Carbon Sequestration in UNC Chapel Hill's Urban Forest

ENST 689 Capstone Project

i-Tree

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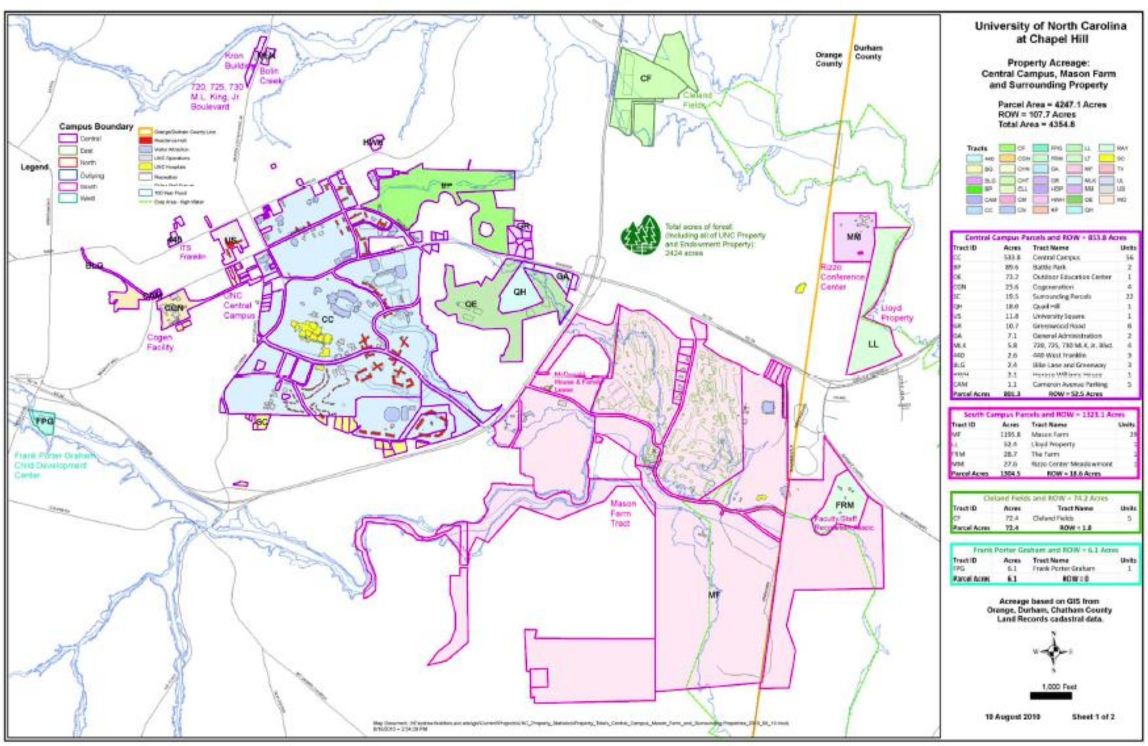

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The UNC Carbon Capstone group conducted a study on carbon sequestration in the Chapel Hill area. For our sites we focused on three areas: the UNC Chapel Hill campus and two other forested areas, the North Carolina Botanical Gardens, and Carolina North. ArcGis was used to create a stratified random sampling regime. Our team consisted of eight members and together our plot sampling and data collection process took six weeks. Data was entered into i-Tree Eco software that produced the results you will find in this report. All of our findings come from our data collection and data analysis from i-Tree eco. The information in the following sections have been examined and transferred from our i-Tree Eco report. The sections that are present are the ones that are specifically relevant to our project.

I. Introduction

A major focus of carbon-neutrality initiatives has been methods to reduce the emission of greenhouse gases, specifically carbon dioxide through measures such as renewable energy, local food, and energy-efficient building insulations. A topic that has been less prevalent has been working towards carbon neutrality through the reduction of greenhouse gases once they are present in the atmosphere- mainly through the preservation of vegetated areas. Research has shown that vegetation plays a major role in the sequestering of carbon dioxide and other pollutants from the atmosphere. For example, in a 2009 study of the urban forest present in Chicago, the 3,585,000 trees which covered 17.2% of the city were estimated to remove 25,200 metric tons of carbon and 888 metric tons of other air pollutants annually. The monetary value of the carbon and pollutants sequestered was estimated to be $6,921,000, based on estimated externality costs associated with pollutants (Nowak et al. 2009).

This sequestering ability of forested areas strongly interweaves with the goal of the University of North Carolina at Chapel Hill to achieve carbon neutrality by 2050; this means achieving a net level of carbon emissions of zero. Considering that despite environmentally conscious improvements on campus the greenhouse gas emissions from UNC-CH reached 531,000 metric tons of carbon dioxide in 2011, this effort to strive for carbon neutrality has a special importance in the environmental sustainability of the University (Arneman 2009). Vegetated areas help UNC-CH achieve carbon neutrality by counting against the carbon dioxide emitted in the operation of the University. Every ton of carbon sequestered on UNC-CH properties decreases net carbon emissions by 1 ton. Currently, UNC-CH holds over 4700 acres, with the majority of these areas forested, providing a substantial area where this sequestration can occur. Three properties were analyzed- the North Carolina Botanical Gardens (743 acres of forested land), Carolina North Forest (750 acres of forest), and the main campus, comprised of 729 acres of contiguous land. These three different sampling areas have diverse land use histories, landscapes and communities, and functions.

