Assessing the value of ecosystem services provided by the University of North Carolina at Asheville's urban forest: A mixed-methods approach

by

Britain Hamrick, Angelina Herbert, and Amelia Racky

Advisors:
Dr. Kathleen Lawlor, Associate Professor of Economics & Director of MS in Environmental Resilience, UNCA

Greg Dobson, GISP, Director of GIS and Engagement, NEMAC

Dr. Jonathan Horton, Professor of Biology, UNCA

Ian Johnson, Senior Geospatial Analyst, NEMAC

Dr. Andrew Laughlin, Associate Professor of Environmental Science, UNCA

Dr. Steve Norman, Research Ecologist, USDA Forest Service Southern Research Station, Threat Assessment Center

Jessica Orlando, Geospatial Research Scientist and Natural Resources Specialist, NEMAC

Dr. Jen Rhode Ward, Professor of Biology, UNCA

Joel Scott, Biological Science Technician, USDA Forest Service Southern Research Station, Coweeta Hydrologic Laboratory

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Abstract: The University of North Carolina at Asheville's (UNCA) 21.2-ha property known as "The Woods" exists as one of the largest unprotected urban forests in Asheville, NC. This location serves as a habitat to a vast and varied number of species, as well as a recreational and educational space for students, residents, and tourists. With future plans to develop this tract of forest underway, it is important to understand the value of the natural assets at stake. A comprehensive ecosystem services values assessment began with community consultation. This method is widely seen as an integral step in environmental conservation and climate resilience planning. Results indicated a strong push for low to no development in "The Woods" property. Following procedures developed for the i-Tree Eco tool, this study conducted a tree inventory enhanced with LiDAR data to assess the ecological and economic benefits of "The Woods." Canopy height models were derived from 2026 and 2017 LiDAR data to estimate forest canopy change before and after a major hurricane impacted the area. Results revealed 7.5 percent canopy loss relative to a field survey from 2021. Canopy height models showed that 62.0 percent of "The Woods" experienced canopy height loss over the 9-year period. Lastly, the field survey and benefit models showed that as of June 2026, "The Woods" stores 2.744 thousand metric tons of carbon dioxide ($1.31 million value) and annually sequesters 101.7 metric tons/year of carbon dioxide, removes 1.268 metric tons/year of air pollution, and prevents 5.66 thousand cubic meters/year of stormwater runoff each year, resulting in a replacement value of $12.1 million and yearly benefits of $82,500. These results indicate that "The Woods" are a valuable provider of ecosystem services even after Hurricane Helene caused significant tree loss.

Keywords: climate resilience, ecosystem services, urban forestry, sustainable development, community engagement, nature-based solutions, tree inventory, LiDAR, tree canopy

1. Introduction

Climate change is increasing risks from heat, flooding, and severe storms worldwide. The rise in global greenhouse gas emissions are largely driven by unsustainable energy use, land-use and land-use change (*1*). As a result, anthropogenic climate change is altering climate patterns and increasing the frequency and intensity of extreme weather events worldwide. Although efforts to mitigate and adapt to climate change are underway, significant gaps remain in both areas, making it increasingly difficult to achieve climate goals across sectors and regions. Limiting global warming requires the sustained achievement of net-zero carbon dioxide emissions. Climate change poses a significant threat to both human and environmental health, and the opportunity to secure a livable and sustainable future is rapidly narrowing.

The Intergovernmental Panel on Climate Change (IPCC) reports that current development pathways, combined with the impacts of climate change, are moving societies further away from sustainable development. In response, communities are increasingly pursuing climate resilient development strategies. Climate resilient development integrates climate change mitigation and adaptation efforts to support sustainable growth, while reducing vulnerability to climate hazards (*1*). Sustainable development seeks to meet present needs without compromising future generations' abilities to meet their own (*2*). Examples of climate resilient development practices include avoiding development within floodplains, maintaining and protecting ecosystem services, and integrating nature-based solutions to manage stormwater runoff. These implementations can reduce exposure to climate risks, strengthen a community's adaptive capacity, and provide additional benefits such as improved air quality, public health, and ecosystem conservation.

Urban forests represent a critical component of climate-resilient development due to the extensive ecological functions and human benefits they provide. In metropolitan areas, urban forests often serve as a natural solution for sustaining both environmental health and human well-being (*3*). Despite these benefits, urban development throughout the eastern United States has frequently occurred at the expense of forested land. This forested land provides valuable ecosystem services, including carbon sequestration, air pollution reduction, urban heat mitigation, stormwater retention, wildlife habitat, recreational opportunities, and environmental education (*3*). Incorporating sustainable urban forestry practices into city planning is therefore not only beneficial, but increasingly necessary for building resilient communities.

Hurricane Helene impacted Western North Carolina on September 27th, 2024, after a heavy predecessor precipitation event the day prior. The French Broad River crested 0.46 meters above the previous historical record, and the Swannanoa River reached 7.96 meters (*4*). Asheville was without power for over two weeks, and drinking water was not restored until late November (53 days after the storm). There were 107 recorded storm-related fatalities in North Carolina (*5*). As a result of the historic rainfall, debris flows and landslides contributed significantly to overall impact, especially in mountainous regions. Unprecedented wind speeds caused entire mountainsides to be stripped of woody growth, leaving the ground incredibly unstable and highly prone to slides. The North Carolina Forest Service estimated that approximately 822,000 acres of damaged timberland equated to $214 million in damages to North Carolina forests.

According to NOAA's Climate Explorer, Buncombe County, North Carolina is projected to see an increase of 2.9 to 5.2℃ in average daily maximum temperature above the 1961–1990 average by the end of the century. The State Climate Summary for North Carolina states that the severity of both droughts and hurricanes will increase as temperatures rise (*6*). As the community recovers from and prepares for future severe weather events in the aftermath of Hurricane Helene, integrating climate resilient development considerations into local planning is crucial.

This research seeks to develop a data-driven and community engaged workflow that emphasizes the importance of conserving and maintaining urban forests to build a climate resilient future. Specifically, the study evaluates the value of ecosystem services provided by the "The Woods," a forested property managed by the University of North Carolina at Asheville (UNCA), through the use of community surveying, i-Tree Eco modeling, and a pre- and post-Hurricane Helene tree canopy assessment using LiDAR-derived models. By quantifying these benefits, this research aims to demonstrate the role of urban forests in advancing climate resilience and supporting sustainable development in Asheville and beyond.

2. Literature Review

2.1 Urban Forests and Ecosystem Services

Ecosystem services provided by urban forests include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, educational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling (*7*). By absorbing and storing atmospheric CO_2, urban forests play an important role in climate change mitigation. Urban forests are also important for local air quality, removing pollutants such as SO_2 and NO_2 and releasing oxygen (*8*) Their cooling effects can assist in controlling the harmful effects of extreme heat and reduce the impacts of the urban heat island effect. They play an essential role in rainwater retention and runoff reduction, reducing the likelihood of flooding and lightening the load on storm drains (*9*). Urban forests act as a form of green infrastructure, reducing costs of built infrastructure like storm water retention treatments and energy conservation through reductions in heating and cooling necessity (*9*).

In addition to the abiotic ecosystem services an urban forest provides, they also serve as a refuge for wildlife, enhancing biodiversity and contributing to the long-term stability of urban ecosystems (*9*). Corridor connectivity is crucial to avoiding habitat loss and fragmentation and maintaining biodiverse ecosystems (*10*). Corridor connectivity allows animals to maintain genetic diversity and adapt to climate change, while also finding food, water and shelter (*10*). Without suitable connectivity within and between habitats, wildlife populations and ecosystems will vastly diminish (*10*). Rapid urbanization in the Western North Carolina region is continuing to encroach on these crucial ecological corridors, further exacerbating anthropogenic causes to climate change. In Asheville, "The Woods" represents the end boundary of the urban-wildland interface that connects from Dortch Avenue through the Botanical Gardens, Chestnut Ridge, Beaver Lake, and Reynolds Mountain to all of the protected lands in the Craggy Mountains (Blue Ridge Parkway, Pisgah National Forest, and the Woodfin and Asheville watersheds) (*11*).

This potential fragmentation affects both the local ecosystems, the wildlife within and around them, as well as the humans that live with these animals. Loss of habitat ultimately leads to a loss in ecosystem services that benefit humans in their everyday lives.

