depicting carbon storage and sequestration on a species level and an individual tree level were compiled and added to a shared folder for reference. These graphs provided a basis for understanding the logistics of carbon intake by species and size, yet they were not relevant to our final results and were simply used as a starting point. This process was completed in Spring 2022.

The South Campus Forest area was explored throughout Spring and early Summer 2022 and plots were selected mid-summer, after which tree measurements could begin.

The measurement process began August 2022 in the South Campus Forest of UNC Asheville; this is a hilly, forested area with several recreational trails running through. Sample plots were manually selected at five distinct points around the main circular trail. As it was mentioned earlier, invasive plant species tend to appear most frequently at disturbed areas such as trails and roadsides[11]. It was with this understanding that we selected a heavily foot-trafficked area to study invasives.

Figure 1. Map of studied area in the South Campus Forest of UNC Asheville. The blue building pictured is the Southern Research Station for the United States Department of Agriculture located at 200 W.T. Weaver Boulevard. The white lines shown represent the main recreational trails running through South Campus Forest and the five green boxes show the location of the five data collection points.

At each of the plots, a center point was determined and from this point, meter tapes were extended 10.0 meters along and orthogonal to the trail to create five 400 m² (0.04 hectare) plots. The center points of each plot were recorded for reference and future research to return and assess any changes or continue to treat. Within each plot, each tree was identified by species and was measured to determine the diameter at breast height (DBH), around 1.3 meters above the ground. Only trees with a DBH greater than 2.5 cm were included in the data collection. Additionally, any invasive plant species near each tree, exotic or not, were identified and treated using a cut-and-paint management method. Invasive trees and shrubs were cut using loppers at their lowest accessible point and painted on each cut end with a triclopyr solution (Garlon 3A) to kill the invasive plant but leave the nearby native plants safe and able to grow. Invasive vines were cut at a high and a low point, leaving a gap in the vine, and were painted on each cut end with the same solution. Finally, each tree was assigned a value on a risk assessment scale based on the percentage of the tree that was covered by invasive species. Unfortunately, there is relatively little existing research on the relative growth rates for certain invasive plant species; for instance, if an Oriental Bittersweet introduction or an English Ivy introduction would overtake and kill a tree more quickly. Rather than speculating in the field about how threatened a tree is by species or how much time a tree has before death, each tree was assigned a value for how threatened it appeared on a scale from 0 to 6.

Table 1. Risk Assessment scale. Due to the lack of information regarding how quickly certain invasive species grow and overtake trees, an objective measurement was created to determine the relative level of threat faced by these trees.

Description	Rank
No invasives within 1.0 meter radius of tree	0
Invasives present within 1.0 m radius but not on tree	1
Invasives covering 0-25% of tree	2
Invasives covering 25-50% of tree	3
Invasives covering 50-75%	4
Invasives covering 75-100% of tree	5
Tree is dead	6

Data was compiled and entered into i-Tree. Plot data was then exported to be processed. Upon receiving results, data was analyzed to determine the total levels of carbon storage and sequestration within the selected plots and per hectare.

3. Results

A total of 118 trees were measured in the South Campus Forest area yet several exclusions had to be made from the final count. Several of the trees that were measured were not growing within the confines of our plots and some trees were so overrun with invasive vines that they were unidentifiable. Trees that fit either of these descriptions were excluded from the data submitted to i-Tree, reducing the final count to 105. Reference to the risk assessment scale (Table 1) revealed that only four of these 105 trees ranked a 0 on the risk assessment scale, meaning that there were no invasive plant species within a 1.0 meter radius of the tree. These trees, for the time being, may be considered “safe,” yet considering how quickly invasive plants can grow, these trees may not remain risk-free for very long. Of the four dead trees included in the final count, two had died because of invasive takeover. The remaining 97 trees were at immediate risk and faced some varying level of threat due to the presence of invasive species.