The University's Main Campus has a landscape history that began when the University was first founded. Main Campus covers 729 acres today and is managed by the UNC Grounds Department. There has been a shift over time on campus from planting annual plants to planting perennial shrubs as well as from planting turf grass to planting native grasses. Over time, more trees native to North Carolina are being planted on campus as part of a sustainable landscape design. The goal of these changes is to protect native plant species and to reduce maintenance, fertilizer/pesticide use, and overall fuel consumption. In addition, all organic waste from landscaping on campus is now being mulched or composted. Campus trees are continuously monitored and cared for by the Grounds Department. In 1999, a tree protection program was started that requires all new development projects on campus to have a tree protection plan. In 2002, a soil erosion and sediment control plan was implemented by the Environment, Health, and Safety Department of the University. Each new development or construction project must have a soil erosion and sediment control plan before the project can go up for bid. Thanks to these changes, the University has won awards for their sustainability efforts. In 1999, the American Society of Landscape Architects recognized the campus as a national landmark of outstanding landscape architecture. In 2005, the Professional Grounds Management Society awarded the campus a Green Star award for campus beauty.

The North Carolina Botanical Garden is another property owned by the University, and was officially founded in 1952. The Botanical Garden is a conservation garden, manifesting the idea of "conservation through propagation." The Garden is a collective of many properties, but we chose to do our project sampling in the forest

Botanical Garden Nature Trail

encompassing the Piedmont Nature Trails. These trails cover an area of about 50 acres and are in a typical Dry-Mesic Oak-Hickory Forest plant community (Randall, 2012). We selected this portion to sample because this area is representative of many other properties owned by the Botanical Gardens, including: the Hunt Arboretum, Laurel Hill Nature Preserve, Stillhouse Bottom Nature Preserve, Parker Preserve, and about one fourth of the Mason Farm Biological Reserve (Randall, 2012). These trails were opened to the public in 1966 and have seen active use since. The trails provide over two miles of hiking of different gradients and are open from dawn until dusk year round.

Carolina North is a more recent University acquisition. A portion of the non-forested land is going to be developed, but a larger area is either forested or has been set aside for conservation and can never be developed. The conservation forestlands have many trail systems that are open to the public year round. Carolina Forest is unique in its land use history in comparison to the other areas. It was previously a landfill for the town of Chapel Hill. Today, this landfill has been closed down and there is currently work being done to properly remove the landfill and attempt to restore the land there. The property is still home to the Horace Williams Airport. Biohabitats, Inc. conducted an ecological assessment of the property in 2006. They collected data and generated inventory maps on many property attributes including: water resources, geological formations, soil groups, tree stand age, land use/cover, morphology, landscape ecology, state, local government, and citizen group natural area designations and proposals, and cultural and historic resources. They categorized the land based on the relative impacts of development on conservation and habitat disturbance. They found that the property houses some threatened and endangered species as well as natural communities in need of conservation and protection. They also found areas of high-quality aquatic habitat, wetland communities, mature hardwood tree stands, migratory bird habitats, and culturally historic sites (Biohabitats, 2007). The Army Corps of Engineers stated that Carolina North serves as an important regional refuge for wildlife compared to the areas directly surrounding the property (Army Corps of Engineers, 2010).

Carolina North Aerial View

II. Project Overview

Three sections of UNC's property were chosen for this study. The first was the botanical gardens, which comprised of 743 acres of forested land, which was chosen because it represents an area which was set aside to preserve flora which are native to North Carolina. This land represents forest that will not become urbanized. The second was Carolina North, which comprised of 750 acres of forested land. This property was chosen because it represents an extensive forested track which will partly be developed in the near future. The third property chosen was the main campus, which comprised of 729 acres of contiguous land. This section was chosen because it is representative of the urban forests surrounding UNC’s academic and medical buildings. On Carolina North and the Botanical Gardens, thirty plots of .01 acres were randomly selected for each area. On the main campus, twenty plots of .1 acres each were randomly selected. The larger plot size was used on main campus to account for greater spatial heterogeneity, in the sense that Carolina North and the Botanical garden lands were all natural forest, whereas the Main Campus has both forested and developed areas. In each of these plots, individual traits such as tree size and health were recorded for each tree, as well as descriptive traits of the overall site, such as shrub cover and land use for entry into i-Tree Eco.