The services provided by urban forests extend beyond environmental benefits to include positive effects on the physiological and psychological wellbeing of metropolitan residents. Noise reduction is one such benefit of urban forests, and research has shown that tall, dense trees combined with soft ground surfaces can reduce the noise from urban soundscape by 50 percent. (*9*). Furthermore, research conducted by Tas and Buyuksakalli at Bursa (2021) Technical University in Turkey took decibel (dBA) readings at 4 locations on campus during the morning and afternoon periods of high traffic. Two of the areas were unforested and two had “tree fences” between the road and university properties (*12*). The “average peak noise level was 65.6 dBA in the morning period and 66.1 dBA in the afternoon period [in the unforested study areas]. The average peak noise level within the tree groups were 53.7 dBA and 54.1 dBA in two periods, respectively (*12*). Urban forests as noise buffers increase real estate values and contribute to a higher level of well-being for the general public (*9*). A person’s quality of life is often based on their proximity to green spaces, and this access has been shown to aid significantly in stress reduction. Studies have shown that landscapes with trees and vegetation produce more relaxed physiological responses compared to places without (*9*). Improved air quality also enhances physical and mental health and results in lower medical costs (*9*).

As climate change intensifies, Western North Carolina will face increasing exposure to hazards such as extreme heat and flooding (*6*) Development within “The Woods” will threaten cities’ local ecosystems, and exacerbate the effects of climate change. Therefore, finding a way to manage wildlife populations while still meeting the economic and social needs of humans through climate resilient development strategies is a core pillar to sustainable urban planning (*3*). Climate resilient development (CRD) strategies seek to maximize the overlap between adaptation and mitigation in order to increase communities’ ability to respond to and recover from the effects of climate change. One key response strategy to approach the environmental instability caused by global change is to promote forest resilience (*13*). The IPCC has suggested that local land use policies can provide effective support for implementing CRD (*14*). Public and privately owned urban forests provide a largely passive, yet highly beneficial, method of resilience for communities as a whole. For example, a report from the US Forest Service identified that New York's “18.6 million acres of forests hold 2.9 billion metric tons of carbon… equivalent to the carbon dioxide that would be released if all the houses in New York State were powered by fossil fuels for the next 100 years (*15*).”

2.2 Community Engagement for Resilience Planning

According to a study conducted by Wibowo et al. on community participation in coastal area management on Karimunjawa Island, “generally, community participation can create sustainable natural resource use by safeguarding residents' economic interests, respecting local cultural practices, and enhancing community awareness of natural resource conservation to achieve the ultimate goal of biodiversity and ecological conservation (*16*).” The concept of place attachment describes how positive affective bonds are formed between individuals and their socio-physical environments; people's relationship to the living environment is a key to understanding their actions and the environmental consequences (*17*). By empowering people to take an active role in resilient development and planning, governing bodies can expect better, long-term success of projects.

This idea is backed by findings from Zhang et al. who researched whether place attachment or community engagement had more of an effect on pro-environmental behaviors (PEB). "Community participation is the most powerful predictor of residents' PEB in the protected areas in our study (*17*)." This finding supports Wibowo et al.'s view that community participation is a significant predictor of success in environmental conservation." They found that attachment to an environment was not enough to motivate residents to take action to preserve it; rather that people need to be able to choose how the spaces are managed.

2.3 I-Tree Eco

The i-Tree Eco software is an adaptation of the Urban Forest Effects (UFORE) model, which was cooperatively developed by the U.S. Forest Service Northern Research Station, the U.S. Department of Agriculture State and Private Forestry's Urban and Community Forestry Program and Northeastern Area, Davey Tree Expert Company, and the State University of New York College of Environmental Science and Forestry. The software was developed to assess forest tree structure and ecological value to support forest management and policy development. Using local weather station, pollution, and tree data, i-Tree Eco quantifies ecosystem services, including carbon storage and sequestration, oxygen production, pollution removal, and stormwater interception (*18*).

The i-Tree Eco software has proved to be a valuable tool for researchers and policy makers to articulate the ecosystem services provided by urban forests. Since its release in 2006, "i-Tree Eco has helped urban tree officers worldwide to find tangible leverage in the means of quantitative mapping, numeric measures, and economic values of ecosystem services. This may in turn help ease gridlocks and potentially support constructive dialogues across sectors, with decision-makers and public engagement (*19*)." Research conducted in Great Britain highlighted that the impacts of i-Tree Eco projects varied due to local context and project delivery but improved understanding and awareness of urban forests may often result in changes to policy making decisions or lead to higher allocation of resources for urban forests. This increased attention offered more attempts for forward planning via knowledge transfer and community engagement (*20*).

2.4 LiDAR

Vegetation canopy structure plays a critical role in maintaining habitat characteristics, fostering biodiversity, and informing effective conservation planning (*21*). Accurate characterization of forest structure is also essential for estimating aboveground biomass, identifying carbon sinks, and monitoring forest change over time. Traditionally, these measurements have relied on field-based forest inventions, which are labor-intensive, time-consuming, and often impractical over large spatial extents. Airborne laser scanning (ALS) using Light Detection and Ranging (LiDAR) technology has emerged as a powerful alternative by providing high-resolution three-dimensional representations of forest structure. Compared with traditional field inventories, LiDAR-based remote sensing offers a more efficient and cost-effective approach to measuring and monitoring forests while maintaining high levels of accuracy (*22; 23*). Furthermore, LiDAR has the advantage of rapidly collecting detailed data across extensive landscapes, making it particularly valuable for large-scale forest monitoring.

Recent research has demonstrated the growing potential of LiDAR for assessing forest disturbance and structural change. Although relatively few studies have quantified fine-scale changes in forest structure using bitemporal LiDAR datasets, existing research has shown promising results. Milan et al. (2026) combined LiDAR with field observations to quantify ice storm damage and found that LiDAR-derived estimates of leaf density and biomass loss closely matched field measurements, demonstrating that LiDAR can serve as a reliable alternative to time-intensive field surveys (*24*). Similarly, Vastaranta et al. (2012) developed a canopy height model (CHM) approach that detected damaged tree crowns by comparing bitemporal LiDAR-derived CHMs. Their study demonstrated that repeated LiDAR acquisitions can effectively and automatically identify forest damage caused by heavy snow, highlighting the utility of multi-temporal LiDAR for monitoring structural disturbances (*23*).

Beyond damage detection, LiDAR has also proven valuable for understanding forest recovery following major disturbance events. Leitold et al. used bitemporal LiDAR to evaluate forest damage and subsequent recovery following Hurricane Maria in Puerto Rico. Their analysis revealed rapid regeneration of canopy gaps and substantial height gains after the initial storm-related losses, providing evidence of strong ecosystem resilience (*25*). These findings illustrate how repeated LiDAR observations can improve understanding of post-disturbance recovery dynamics while supporting more accurate modeling of carbon storage, water cycling, and ecosystem energy balance.

Collectively, these studies demonstrate that LiDAR is becoming an increasingly reliable tool for rapid, accurate, and large-scale assessments of forest structural change. However, relatively few studies have applied high-resolution bitemporal LiDAR to quantify fine-scale changes in forest canopy structure following disturbance, highlighting the need for additional research to evaluate forest damage and recovery across diverse forest ecosystems.

3. Data and Methodology

This study consists of four main parts: 1) a community engagement survey to collect student and faculty opinions on development of the "The Woods," 2) a LiDAR tree canopy assessment to evaluate forest structure before and after Hurricane Helene, 3) an orthoimagery validation of LiDAR data and 4) an on-the-ground tree inventory to assess the ecosystem services provided by the "The Woods." Results were compared to the 2022 field study on ecosystem services provided by "The Woods" to estimate how Hurricane Helene may have impacted these ecosystem services (*26*).

3.1 Study Area: "The Woods"

The study area is situated at UNCA in the City of Asheville, which as of 2024, has an estimated population of 94,983 (U.S. Census Bureau, 2024). According to the City's Tree Canopy Assessment, tree canopy covered approximately 56 percent of the City of Asheville in

2022 (*27*). A previous report found that Asheville's tree canopy is declining with a 6.4 percent loss in tree canopy from 2008 to 2018 (*28*). Post-Hurricane Helene assessments of canopy cover and loss are currently underway. In April, 2021, The UNC System Board of Governors approved UNCA's request to designate several parcels of University property as a Millennial Campus, including 29 buildings and spanning a total of 85.1-ha. According to the UNC System, "A Millennial Campus designation gives universities regulatory flexibility to finance projects and to collaborate with industry and the private sector on innovative ventures. To receive approval from the Board of Governors, a Millennial Campus must enhance an institution's research and teaching missions and drive economic development in the area."