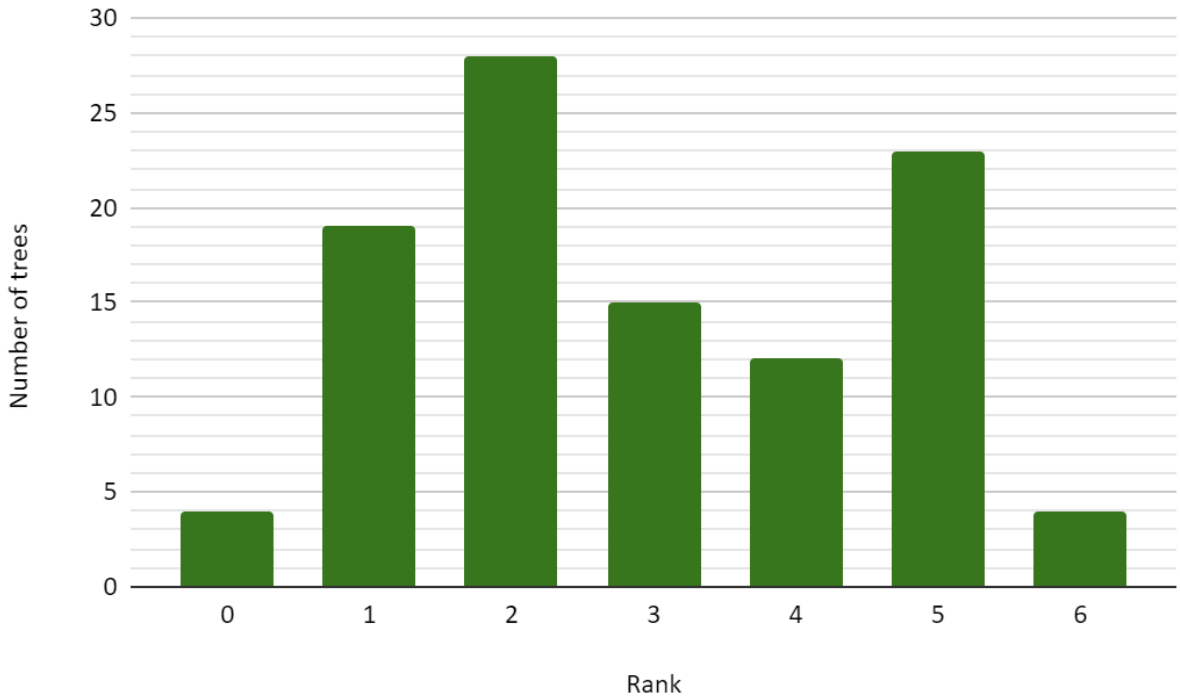

Figure 2. Number of trees within each risk assessment ranking.

Further along, the question arose as to whether invasive plants showed any discrimination in which native plants they would take over; For instance, is a vine more likely to grow up a fully grown tree or a sapling? Figure 3 shows the distribution of risk assessment rankings among trees of different sizes. There is no visible correlation between tree size and the probability of its being taken over. In other words, invasive plants do not seem to show any preference in growing on a larger, more fully grown tree versus a sapling, and aside from their proximity to an invasion, there seems to be no clear indicator that any one size tree is more susceptible than another.