The USDA Forest Service adapted the peer-reviewed i-Tree software suite to enable urban forestry analysis and benefit assessments. i-Tree Eco is an adaptation of the Urban Forest Effects (UFORE) model, which was cooperatively developed by US Forest Service Northern Research Station (NRS), the USDA State and Private Forestry's Urban and Community Forestry Program and Northeastern Area, the Davey Tree Expert Company, and SUNY College of Environmental Science and Forestry. The UFORE model was conceived and developed by David J. Nowak and Daniel E. Crane (USFS, NRS), and Patrick McHale (SUNY-ESF). The i-Tree software package provides the user with the ability to find the benefits of trees on carbon sequestration, pollution removal, building energy consumption, and hydrology; however, for the purpose of this study only carbon sequestration and pollution were analyzed. Data collection was based around inputs needed for these calculations by the software.

ArcGIS was used as the method to obtain our randomly sampled plots. The US Forest Service designed a special tool in ArcGIS to create random samples i-Tree Eco projects. The tool allows the user to create random sampling plots once they have selected their areas of interest and created a sampling regime. First the map was created using the following as map inputs: UNC basemap, UNC_property, Orange County aerial photograph, and Carolina North trails.

2 Plots in Carolina North with Buffers

The UNC basemap contains roads, buildings, and other landmarks which are important in understanding the location of the plots prior to field sampling; this allowed sampling to be done in a more efficient manner. The UNC-property data contained information on all of UNC owned properties and allowed our chosen areas to be selected in ArcGIS. The Orange county aerial photograph was again useful as it added in planning field sampling routes. The Carolina North trails were used to make a printed map showing the plots in relationship to the trails; this allowed the team to effectively plan routes for data collection. In ArcGIS the three areas of interest (Botanical Gardens, Carolina North, and main campus) were selected individually and random samples were created for each using the i-Tree random samples tool. The random samples produced are shown as points on the map with GPS coordinates. Buffers were created around each plot based on the size of the plot to be measured. The buffers are necessary as they give the size of the plot area to be sampled either 0.1 acre for main campus or 0.01 acre for Botanical Gardens and Carolina North. The data created in ArcGIS on the sample plots and plot sizes were exported to the i-Tree Eco program. The team then planned field sampling based on the locations of these plots with respect to each other.

Plots were established in the field by entering the coordinates given by the ArcGIS random sample into GPS's. A center point was established at each plot, and the plots were then traced out in a circular manner with a tape measure, with 37 foot radii for the 0.1 acre plots and 11.5 foot radii for the 0.01 acre plots. Reference objects were recorded so that plots could easily be found in the future.

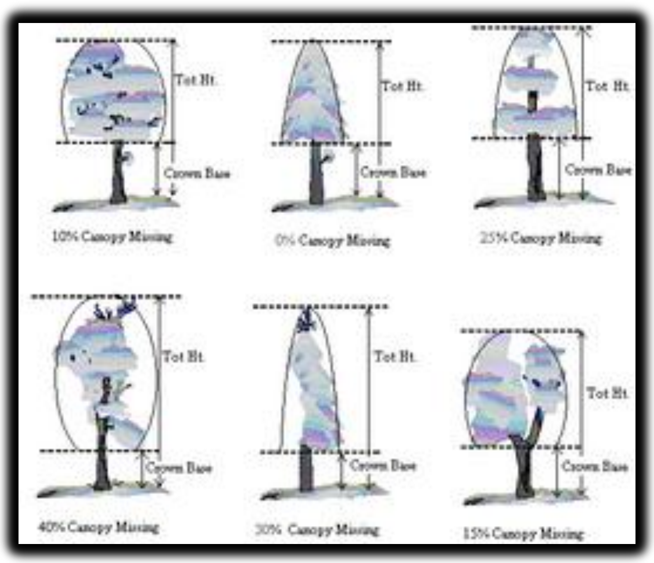
Percent tree cover, land use category (forest, parking lot, road), percent ground cover, and shrub cover were all calculated. This gave us estimates for how much carbon was being sequestered by non-tree flora, as well as estimates for what percentage of the plot might be available for future tree growth.

Every tree within these plots was identified using the 'Tree Finder' dichotomous key (Watts, 1998). This key employs observations on leaf characteristics such as venation, branching patterns, and bark patterns structure. Distance of each tree from center of plot and cardinal direction from center were also measured with compass and tape measurer to calculate spatial tree density.

Tree circumference at breast height was measured using a tape measure. All trees with a circumference of less than 3.14 inches were ignored. This was because small saplings have a low rate of surviving to adulthood, especially when overshadowed by larger trees.

Additionally, the amount of carbon sequestered by small saplings is negligible compared to that sequestered by adult trees. The diameter of the crown was measured in both a south to north direction and in an east to west direction by having two researchers standing underneath opposite fringes of the crown with a tape measure between them. The total height of the tree, the height of the living portion of the tree, and the height of the bottom of the crown were all calculated using the distance of an observer from the tree and the angle at which an observer had to tilt his or her head upward in order to look at the measured portion of the tree. A clinometer was used to measure this angle.

The portion of the crown that was 'missing', as in the portion of the crown that was missing from an idealized convex shape, and the portion of the crown that was dead were both then qualitatively measured. Finally, all crowns were treated as having five



surfaces (four sides and one top) and the number of these surfaces which would receive sunlight at noon was recorded.