The portion of UNCA's Millennial Campus that was most recently designated for development is located south of the main campus (called "South Campus" or "The Woods") and is situated next to the Five Points neighborhood. The total area of "The Woods" is 21.2-ha (Figure 1). As one of Asheville's last urban forests, "The Woods" has supported the university and community for years, serving as a recreational space for residents and living classroom by many professors and students. Historically, "The Woods" was deforested and served as a dairy farm for Dr. Karl Von Ruck's Winyah Sanitarium farm. The institution was a facility for the study and treatment of tuberculosis. "The 150-by-30-foot stone foundation of his dairy barn and the pasture's now century-old white oak grove compose an archaeological site…(*29*)" After the discontinuation of the dairy facility, the land returned to a forested state.

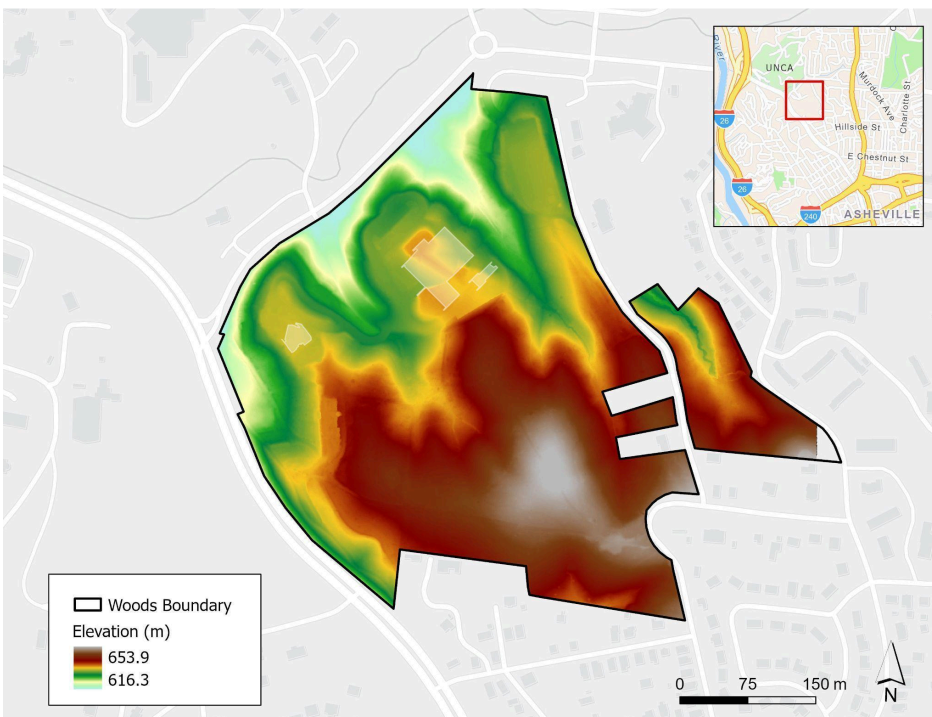


Figure 1. Digital Elevation Model of "The Woods" urban forest property (21.2-ha) owned by UNCA.

At UNCA, 17 biology courses and 21 environmental science courses utilize "The Woods" property (*30*). Additionally, there have been $688,000 in grants that funded projects involving the Urban Forest and Chestnut Ridge. An assessment conducted by Keller (2022) estimated that "The Woods" sequesters 75.5 metric tons of carbon dioxide annually, stores 3,450 metric tons of carbon dioxide, and prevents approximately 294,700 cubic feet of stormwater runoff each year.

Wooded properties serve as a vital teaching tool at university campuses nationwide; Indiana University boasts close-to-campus properties such as Dunn's Woods, as well as its' Research and Teaching Preserve (RTP). The RTP is composed of seven separate properties, spread over three counties. According to the school, "500 IU undergraduate and graduate students each year conduct course-based research or participate in outdoor laboratory exercises." Harvard University has The Harvard Forest, a 3,750-acre field site used for research and education. The area is not only utilized by Harvard students but also by a range of approximately 1,000 K-12, undergrad and graduate students each year. One summer research program "involves 20 to 30 undergraduates who conduct a range of independent research on wildlife and conservation topics. Of that number, around 80 percent come from different schools and 20 percent from Harvard (*31*)." Recently the property has been the study area for the successional ecology of returning a golf course to a meadow.

Aside from research and recreation, "The Woods" millennial campus property provides habitat for over 1,800 species of birds, mammals, reptiles, insects and flora (*32*). Following Hurricane Helene in September 2024, community concerns about flooding, stormwater management, and ecosystem preservation intensified. Community opposition to development of this parcel was substantial, with more than 15,000 individuals signing a petition opposing the proposal. By August 2025, the university paused the proposal and committed to evaluating alternative development options.

3.2 Community-Engaged Survey

In response to the absence of community engagement by the UNCA Millennial Campus Committee, a community-engaged qualitative survey was conducted in October 2025, by the 2025/2026 Masters of Science in Environmental Resilience graduate students to gauge student and faculty opinions on development of the UNCA Millennial Campuses. Questions were altered to provide relevant questions to both students and faculty, and consisted of a mix of multiple choice and short answer questions. A list of the questions provided is in Appendix I. The surveys were completed using Google Forms. Data collection was deployed university wide for 30 days. Based on the survey responses, alternative proposals were developed that integrate community feedback and university values, informed by climate resilience strategies.

3.3 Tree Inventory

The 30-plot urban forest tree inventory was conducted in June 2026 by a crew of three graduate students. In 2022, Jordan Luff, a Management Forester formerly with the NC Forest Service, generated random plot locations throughout UNCA's forests using Plot Hound (*26*). Sixty permanent 0.04 ha (0.1 acre) plots were placed in "The Woods." This study was intended to support the University's carbon neutrality goals and development of a Climate Action Plan by quantifying the carbon stock of the University's forested properties. Half of these existing plots (30) were sampled for this study (Figure 1a). Every other plot, starting from the top left corner of the property, was selected for this assessment. Sampling challenges arose due to the summer season, dense shrub growth, invasive species, and downed trees, which made certain plots difficult to navigate (Figure 1b).

Figure 2. a) Map illustrating the 30 plot centers (blue) sampled in “The Woods.” b) Typical dense understory in one of the research plots.

The 30 plots were circular with an area of 401.15 m² (diameter of 22.6 m). Meter tapes were extended from each flagged plot center from N-S and E-W to define a 0.01 ha circular plot. A shapefile containing plot center coordinates was loaded onto the Gaia GPS mobile application for locating and establishing plot centers in the field. While plot centers were marked by capped rebar in the previous study, these were no longer locatable in the property due to recent downed trees and human disturbance. To compensate for this limitation, flags were placed as close as possible to previous plot centers and new coordinates were recorded using Apple Maps. There could be a 5-30 m difference between the intended and recorded plot centers, as a result of varied access to satellites, cellular towers, and Wi-Fi hotspots. Plots were inventoried by quartile (Figure 2). Following methodology outlined by the i-Tree Eco field manual and used in the 2022 survey, the diameter at breast height (at 1.3 m above ground level; DBH) of all live trees (DBH ≥ 3.5 cm) was measured (n = 857) (*26; 33*). The tree species (n = 51) and the percent tree canopy cover at intervals of 5% were recorded. The PictureThis mobile application (*32*) was used to support species identification, and a densiometer was used to determine percent tree canopy cover at each plot center.

a)  b) 

Figure 3. Field data collection, a) meter tape and b) densiometer reading taken at plot center

The tree parameters were entered into the i-Tree Eco V6 software application for the calculation of ecosystem services, where the most recently available benefit values were automatically added by i-Tree. Along with user-inputted tree inventory data, i-Tree Eco uses local air pollution and meteorological data for the calculation of ecosystem services. The latest data available (2024) was used for this study. The Asheville Regional Airport (NCEI ID: 723150-03812) was used for weather data, and pollution stations within a 100-km radius of the study area were selected for particulate matter less than 2.5-µm ($PM_{2.5}$), particulate matter less than 10-µm and greater than 2.5-µm (PM_{10}), ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) data (Table 1). Carbon monoxide (CO) was not reported because the nearest station was over 100-km away.