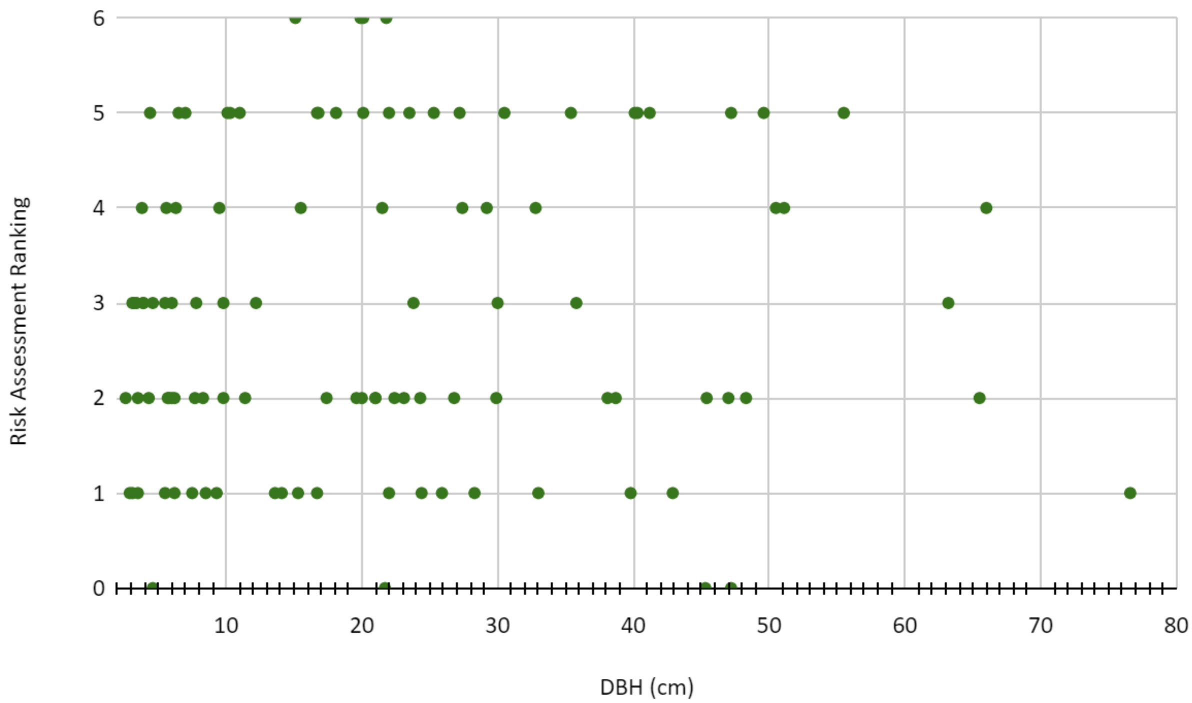

Figure 3. Relationship between a tree's DBH and their risk assessment ranking to determine if there is any correlation between a tree's size and its likelihood of being invaded.

The majority of the trees measured in South Campus Forest were threatened by some combination of invasive species, rather than just one at a time. The most frequently encountered threats to these trees were Oriental Bittersweet (*Celastrus orbiculatus*), English Ivy (*Hedera helix*), Poison Ivy (*Toxicodendron radicans*), and Chinese Privet (*Ligustrum sinense*). These plants constituted 68.3% of the invasives witnessed, measured, and treated in South Campus Forest. It is important to note that plants which are native to an area still have the capacity to be invasive without being exotic. This can be seen in poison ivy (*Toxicodendron radicans*), for instance, which is native to this region but whose vines have caused additional stress to large areas of our forests. Thus, poison ivy was included in Figure 4 to demonstrate the wide range of invasive species threat that is faced by UNC Asheville's forests.