These measurements were taken because the amount of carbon sequestered in a year depends heavily on tree size, genera, health, and how its neighbors are inhibiting its growth.

Data from the 80 sampled field plots was entered into i-Tree Eco software, version 5, for analysis. All data collection was entered into an Excel spreadsheet in order to be used for later analysis. However, i-Tree would not allow direct uploading of spreadsheets into the software so data entry was time intensive. Once we entered in the data we were able to submit the i-Tree Eco file for analysis. After receiving the i-Tree reports we also submitted separate data for each site (Carolina North, Main Campus, and the Botanical Gardens) and received separate reports for each. The i-Tree Eco program analyzed the data and created detailed full reports, the results of these reports will be discussed in the following sections. It is important to keep in mind that with number of plots sampled that all analysis is subject to an error of 20 percent.

III. Tree Characteristics of the Urban Forest

UNC-Chapel Hill's forests have an estimated 748,000 trees. Trees that have diameters less than 6-inches (15.2 cm) constitute 56.4 percent of the population. The three most common species are Red maple (20.0 percent), Sourwood (11.2 percent), and American Beech (9.5 percent).

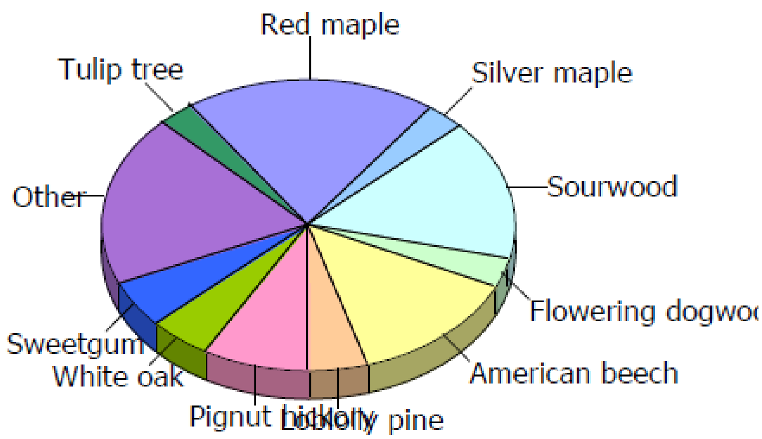


Figure 1. Tree species composition in UNC-Chapel Hill

The overall tree density based on our analysis for UNC-Chapel Hill's Main Campus, Carolina North, and Botanical Garden sites is 922 trees per hectare. The highest tree densities at UNC-Chapel Hill occur in the Botanical Gardens with 1285 trees per hectare followed by Carolina North with 935 trees per hectare. As expected, Main Campus had the fewest trees per hectare with less than 400.

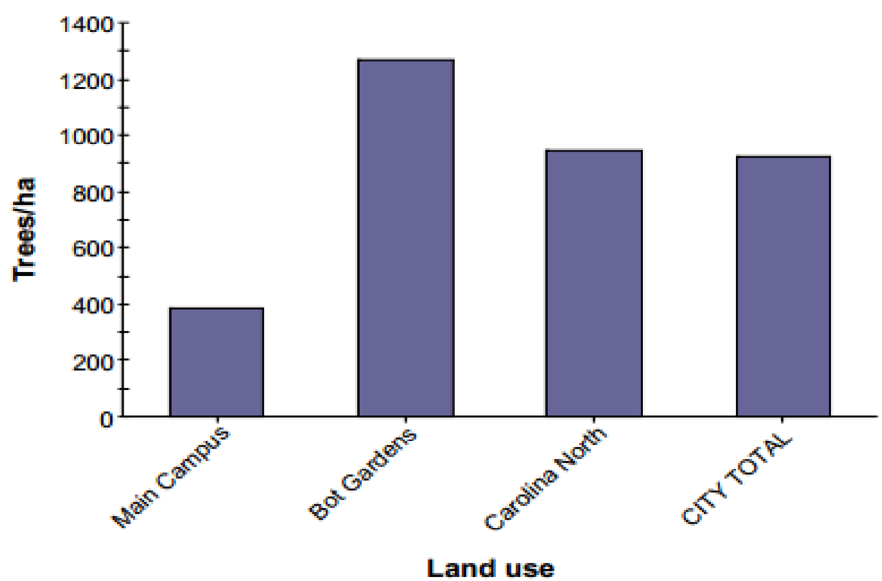


Figure 2. Number of trees/ha in UNC-Chapel Hill by land use

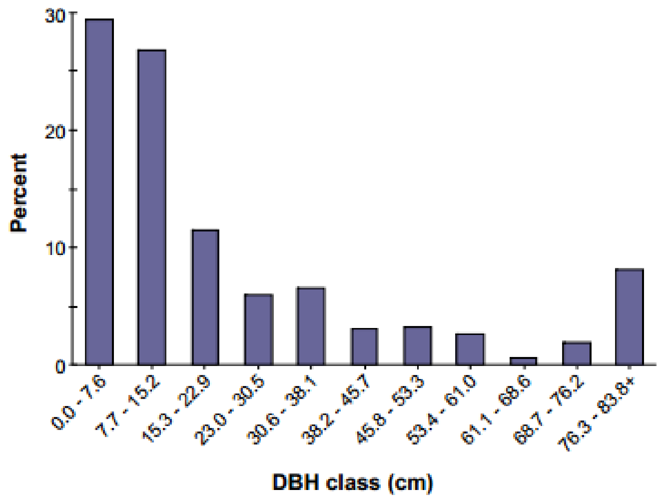


Figure 3. Percent of tree population by diameter class (DBH=stem diameter at 1.37 meter)