Table 1. Air pollution stations and distance from study area

Location	**Station ID**	**Distance (km)**	**Parameter**
Buncombe County, NC	0030	9.7 km	O_3
Buncombe County, NC	0034	4.0 km	$PM_{2.5}$, PM_{10}
Greenville County, SC	0015	82.9 km	NO_2
Haywood County, NC	0013	27.4 km	SO_2

3.3.1 Air Pollution Removal

By lowering air temperatures, immediately eliminating air and pollutants, and lowering building energy consumption, the urban forest can contribute to better air quality. As a result, the power sources' emissions of air pollutants are reduced. Although integrative studies have shown that an increase in tree cover results in a decrease in ozone generation, trees also release volatile organic chemicals that can contribute to ozone creation (*18*). Field data and current pollution and meteorological data were used to estimate the amount of pollutants that trees in "The Woods" removed.

The elimination of air pollution for O3, SO2, NO2, PM2.5, and PM10 was calculated. Based on a combination of big-leaf and multi-layer canopy deposition models, hourly tree-canopy resistances for ozone, sulfur, and nitrogen dioxide are computed to determine air pollution removal estimates (*34; 35*). The number of negative health effects and related economic value for ozone, sulfur dioxide, nitrogen dioxide, and particulate matter smaller than 2.5 µm were determined using data from the Environmental Benefits Mapping and Analysis Program (BenMAP) of the U.S. Environmental Protection Agency (*18*). The prices of $3,646 per ton for ozone, $402 per ton for nitrogen dioxide, $111 per ton for sulfur dioxide, $223,319 per ton for particulate matter less than 2.5 µm, and $8,733 per ton for particulate matter less than 10 µm and greater than 2.5 µm were used to calculate the pollution removal value for this analysis.

3.3.2 Carbon Storage and Sequestration

By storing atmospheric carbon (from carbon dioxide) in their tissue and changing how buildings use energy, urban trees can help slow down climate change by reducing carbon dioxide emissions from fossil fuel-based power sources (*34*). Because they store carbon in their annual growth, trees lower the quantity of carbon in the atmosphere. The size and health of the trees enhance the quantity of carbon trapped each year. Another way trees affect global climate change is through carbon storage; as a tree develops, it retains more carbon in its stored tissue. A tree releases a large portion of its stored carbon back into the atmosphere when it dies and decomposes. Therefore, the quantity of carbon that can be released if trees are allowed to die and degrade is indicated by carbon storage. While maintaining healthy trees can help store carbon, it can also increase carbon emissions (*18*). When a tree dies, its wood can be used to make long-lasting wood products, heat buildings, or generate electricity, all of which can help lower carbon emissions from fossil fuel and wood-based power plants as well as from the breakdown of wood.

The quantity of carbon stored in woody vegetation's above-ground and below-ground components is known as carbon storage. Equations from the literature and measured tree data were used to determine each tree's biomass in order to compute current carbon storage. The biomass of open-grown, well-maintained trees is typically lower than what forest-derived biomass models indicate (*18*). The biomass results for open-grown urban trees were multiplied by 0.8 to account for this variation. For trees found in natural stand conditions, no modifications were done. By multiplying tree dry-weight biomass by 0.5, stored carbon was produced.

The process by which plants absorb carbon dioxide from the atmosphere is known as carbon sequestration. The current tree diameter (year x) was added to the average diameter growth from the relevant genera, diameter class, and tree condition to estimate the tree diameter and carbon storage in year x+1. This allowed for the estimation of the gross quantity of carbon sequestered annually. Estimated or tailored local carbon values serve as the basis for carbon storage and sequestration values. Based on the U.S. carbon value (*36*), the carbon storage and sequestration values for this analysis are computed at $477 per metric ton.

3.3.4 Avoided Runoff

In many metropolitan locations, surface runoff can be problematic since it can contaminate rivers, lakes, streams, wetlands, and oceans. A percentage of the precipitation that falls during an event is absorbed by vegetation, such as trees and shrubs, while the remainder falls to the ground. Surface runoff is the amount of precipitation that falls to the ground without penetrating the soil (*37*). Surface runoff is increased in metropolitan environments due to the huge number of impermeable surfaces. Because their root systems encourage penetration and storage in the soil, urban trees and shrubs help reduce surface runoff by absorbing precipitation. In 2024, the Asheville region received 166.7-cm of precipitation (Figure 4).

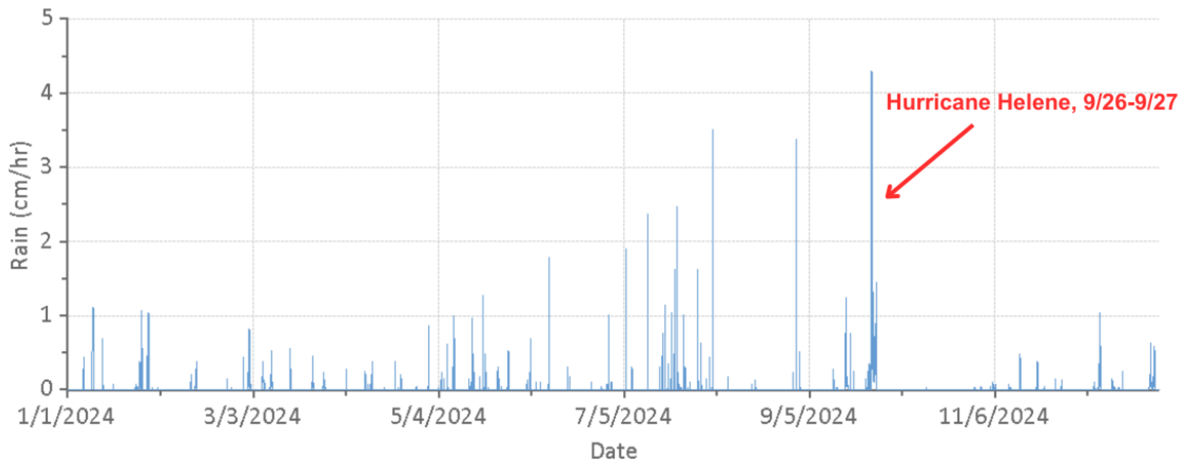


Figure 4. Precipitation recorded by the Asheville Regional Airport Weather Station for the year 2024 in cm/hr.

The difference between annual runoff with and without vegetation, or rainfall interception by vegetation, is used to compute annual avoided surface runoff. Only the precipitation absorbed by leaves is taken into consideration in this approach, even if tree leaves, branches, and bark may also catch precipitation and thereby reduce surface runoff. The U.S. Forest Service's Community Tree Guide Series (*38*) serves as the U.S. value of averted runoff. The prevented runoff value in this research is determined using the $2.36 per cubic meter price.

3.4 LiDAR Tree Canopy Assessment

The first point cloud was downloaded for the tile containing "The Woods" through the U.S. Geological Survey National Map GIS Data Downloader (*39*). LiDAR data was collected for 21 North Carolina counties by NC Emergency Management at a 0.35-m nominal post spacing (NPS) using the Geiger-mode LiDAR collection method in February through April, 2017 during leaf-off conditions. To assess the damage that occurred through Hurricane Helene's passage of western North Carolina on September 27th, 2024, the North Carolina Collaboratory began a project to create high-resolution LiDAR and digital orthophotography across the 12 hardest-hit counties in western North Carolina. LiDAR was flown during the winter of 2026 from January through March. This dataset was retrieved from the NC Emergency Management Spatial Data Download website (*40*). All data were delivered in the North Carolina State Plane Coordinate System, with a horizontal datum of NAD83 (2011), vertical datum of NAVD88 (Geoid 12B), in US Survey Meters. Classification errors were manually corrected, and all classifications other than vegetation (low, medium, and high) and ground were removed from the point clouds.

LiDAR data were processed in ArcGIS Pro version 3.6.1. Digital Elevation Model and Digital Surface Model rasters were generated at 0.3-m resolution for both years using the LAS Dataset to Raster tool. Digital Elevation Models were compared to ensure that significant bareground change did not occur across the study period. Buildings, roads, parking lots, and pedestrian infrastructure were digitized by manually tracing features from 2019 NC orthoimagery with three bands of red, green, and blue and a resolution of 15-cm (*41*). All impervious surfaces were then masked out of the LiDAR-derived rasters using the Extract by Mask geoprocessing tool. Canopy Height Models (CHMs) were developed using the Raster Calculator geoprocessing tool (Figure 5). The Focal Statistics geoprocessing tool was performed using a 5x5 focal max to reduce noise. Canopy height below 2-m was filtered out using the Set Null geoprocessing tool. Lastly, relative percent change between the 2026 and 2017 CHMs was calculated with the Raster Calculator geoprocessing tool.

a)

b)

Figure 5. Map of CHMs derived from LiDAR point clouds at 0.3-m resolution with impervious surfaces and vegetation below 2-m removed for years 2017 (a) and 2026 (b).