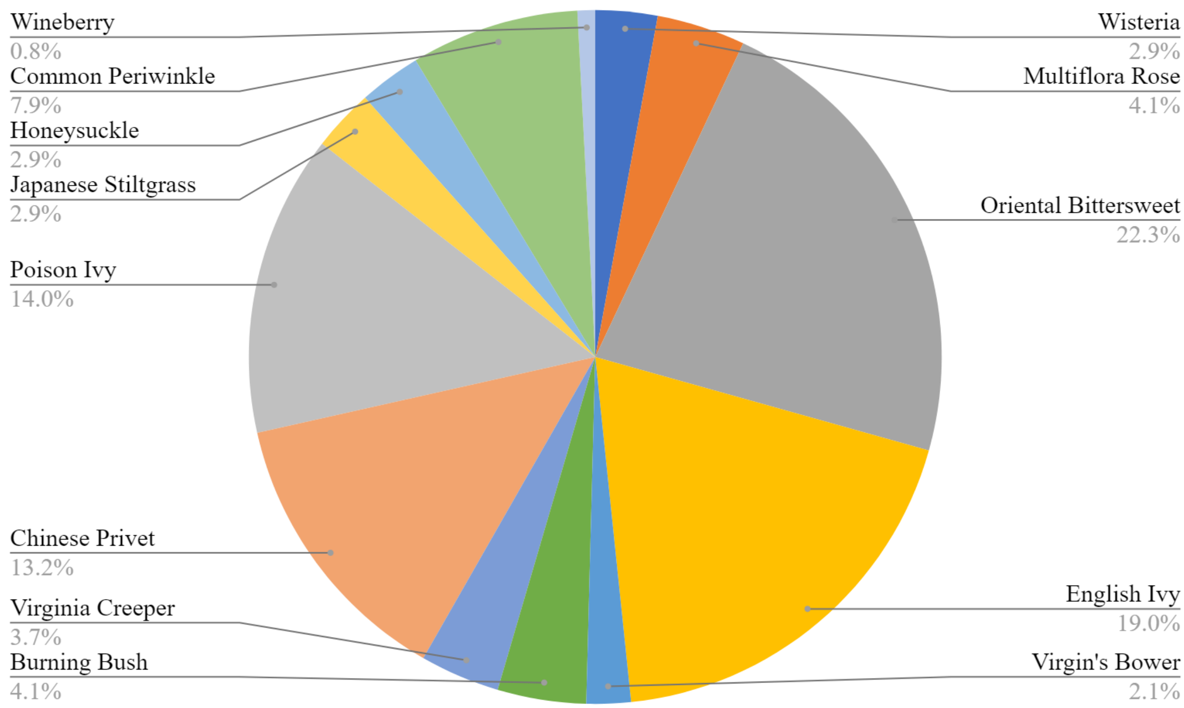

Figure 4. Abundance of each invasive plant species present.

The plots measured in South Campus Forest are estimated to store 26.27 metric tons of carbon; about 131.35 metric tons per hectare. The gross annual carbon sequestration value for the same area is 0.895 metric tons of carbon, or approximately 22.38 metric tons per hectare. A previous study of UNC Asheville's South Campus Forest took place in 2022 by undergraduate research student Anna-Lisa Keller. Keller's study yielded similar, yet slightly higher results to our own. This is likely due to the difference in methodology between the two studies. Keller's plots were systematically laid out as a grid system on which each plot point was equidistant from the next[15]. On the other hand, the plots measured in this study were manually selected along a recreational trail. Each area of a forest through which a trail passes decreases the potential for tree growth in that specific area. As a result, the plots measured had a lesser percentage of tree cover and thus, less potential for carbon storage and sequestration per plot and per hectare.

Table 2. Comparison between plot area, tree density, and carbon sequestration and storage data collected from the University of Georgia and the University of Pennsylvania.

	University of North Carolina Asheville	University of North Carolina Asheville (Keller 2022)	University of Georgia (Fox et. al. 2020)	University of Pennsylvania (Bassett 2015)
Area	0.2 ha	35 ha	94.1 ha	64.7 ha
Tree Density	525 trees per ha	1046 trees per ha	73.5 trees per ha	63.2 trees per ha
Sequestration	0.895 mt	140.6 mt	64.9 mt	37.8 mt
Storage	131.35 mt/ha	125.6 mt/ha	36.6 mt/ha	11 mt/ha

Similar studies of carbon storage and sequestration on college campuses have previously taken place whose results may be compared and contrasted to those of this study. In 2015, Corinne G. Bassett undertook research at the University of Pennsylvania and measured 4086 trees growing on the university's highly urbanized campus. These trees were found to store about 715.4 metric tons of carbon[16]. A similar study in 2020 by William Fox, Puneet Dwivedi, Roger C. Lowe III, Sarah Welch, and Madison Fuller found that 6915 trees on the campus of the University of Georgia hold 3450.4 metric tons of carbon[17].

This data would suggest that by hectare, UNC Asheville stores and sequesters more carbon annually than either of the compared campuses, however it is important to note the difference in methodology between these studies that could account for this conclusion. Both Fox's study at the University of Georgia and Bassett's study at the University of Pennsylvania collected data from the entire main campus of their respective schools[16],[17]. Both of these campuses are much more urbanized than UNC Asheville's campus. Additionally, this study as well as Keller (2022) specifically chose to measure only UNC Asheville's forested properties[15] and did not come in contact with sidewalks, academic buildings, grassy areas, or other non-forested land like Fox and Bassett wold have. Thus, it is to be expected that data collected only from a forested area would suggest that the entire campus stores and sequesters more carbon than either of the compared campuses, but since data from the entire campus of UNC Asheville has yet to be collected, this claim is unable to be supported one way or the other.

Table 3. Species, DBH, carbon storage, and carbon sequestration of the four trees measured in South Campus Forest that were not yet threatened by invasive plants.

Tree Species	DBH	Sequestration	Storage
White Oak *Quercus alba*	21.7 cm	0.00517 mt/year	0.114 mt
Blackjack Oak *Quercus marilandica*	47.2 cm	0.000318 mt/year	0.853 mt
Red Mulberry *Morus rubra*	4.6 cm	0.000499 mt/year	0.00158 mt
Black Cherry *Prunus serotina*	45.3 cm	0.0310 mt/year	0.772 mt

The above trees ranked a 0 on the risk assessment scale and may thus be considered "safe" for the time being, yet there is no telling how soon any of these trees may be threatened by invasive takeover. Combined, these trees store

1.74 metric tons of carbon and sequester an additional 0.037 metric tons annually. The storage capacity of these four unthreatened trees is only able to offset around 0.0000966% of UNC Asheville's yearly carbon emissions.