Urban forests are composed of a mix of native and exotic tree species. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. Increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but it can also pose a risk to native plants if some of the exotic species are invasive plants that can potentially out-compete and displace native species. In UNC-Chapel Hill's forests, about 95 percent of the trees are species native to North America, while 92 percent are native to the state. Species exotic to North America make up 5 percent of the population. Most of the exotic tree species have an origin from Australia (1.5 percent of the species). It is important to note that most of the exotic species are found on main campus based on the individual i-Tree reports.

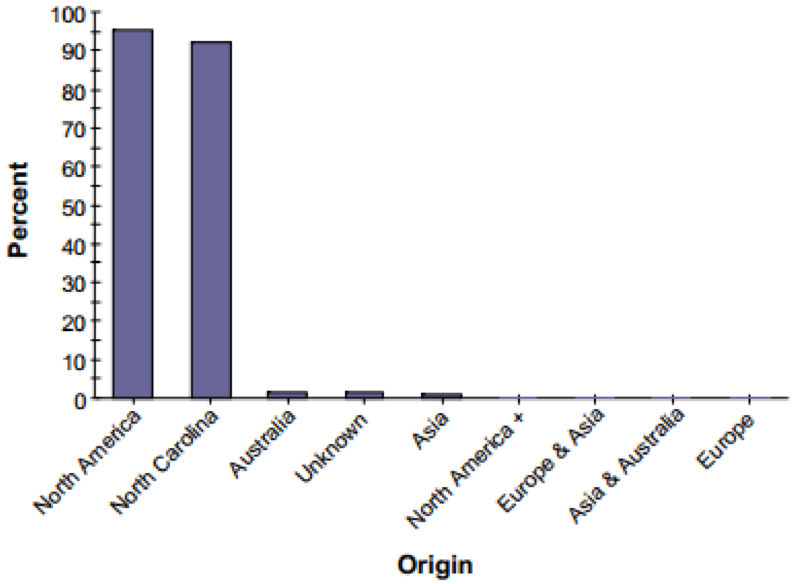


Figure 4. Percent of live trees by species origin

IV. Urban Forest Cover and Leaf Area

Many tree benefits equate directly to the amount of healthy leaf surface area of the plant. In UNC-Chapel Hill's forests, the three most dominant species in terms of leaf area are American beech, Red maple, and White oak.

The 10 most important species are listed in Table 1. Importance values (IV) are calculated as the sum of relative leaf area and relative composition.

Table 1. Most important species in UNC-Chapel Hill

Species Name	*Percent Population*	*Percent Leaf Area*	*IV*
Red maple	20.0	15.5	35.5
American beech	9.2	18.2	27.3
Loblolly pine	8.7	8.0	16.7
Sourwood	11.2	5.2	16.4
White oak	4.0	12.3	16.4
Sweetgum	9.5	3.3	12.8
Pignut hickory	6.4	4.7	11.1
Winged elm	4.2	4.1	8.2
Tulip tree	2.9	4.9	7.9
Flowering dogwood	3.2	2.0	5.2

The two most dominant ground cover types are Bare Soil (59.3 percent) and Duff/mulch (29.8 percent). All of the cement and building ground covers were located on main campus.

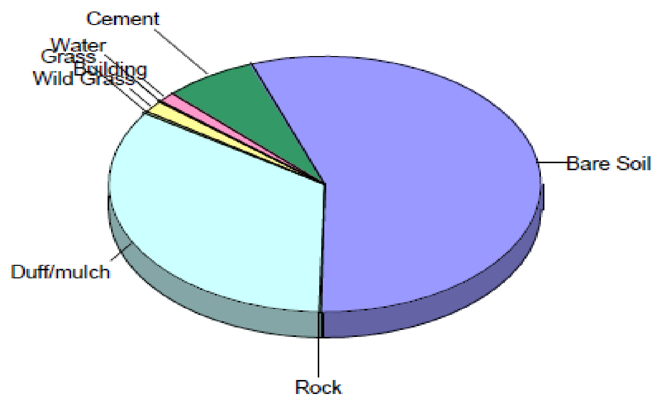


Figure 5. Percent ground cover in UNC-Chapel Hill

V. Air Pollution Removal

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from power plants. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation (Nowak, 2000).