3.5 Orthoimagery

The LiDAR-derived CHMs were validated by comparing individual trees derived from high-resolution true color aerial orthoimagery closest to the 2017 to 2026 study periods. As part of the North Carolina Orthoimagery Program, imagery was flown in 2019 and 2025 with a resolution of 15-cm. The 2019 imagery was downloaded from NC OneMap and the 2025 imagery was downloaded from the City of Asheville's Open Data Portal (*41*). Esri's Tree Detection deep learning model package developed for forestry and vegetation management in the United States was used to identify individual trees (*42*). This model has a precision score of 0.66 and recall of 0.79.

Figure 6. Aerial orthoimagery of the study area, 2019 on the left and 2025 on the right.

4. Results

4.1 Community Engagement and Survey Results

To understand campus priorities and engage with the community, we conducted visioning workshops and surveys of UNCA students and faculty. The survey received 117 student responses and 65 faculty responses, representing a response rate of 4 percent and 34 percent respectively. Students were asked the zipcode of their high school to provide geographic insight into the university's pool of incoming students. While most students were from North Carolina (83 of 112 or 74% of respondents who provided zipcodes), 19 different states were represented in the survey. In North Carolina, the majority of respondents were from the Raleigh-Durham-Cary combined statistical area (28 respondents). The majority of student respondents were against any kind of development of "The Woods". Several respondents suggested small-scale development options, including sheltered outdoor classrooms and study spaces, tennis courts, walking trails, outdoor activity center, and art/sculpture space. Results showed 62 percent of student respondents mentioned preserving "The Woods" as greenspace, 13 percent of student respondents were in favor of small-scale development and 0.07 percent of student respondents had no suggestions for "The Woods" Millennial Campus property.

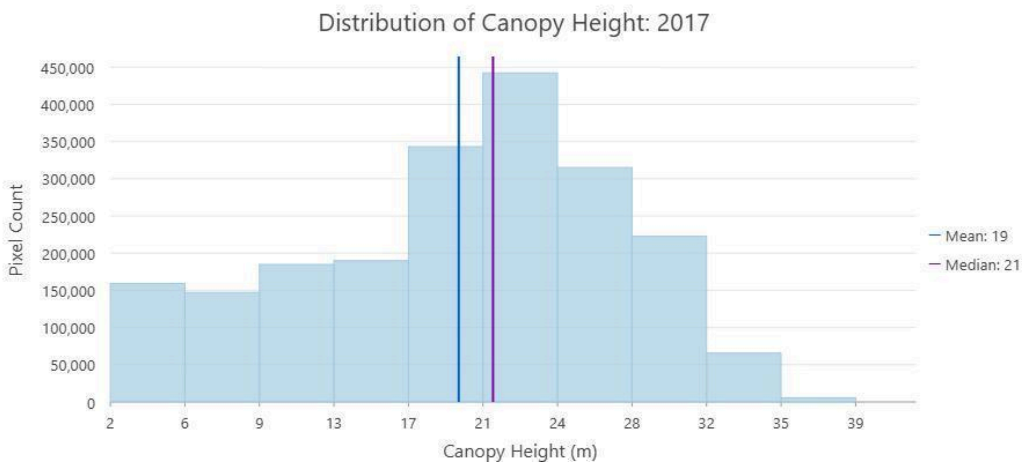
Similarly, faculty were largely against development of "The Woods". Some suggested that development should be restricted to the roadside. A total 45.5 percent of faculty respondents mentioned preserving "The Woods" as greenspace and 25.5 percent of faculty respondents were in favor of small-scale development. Others were supportive of greater development but were critical of the University's original proposal to build a soccer stadium in "The Woods." Results read 0.05 percent of faculty respondents were in favor of the stadium development proposal. The faculty had similar suggestions for small-scale development options to the students, and for greater development they suggested building affordable housing for the community and more research and academic facilities on the property. Lastly, 0.07 percent of faculty respondents had no suggestions for "The Woods" Millennial Campus property.

Students identified the Ramsey Library, Highsmith Student Union, Lookout Observatory, Botanical Garden, and surrounding forested areas as valued campus assets. Students preferred future developments included academic facilities, outdoor recreation opportunities, expanded dining options and affordable student housing. Respondents consistently emphasized preserving outdoor spaces and strengthening recreational opportunities. The large majority of students opposed major development within "The Woods," with only one student response in favor of a high development option.

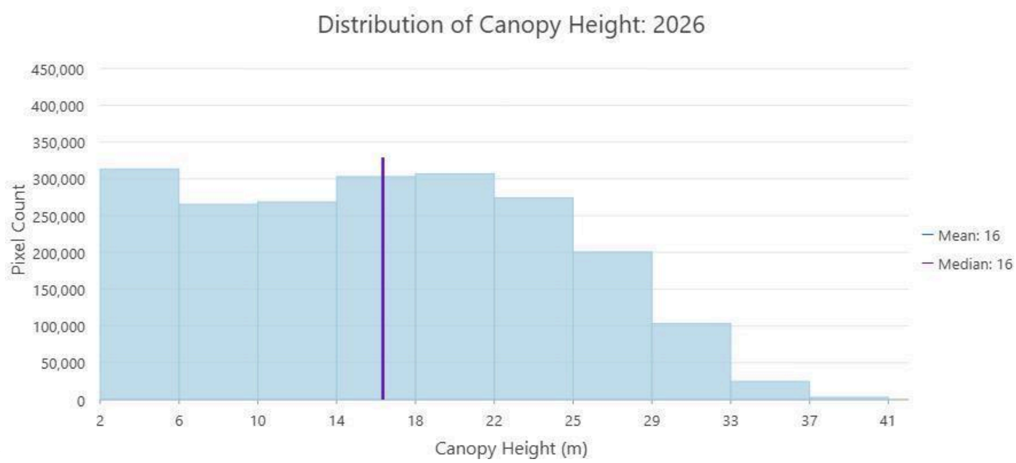
Faculty responses mirrored many student perspectives. Survey results highlighted preferences for outdoor recreation facilities, childcare facilities and affordable student, faculty and staff housing. Faculty also emphasized improving existing academic infrastructure, increasing affordability, and enhancing community collaboration. Similar to students, most faculty opposed development within "The Woods," with many recommending future development occur on an alternative property. Four faculty members ranked a high-intensive development among their top three preferred development options.

4.2 LiDAR Assessment Results

Canopy height histograms of the 2017 and 2026 CHMs were generated to visualize canopy structure change between the two years (Figure 5). The mean (65.09-m) and median (69.53-m) canopy heights were higher in 2017 than the mean (54.12-m) and median (54.12-m) canopy heights in 2026. The distributions show relatively taller tree canopies in 2017 and significantly shorter canopies in 2026.



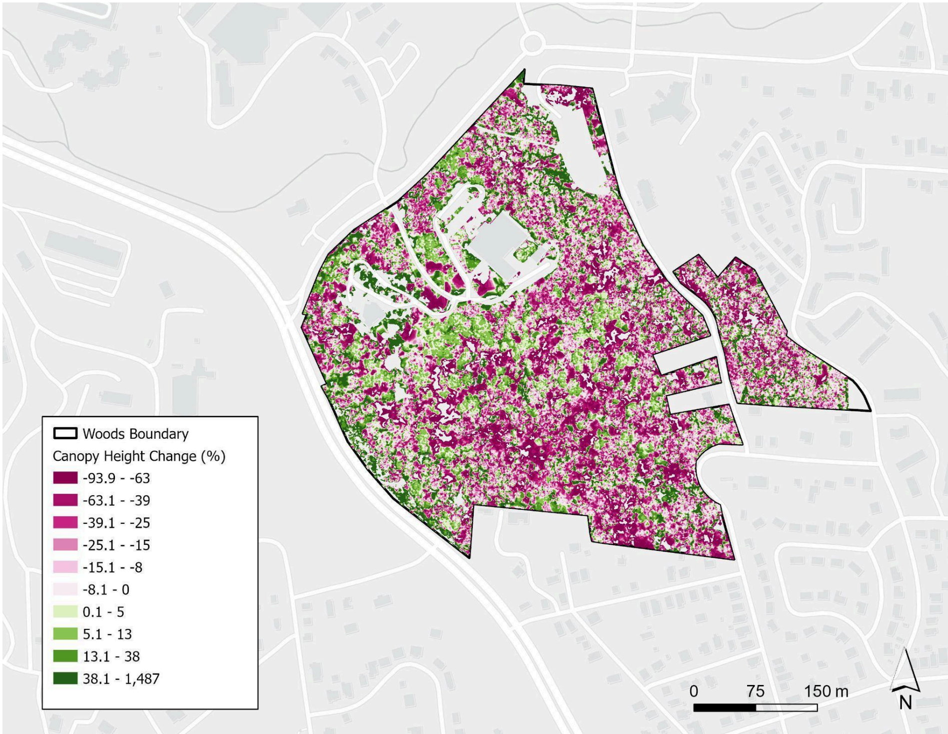
a)



b)

Figure 7a and b. Histograms of LiDAR-derived canopy height for years 2017 (a) and 2026 (b).