4. Discussion

4.1 UNC Asheville's Emissions

In 2021, Chancellor Nancy J. Cable of UNC Asheville signed the school's first carbon commitment, one school out of only 400 colleges and universities that have pledged carbon neutrality by 2050[18]. This commitment involved the creation of a Climate Action Plan detailing the methods the university plans to use to achieve its goal of carbon neutrality. Among these methods are the installation of solar panels on all compatible campus buildings, switching all university-owned vehicles to electric models, and implementing a living machine for water treatment[18]. Though these changes alone are not likely to fully offset the carbon output of the university, they detail a feasible plan to get closer to the goal.

Keller (2022) estimated that the carbon-storing potential of the Urban Forest (South Campus Forest) and Sandy Bottom Preserve areas of UNC Asheville's campus only offsets around 0.78% of the university's annual emissions[15]. This data also was calculated under the assumption that the trees measured are healthy and face no outside threats. Unfortunately, the trees on this campus are not free from outside threats. Nearly every tree measured was immediately threatened by the presence of invasive species and every sample plot chosen for this study was heavily overrun with invasives. In other words, the best estimate is that 0.78% of UNC Asheville's annual carbon output is sequestered within these trees, but that number is likely to decrease the longer the campus's forests go without treatment.

4.2 Future Studies

Due to time constraints, several of the tasks originally sought after were not able to be completed. First, there is very little existing research on the growth rates of different species of invasive plants in their nonnative habitats. It is due to this shortcoming that the remaining time left in an invaded tree's life is unable to be estimated. Also, there is little information available regarding the interactions of invasive plant species within their introduced environment. Researchers have noted the importance of treating all invasive species present in an area, rather than just treating one and allowing the others ample opportunity to continue their growth[19], yet aside from this observation, little is known about how these plants interact. Further research into the growth and interaction of exotic invasive plants is needed to better understand the full scope of the threat they pose.

What is known for certain is that the natural lifespans of native trees have been and will continue to be cut short without invasive plant management. Treatment of invasive plants is necessary and should begin as soon as possible. Several invasive plant work days have been hosted on UNC Asheville's campus by different organizations including the Invasive Plant Management Club and it is recommended that these continue more frequently if possible.

Additionally, it will be necessary to ascertain the relative carbon storage capacity of the invasive plants present on UNC Asheville's campus. It has been suggested that invasive plants have higher rates of photosynthesis in their nonnative habitats and thus, would be able to sequester carbon dioxide from the atmosphere more quickly than a native tree could[12]. This is not to suggest that invasive plants are beneficial to offset campus emissions, as their unrestrained growth is likely to have far much more disastrous impacts on the local environment, but rather serves to address the fact that little research exists has been conducted to compare rates of native and invasive plant growth and sequestration. Future research would have to undertake the task of measuring invasive plant carbon storage capacities to gain an understanding of the potential for continued offsets in a healthier, more sustainable manner.

5. Conclusion

The University of North Carolina at Asheville has pledged carbon neutrality by the year 2050. In their best shape, the forested areas on campus could contribute substantially to offsetting UNC Asheville's carbon emissions; yet, they are heavily overrun with exotic invasive plants. It will be imperative in the near future to manage these forests and remove the threat of invasive takeover. This will reduce the threat of premature tree death and will keep carbon stored in trees as biomass, rather than released back into the atmosphere through heterotrophic respiration. The results found in this study are applicable to the world beyond as invasive species have spread to most corners of the Earth and show no signs of slowing down. With proper understanding of their growth partnered with intense forest management, it is possible to halt the unimpeded growth of these offensive plants and restore our forests to their full potential as carbon sinks. They will be crucial weapons within the coming years in the fight against anthropogenic climate change.

6. Acknowledgments

I would like to acknowledge and express my gratitude for the invaluable guidance and support of my faculty advisor, Dr. Dee Eggers, without whom this project would not have been possible. I would also like to thank Dr. Alison Ormsby for her much-appreciated and valued insight into this project, as well as her work with UNC Asheville's Climate Action Plan. I am grateful to my research partners, Leah Given and Gabbie Wray, for their assistance and encouragement in the field and throughout the duration of this project.

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