Pollution removal by trees and shrubs in UNC-CH was estimated using field data and recent weather data. Weather data was obtained from weather station 723060-13722 located in Raleigh, NC. Pollution removal was greatest for ozone. It is estimated that trees and shrubs remove 67 metric tons of air pollution (ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 10 microns (PM10), particulate matter less than 2.5 microns (PM2.5), and sulfur dioxide (SO2)) per year with associated economic and health benefits.

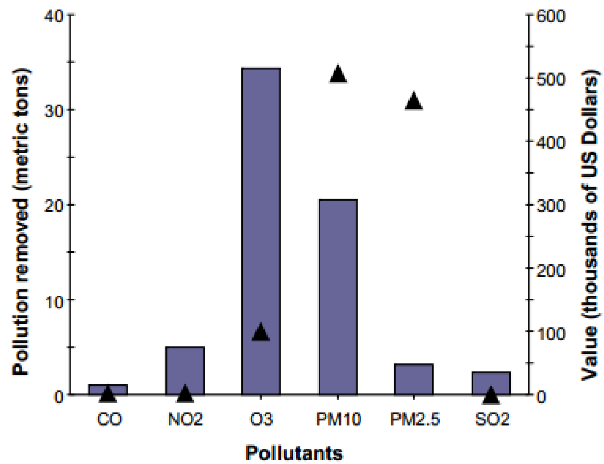


Figure 6. Pollution removal (bars) and associated value (points) for trees in UNC-Chapel Hill
Pollution removal and value for PM10 excludes PM2.5 removal and value

VI. Carbon Storage and Sequestration

Climate change is a phenomenon of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power plants (Abdollahi,2000).

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of UNC-Chapel Hill's trees is about 7,330 metric tons of carbon per year. Net carbon sequestration (the amount of carbon sequestered minus the amount lost to tree death or decay) in the urban forest is about 6,120 metric tons.

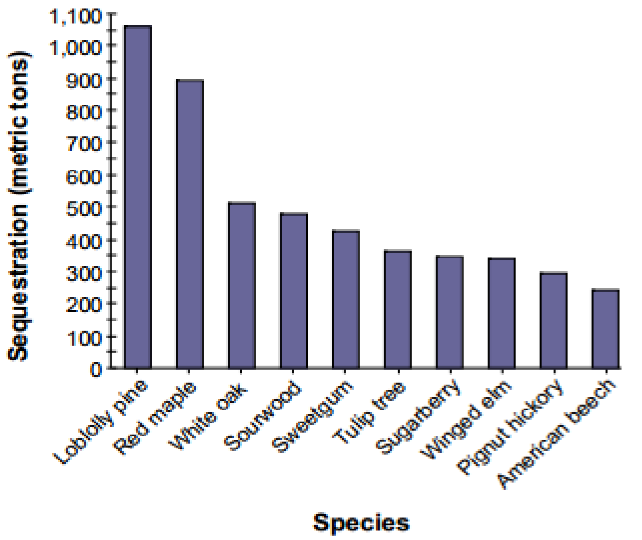


Figure 7. Carbon sequestration and value for species with greatest overall carbon sequestration in UNC-Chapel Hill

As trees grow they store more carbon as wood, and as they die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in UNC-Chapel Hill's forests are estimated to store 216,000 metric tons of carbon. Of the species sampled, Loblolly pine stores and sequesters the most carbon (approximately 30.7% of the total carbon stored and 17.3% of all sequestered carbon.)

VII. Oxygen Production

Oxygen production is one of the most commonly cited benefits of urban trees. The net annual oxygen production of a tree is directly related to the amount of carbon sequestered by the tree, which is tied to the accumulation of tree biomass.

Trees in UNC-Chapel Hill's forests are estimated to produce 16,300 metric tons of oxygen per year. However, this tree benefit is relatively insignificant because of the large and relatively stable amount of oxygen in the atmosphere and extensive production by aquatic systems. Our atmosphere has an enormous reserve of oxygen. If all fossil fuel reserves, all trees, and all organic matter in soils were burned, atmospheric oxygen would only drop a few percent (Broecker, 1970).

Table 2. The top 20 oxygen production species.

Species	*Oxygen (metric tons)*	*Net Carbon Sequestration (metric tons/yr)*	*Number of trees*	Leaf Area (square kilometers)
Loblolly pine	2,827.73	1,060.40	65,190.00	4.78
Red maple	2,380.08	892.53	149,826.00	9.21
White oak	1,360.43	510.16	30,256.00	7.34
Sourwood	1,273.47	477.55	84,165.00	3.10
Sweetgum	1,140.19	427.57	70,718.00	1.98
Tulip tree	971.55	364.33	21,758.00	2.95
Sugarberry	917.28	343.98	7,813.00	1.37
Winged elm	905.09	339.41	31,250.00	2.41
Pignut hickory	790.45	296.42	47,696.00	2.81
American beech	642.32	240.87	68,544.00	10.83
Mockernut hickory	407.71	152.89	1,819.00	0.06
Black walnut	310.13	116.30	1,563.00	0.19
Flowering dogwood	255.60	95.85	24,155.00	1.18
Southern red oak	241.97	90.74	10,163.00	1.74
Slippery elm	211.39	79.27	10,812.00	1.79
Black oak	192.08	72.03	4,664.00	0.27
Black birch	187.31	70.24	1,563.00	0.02
Shortleaf pine	172.48	64.68	11,404.00	1.24
Willow oak	147.57	55.34	4,296.00	0.39
Silver maple	145.57	54.59	15,117.00	1.25