Overall, 62.0 percent of "The Woods" experienced canopy height loss and 35.1 percent of "The Woods" experienced canopy height gain (Figure 6). The remaining area experienced no change. The greatest amount of canopy height loss was concentrated in the southern portion of the forest.

a) 

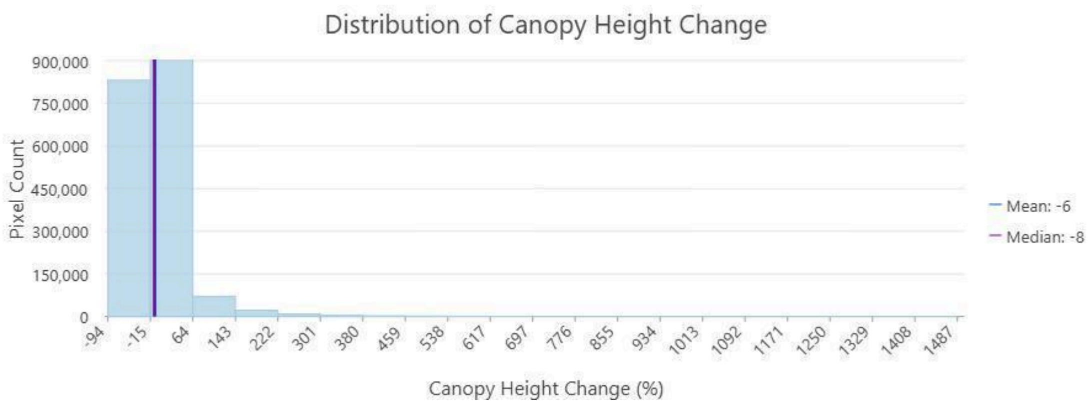
b) 

Figure 8 a and b. Map of relative percent change in canopy height between 2017 and 2026 (a). Canopy height loss is symbolized in pink and canopy height gain is symbolized in green. (b) Histogram of canopy height change.

4.3 Orthoimagery Results

Orthoimagery maps were utilized to validate the CHM maps. Esri's Tree Detection model identified 1,293 trees in the 2025 orthoimagery and 1,503 trees in the 2019 orthoimagery, corresponding to an individual tree loss of 14.0 percent (Figure 9).

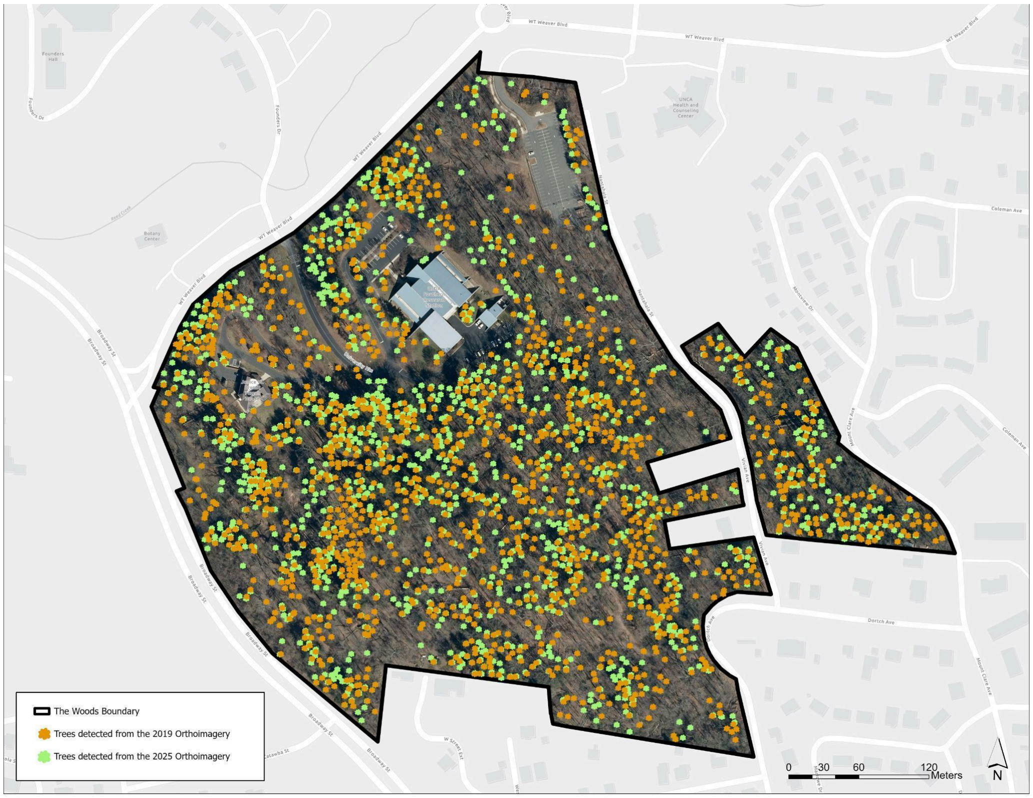


Figure 9. Map of individual trees in "The Woods" identified by Esri's Tree Detection model for 2019 and 2025 orthoimagery.

4.4 Ecosystem Service Results

Based on this study's plot measurements, the i-Tree Eco tool estimates that "The Woods" hosts 14,970 trees with a tree cover of 83.8 percent. The majority of trees surveyed (63.1%) had a DBH <15.2-cm. The three most common species are Eastern white pine (17.5%), Tulip tree (13.8%), and Black cherry (9.8%) (*43*). The overall tree density is 705.9 trees per hectare (Table 1). Tree characteristics remained relatively consistent with the 2022 study, which estimated 19,850 trees from 2,105 trees sampled, tree canopy cover of 91.3 percent, and tree density of 867.3 trees per hectare. The three most common species were also Eastern white pine (20.5%), Tulip tree (10.5%), and Black cherry (8.3%) (*43*). These results suggest a 7.5 percent loss in tree canopy cover in "The Woods" between 2021 and 2026. It is important to note that this number of tree canopy loss cannot be completely attributed to the destruction caused by Hurricane Helene.

Species Name	Percent Population	Percent Leaf Area	Importance Value
Tulip tree	13.8	34.9	48.7
Eastern white pine	17.5	21.6	39.1
Black cherry	9.8	6.6	16.4

Black oak	4.3	7.5	11.8
White oak	5.6	5.2	10.8
Red maple	7.0	1.9	8.9
Black gum	5.4	2.6	7.9
Eastern redbud	5.8	1.5	7.3
Southern red oak	1.6	5.0	6.6
Mockernut hickory	4.2	1.4	5.6

Table 2. Most important species in "The Woods." Importance value is calculated by summing the percent population and percent leaf area.

In "The Woods," about 88 percent of the trees are species native to North America and North Carolina. Species exotic to North America make up 12 percent of the population. Most exotic tree species have an origin from Oceania (6% of the species) (*43*). In the 2022 study, 90 percent of the trees were species native to North America, while 86 percent were native to North Carolina. Species exotic to North America made up 10 percent of the population. Most exotic tree species had an origin from Europe & Asia (5% of the species). Invasive tree species comprise 2.8 percent of the tree population, whereas the 2022 study found that invasive species comprised 8.3 percent of the tree population. The three most common invasive species in the present study are Norway maple (1.6% of population), Tree of heaven (0.7%), and Amur honeysuckle (0.2%). The 2022 study's most common invasive species were Norway maple (4.5 percent of population), Chinese privet (1.9%), and Tree of heaven (1.4%).