VIII. Structural and Functional Values

Urban forests have a structural value based on the trees themselves (e.g., the cost of having to replace a tree with a similar tree). The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees (Nowak, 2002). Structural values are determined using tree evaluating methods of the Council of Tree and Landscape Appraisers and field data from eight US cities.

<u>Structural values:</u>

• Structural value: $893 million

• Carbon storage: $16.9 million

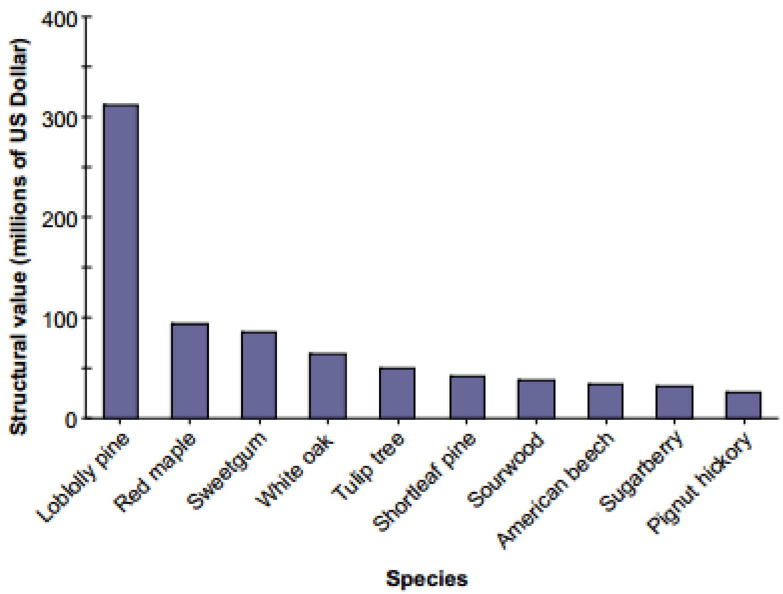


Figure 8. Structural value of the 10 most valuable tree species in UNC-Chapel Hill

III. Discussion

The purpose of this project was to fill in the lack of information UNC had on the carbon sequestration and storage of the forests throughout campus. We expected to fill this gap of knowledge by collecting data at our three sites and using i-Tree Eco to analyze the data we collected. Some initial expectations we had were that Carolina North and the Botanical Gardens would have higher carbon sequestration and carbon storage compared to Main Campus due to their heavily forested land.

This study should be expanded to take temporal variations into account in future studies. The amount of carbon annually sequestered by the forested lands of UNC can be assumed to be constant for the present, but this value may change temporally based on construction at Main Campus and the Carolina North Forest, and changes in overall forest health. Therefore, we recommend that this study be conducted approximately every five years in order to examine the change in carbon sequestration over time. If this study were to extend for a long enough period of time, a model could even be built to account for change in carbon sequestration as a function of yearly climate variables and land use change.

Additionally, in the future the main campus area should be analyzed separately from Carolina North and the Botanical Gardens. These areas represent very different forest compositions, the Main Campus being mainly urban forest while the other two areas are natural forest. Therefore, having an average of two vastly different sequestration rates is less informative than distinguishing between the land use patterns of Carolina's forests. Furthermore, this will allow for us to use the part of the i-Tree program which accounts for tree effects on buildings. Currently, we do not account for tree impacts on the energy use of campus buildings, which has been shown to have a large impact on carbon sequestration rates in past i-Tree analysis of other sites. However, if each of the three sites is analyzed separately, then more plots will be needed per site in order to reach an acceptable margin of error.

In addition to using i-Tree to account for tree effects on building energy use, future studies should use i-Tree to account for changes in watershed hydrology and stream flow as a function of forested lands. While not directly related to the carbon sequestration rate, this information can be utilized by ongoing studies attempting to manage storm water runoff.

We did not survey the section of Carolina North which is available for construction. In the future, we recommend a study to find the carbon sequestration rate of the land which will be built upon. This will allow for the University to account for the amount of carbon sequestration and storage which will be lost upon deforestation.

Logistically, more effort should be taken by future studies to ensure that all equipment is standardized. Small errors may have propagated throughout this study because the study because data was taken using different equipment at each location. In addition, 3-d coordinates should be utilized in choosing plots. Conversions from 2-D coordinate points to 3-D GPS’s may have caused error in finding sampling location. More accurate GPS technology should be utilized as well, to minimize the amount of estimation that researchers have to make when finding sampling plots. This will eliminate any sampling bias on from researchers when choosing plot center points.

Appendix I: i-Tree Eco Model and Field Measurements

i-Tree Eco is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects (Nowak, 2000), including:

- Urban forest structure (e.g., species composition, tree health, leaf area, etc.).
- Amount of pollution removed hourly by the urban forest, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<2.5 microns and <10 microns).
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants.
- Structural value of the forest, as well as the value for air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by pests, such as Asian longhorned beetle, emerald ash borer, gypsy moth, and Dutch elm disease.

To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations (Nowak, 1994). To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1.

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O_2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition (Nowak, 2007).

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi, 1987; Baldocchi, 1988). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell, 1972 and Lovett, 1994) that were adjusted depending on leaf phenology and leaf area. Removal estimates of particulate matter less than 10 microns incorporated a 50 percent re-suspension rate of particles back to the atmosphere (Zinke, 1967). Recent updates (2011) to air quality modeling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values (Hirabayashi, 2011).

Air pollution removal value was calculated based on local incidence of adverse health effects and national median externality costs. The number of adverse health effects and associated economic value is calculated for ozone, sulfur dioxide, nitrogen dioxide, and particulate matter <2.5 microns using the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP). The model uses a damage function approach that is based on the local change in pollution concentration and population (Davidson, 2007).

National median externality costs were used to calculate the value of carbon monoxide removal. As particulate matter <10 microns is inclusive of particulate matter <2.5 microns, the pollution removal value for particulate matter <10 microns utilizes both local incidence values from particulate matter <2.5 microns and national median externality costs from particulate matter <10 microns to estimate the air pollution removal values. Thus the value for particulate matter <10 microns = ((PM10 (mt/yr)-PM2.5 (mt/yr))*median externality)+PM2.5 ($/yr).

Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition, and location information (Nowak, 2002).

Appendix II: Relative Tree Effects

The urban forest in UNC-Chapel Hill provides benefits that include carbon storage and sequestration, and air pollutant removal. To estimate the relative value of these benefits, tree benefits were compared to estimates of average municipal carbon emissions (EIA, 2003), average passenger automobile emissions (Graham, 1992), and average household emissions (Houck, 1998).

<u>Carbon storage is equivalent to:</u>

- Amount of carbon emitted in UNC-Chapel Hill in 247 days
- Annual carbon (C) emissions from 143,000 automobiles
- Annual C emissions from 71,700 single-family houses

<u>Carbon monoxide removal is equivalent to:</u>

- Annual carbon monoxide emissions from 4 automobiles
- Annual carbon monoxide emissions from 19 single-family houses

<u>Nitrogen dioxide removal is equivalent to:</u>

- Annual nitrogen dioxide emissions from 352 automobiles
- Annual nitrogen dioxide emissions from 235 single-family houses

<u>Sulfur dioxide removal is equivalent to:</u>

- Annual sulfur dioxide emissions from 3,830 automobiles
- Annual sulfur dioxide emissions from 64 single-family houses

<u>Particulate matter less than 10 micron (PM10) removal is equivalent to:</u>

- Annual PM10 emissions from 69,700 automobiles
- Annual PM10 emissions from 6,720 single-family houses

<u>Annual carbon sequestration is equivalent to:</u>

- Amount of carbon emitted in UNC-Chapel Hill in 8.4 days
- Annual C emissions from 4,800 automobiles
- Annual C emissions from 2,400 single-family houses

Note: estimates above are partially based on the user-supplied information on human population total for study area.

Appendix III: General Recommendations for Air Quality Improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmosphere environment. Four main ways that urban trees affect air quality are (Nowak, 1995):

- Temperature reduction and other microclimate effects
- Removal of air pollutants
- Emission of volatile organic compounds (VOC) and tree maintenance emissions
- Energy effects on buildings

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the impact of trees on air pollution.

Cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC emitting species, leads to reduced ozone concentrations in cities (Nowak, 2007). Local urban management decisions also can help improve air quality. The table below has some recommendations from the USDA Forest Service.

Strategy	***Result***
Increase the number of healthy trees	Increase pollution removal
Sustain existing tree cover	Maintain pollution removal levels
Maximize use of low VOC-emitting trees	Reduces ozone and carbon monoxide formation
Sustain large, healthy trees	Large trees have greatest per-tree effects
Use long-lived trees	Reduce long-term pollutant emissions from planting and removal
Use low maintenance trees	Reduce pollutants emissions from maintenance activities
Reduce fossil fuel use in maintaining vegetation	Reduce pollutant emissions
Plant trees in energy conserving locations	Reduce pollutant emissions from power plants
Plant trees to shade parked cars	Reduce vehicular VOC emissions
Supply ample water to vegetation	Enhance pollution removal and temperature reduction
Plant trees in polluted or heavily populated areas	Maximizes tree air quality benefits
Avoid pollutant-sensitive species	Improve tree health
Utilize evergreen trees for particulate matter	Year-round removal of particles

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