4.4.1 Avoided Runoff

The trees in "The Woods" help to reduce runoff by an estimated 5.66 thousand cubic meters a year with an associated value of $13 thousand (*43*, Figure 10, Figure 11). This estimate is 2.64 thousand cubic meters lower than the avoided runoff value in the 2021 field survey.

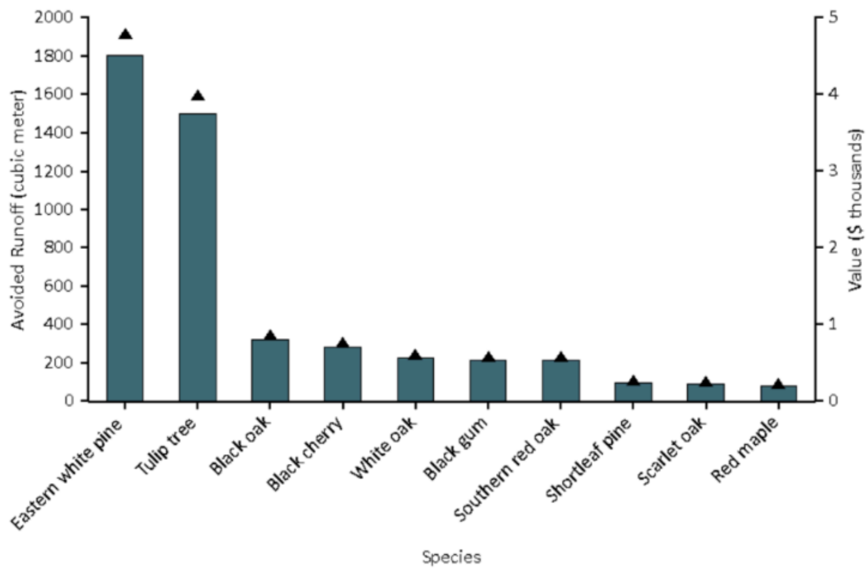


Figure 10. iTree Eco avoided runoff (triangles) and values (bars) for species in "The Woods" with greatest overall impact on avoided runoff

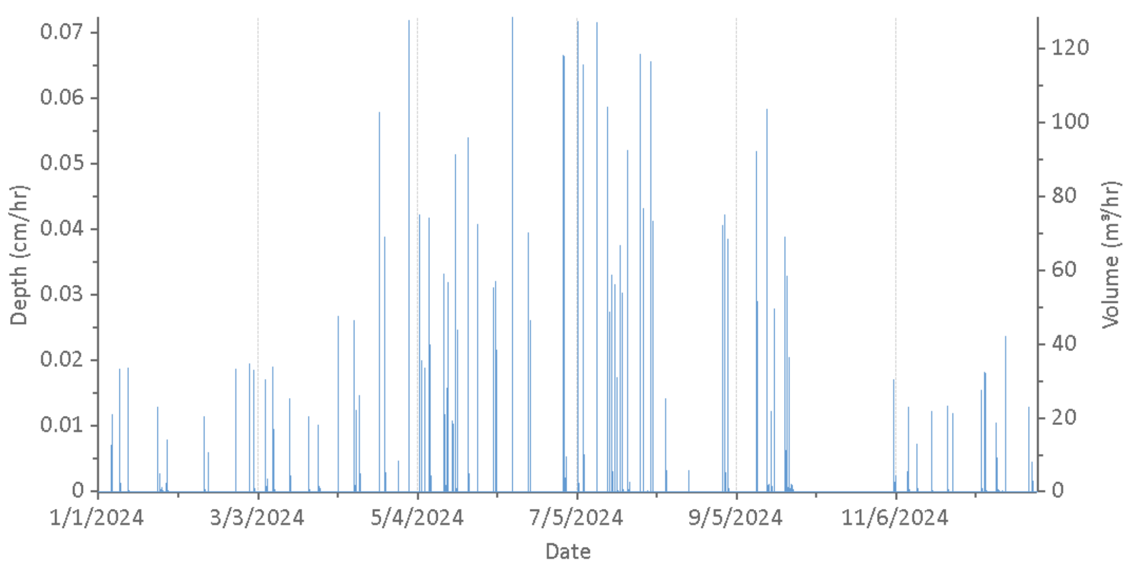


Figure 11. Avoided runoff by all trees in “The Woods” by depth (cm/hr) and volume (cubic meters/hr)

4.4.2 Air Pollution Removal by Urban Trees

Pollution removal was greatest for PM_{10}* (Figure 12). It is estimated that trees remove 1.268 metric tons of air pollution (ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter less than 2.5 microns ($PM_{2.5}$), particulate matter less than 10 microns and greater than 2.5 microns (PM_{10}*), and sulfur dioxide (SO_2)) per year with an associated value of $20.6 thousand (*43*).

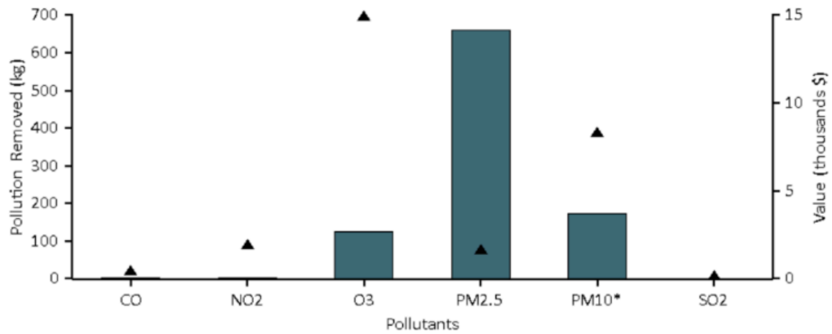


Figure 12. Annual pollution removal (triangles) and values (bars) by trees in "The Woods"

4.4.3 Carbon Storage and Sequestration

The gross sequestration of "The Woods" trees is about 101.7 metric tons of carbon per year with an associated value of $48.5 thousand. Net carbon sequestration in the urban forest is about 75.76 metric tons (*43*, Figure 13). Gross carbon sequestration in "The Woods" increased from 2021 by 33.2 metric tons.

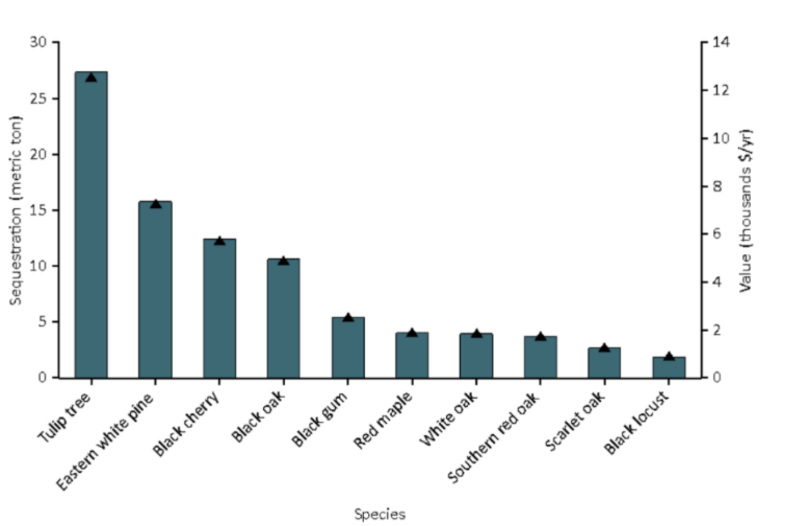


Figure 13. Estimated carbon sequestration (points) and values (bars) for urban tree species with the greatest sequestration capacity

Trees in "The Woods" are estimated to store 2,740 metric tons of carbon ($1.31 million), which is 398 metric tons less than the 2021 estimate. Of the species sampled, the Tulip tree stores and sequesters the most carbon (approximately 30.5% of the total carbon stored and 26.3% of all sequestered carbon) (Figure 14, *43*).

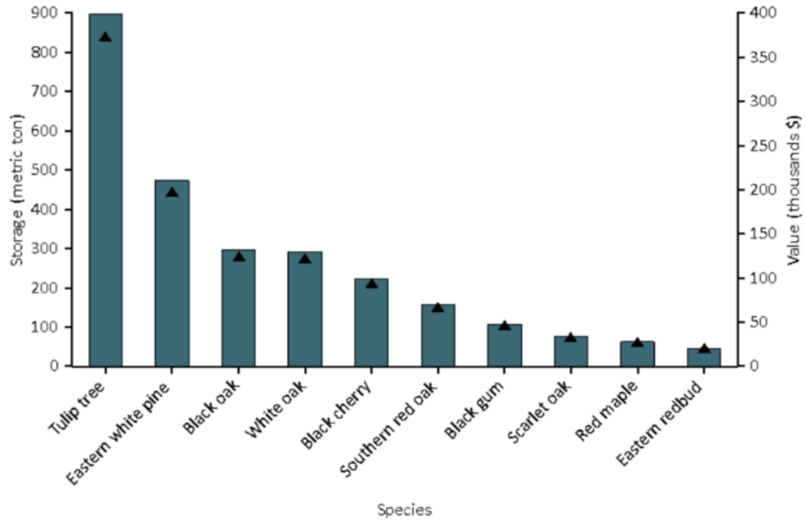


Figure 14. Estimated carbon storage (points) and values (bars) for urban tree species with the greatest storage capacity

The replacement value (the cost of replacing a tree with a tree of similar value) for all trees in “The Woods” is $12.1 million, which is $3.4 million less than its replacement value in 2021. Combined annual benefits of air pollution abatement, avoided stormwater runoff, and carbon sequestration provided by “The Woods” are $82,500.

5. Recommendations for Management and Future Development

The results of this study support a management strategy centered on preserving and enhancing the long-term resilience of UNCA's urban forest, “The Woods”, addressing planned campus growth in line with the University’s stated commitments to sustainability, inclusion, and experiential learning. Recommendations are summarized below.

5.1 Forest Management

To take advantage of the ecosystem services provided by “The Woods” under a changing climate, the University should establish a campus tree advisory committee involving staff, students, and community members and develop a comprehensive Urban Forest Master Plan as part of a broader Climate Action Plan. Such a plan would establish long-term goals for forest conservation, maintenance, carbon management, biodiversity protection, invasive species control, and climate adaptation while providing guidance for future development decisions.

As part of the plan, urban forest health assessments should be conducted regularly to identify hazardous trees and evaluate long-term recovery. Rather than widespread clearing, management should emphasize selective removal of hazardous, diseased, or structurally compromised trees while retaining healthy mature trees that provide the greatest ecosystem services. Restoration efforts should prioritize invasive species removal and diversifying native species that are well adapted to projected future climate conditions and resistant to pests and disease. Increasing species diversity will improve forest resilience to future disturbances while maintaining wildlife habitat and reducing the risk of extensive canopy loss from a single species decline. Continued management of invasive plant species should remain a priority; ongoing monitoring and removal efforts will help protect native biodiversity and support natural forest regeneration.

5.2 Climate-Resilient Development

Future Millennial Campus planning should prioritize low-impact development that minimizes forest fragmentation and preserves existing ecosystem services. Whenever feasible, development should be directed toward already disturbed or previously cleared parcels, rather than intact forest.

Two development alternatives are proposed based on community input. The low-development scenario emphasizes preservation of "The Woods" while locating new infrastructure on previously cleared land. Recommended facilities include affordable student housing, a childcare center, outdoor classrooms, a community garden or public park, and a sculpture forest that supports education, recreation, and community engagement. The medium-development scenario allows limited development along the forest perimeter while maintaining the ecological integrity and educational value of the interior forest. Additional recommendations include a community center, student-run coffee shop, food hall, outdoor recreation facilities, and an amphitheater designed using sustainable building practices. Any faculty or community housing should be prioritized on already cleared portions of the Millennial Campus to minimize additional tree loss.

Regardless of the development scenario selected, projects should incorporate climate-resilient design principles, including LEED-certified construction, low-impact development practices, green infrastructure, expanded stormwater management systems, permeable surfaces, native landscaping, and energy-efficient buildings. These measures will reduce flood risk, improve water quality, increase energy efficiency, and enhance the University's ability to adapt to future climate conditions.

5.3 Community Engagement and Future Opportunities

Meaningful community engagement should remain central to future planning efforts. Survey responses indicated that many students and faculty felt excluded from previous development discussions. Continued public participation through workshops, surveys, and collaborative planning processes will help ensure that future campus development reflects community priorities while building long-term trust and institutional support.

Furthermore, citizen science methods should be employed to involve the community in the stewardship of “The Woods.” One option is a community-engaged tree inventory. For example, the City of Charlotte, NC has developed a crowdsourced tree mapping application called “Tree by Tree” where residents upload trees in their neighborhoods through their mobile devices to inform where the city should concentrate their tree planting efforts (*44*). Similarly, Duke University interns developed the “Duke University Tree Viewer” to map the campus’s nearly 17,000 trees (*45*). The publicly available map catalogues over 240 tree species, enabling the broader community to learn about the trees on campus and help Duke University fulfill part of the requirements of becoming a Level II arboretum accredited by ArbNet.

6. Conclusions

This study demonstrates the critical role that urban forests play in supporting climate resilience, biodiversity conservation, and sustainable campus planning. By integrating community engagement, field-based forest inventory methods, LiDAR-derived canopy analysis, orthoimagery validation, and i-Tree Eco ecosystem service modeling, this research developed a comprehensive assessment of the ecological value of UNCA's urban forest, "The Woods."

The findings indicate that Hurricane Helene substantially altered the structure of the forest canopy, with LiDAR analysis showing widespread canopy height reductions across much of the property. Comparisons with the 2022 forest inventory also suggest measurable declines in canopy cover, emphasizing the long-term effects that extreme weather events can have on urban forest ecosystems. Each of the methods provide different insights into forest structure and come with their respective shortfalls. When used together, these methods can provide a more comprehensive picture of urban tree canopy. Despite the disturbance caused by Hurricane Helene, "The Woods" continues to provide significant ecosystem services through carbon storage and sequestration, air pollution removal, stormwater catchment, wildlife habitat, recreational opportunities, and outdoor education. These benefits highlight the importance of preserving urban forests as nature-based solutions for climate change mitigation and adaptation.

The community engagement component further demonstrated that students and faculty strongly value "The Woods" for its ecological, education, and recreational functions. Survey results consistently favored minimal development while emphasizing affordability, outdoor learning, and public accessibility. These findings reinforce the importance of incorporating community perspectives into land-use planning and suggest that future development should prioritize both environmental stewardship and campus needs.

Overall, this research illustrates how integrating ecological assessment with community participation can support evidence-based decision making for resilient campus development. This research ultimately argues that the future of "The Woods" should not be viewed as a choice between conservation and development, but as an opportunity to demonstrate how universities can integrate both through climate-resilient planning. As climate change continues to increase the frequency and severity of disturbances such as Hurricane Helene, protecting and actively managing urban forests will become increasingly important for maintaining ecosystem services and strengthening community resilience. Urban forests are long-term investments in community resilience, providing benefits that extend well beyond campus boundaries through carbon storage, stormwater management, biodiversity conservation, public health, and environmental education. By recognizing "The Woods" as natural climate-resilient infrastructure and incorporating its value into future planning decisions, UNCA has the opportunity to become a regional leader in resilient campus design and sustainable land stewardship. The methods presented in this study provide a transferable framework that can be applied by universities and municipalities seeking to quantify ecosystem services, evaluate disturbance impacts, and incorporate climate resilience into future planning efforts.

7. Author Contributions

Britain Hamrick, Angelina Herbert, Amelia Racky- conceptualization, methodology, data collection, data analysis, writing, visualization

All authors have read and agreed to the published version of the manuscript.

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9. Institutional Review Board Statement

The University of North Carolina at Asheville's Institutional Review Board (IRB) determined the surveys in this study qualify for exemption status (IRB Project #2377660-1).

10. Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

11. Data Availability Statement

All data produced in this study are provided in the Supplementary Materials section. All datasets used in this study are derived from publicly available sources and published datasets cited within the publication. No new datasets were generated or analyzed that require restricted access. Further details are available from the corresponding author upon reasonable request.

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13. Conflicts of Interest

The authors declare no conflicts of interest.

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15. Supplementary Materials

Appendix I. Community-Engaged Survey Questionnaires

Faculty Survey_ Millennial Campus Preferences - Google Forms.pdf

Student Survey_ Millennial Campus Preferences - Google Forms.pdf

Appendix II. i-Tree Eco Supplemental Materials

iTree_metadata.pdf

iTree_report.pdf