ABSTRACT

THE EVALUATION OF CARBON BENEFITS PRODUCED BY URBAN STREET TREES

by
Hanyu Wang

Urban tree service and urban forestry are important fields that focus on the care and management of trees in urban areas. Urban trees provide numerous benefits around all aspect, including carbon storage, improving air and water qualities. Carbon storage refers to the process of removing carbon dioxide (CO2) from the atmosphere and storing it in various reservoirs, and in this case, in trees and forests.

i-Tree is a suite of software tools developed by the United States Forest Service that provides a range of resources for assessing and managing forests. i-Tree Eco is one of the more used tools from iTree suite. It is mainly used for assessing the structure and function of urban forests. In this project, i-Tree Eco is used to process data samples collected from the campus of New Jersey Institute of Technology (NJIT). iTree-Eco provides estimated calculations on multiple aspects. The evaluation will be more focused on the carbon sequestration and carbon storage of each species.

The overall objective of this thesis is to evaluate the current and potential carbon benefits produced by the trees of the NJIT campus, as a model of a typical urban campus. There are two sub objectives. One is to analyze the i-Tree package with provided documentation, trying to replicate some of the outputs using new written functions. Second is to analyze the reports generated by i-Tree Eco to making environmental plans.

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by
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A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Biological Sciences

Department of Biological Science

May 2023

APPROVAL PAGE

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DEDICATION

I dedicate this thesis to my parents, who have been supportive all my life. I would never have made this far if it wasn’t for them.

I also dedicate this work to all the people who have helped me over the years; professors, colleagues, friends, and even those cute animals on campus.

Thank you all for your love and support.

ACKNOWLEDGMENT

To start with, I would like to express my deepest gratitude to my thesis advisor, Dr. Gareth Russell, who's been extremely supportive through the years.

Also, I would like to thank the committee members Dr. Daniel Bunker, and Dr. Xiaonan Tai. Dr. Bunker also leads our Urban Ecology Lab group; he's helped me a lot through the year. Dr. Tai also have taught me in the GIS course, and I'm certain that the skills I acquired from the class will come in handy in my future career.

I would also like to thank all the other members in the Urban Ecology Lab: Dr, Maria Stanko, Dr. Caroline DeVan, and the other student members who have been in any sorts of help to me and to the UEL group.

Last but never the least, I will forever thank my parents for being supportive all my life.

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CHAPTER 1

INTRODUCTION

1.1 Urban Forestry

Urban tree service and urban forestry are important fields that focus on the care and management of trees in urban areas. With increasing urbanization around the world, the importance of preserving and enhancing the green infrastructure in cities has become more prominent. Urban trees provide numerous benefits to the environment, including improving air and water quality, reducing the urban heat island effect, mitigating the impacts of climate change, and supporting biodiversity (Goddard et al., 2010; McPherson et al., 2013).

Urban tree service involves the maintenance and care of trees in urban areas, such as pruning, planting, and removal. This service is typically provided by certified arborists who have specialized training and experience in the care and maintenance of trees (ISA, 2021). The main aim of urban tree service is to protect urban trees at first while also enhancing their economic value and the benefits they produce to the environment and human society.

Urban forestry is a broader field that encompasses the management of urban trees and forests as a whole. This includes not only the care and maintenance of individual trees, but also the planning and implementation of urban forest programs and policies.

Urban forestry aims to create sustainable, healthy, and resilient urban forests that can provide long-term benefits to the community, the environment, and the economy (Nowak and Greenfield, 2018).

Overall, urban tree service and urban forestry play a crucial role in maintaining and enhancing the urban environment. Through careful planning, management, and care of urban trees and forests, we can create more livable and sustainable cities that benefit both people and the planet.

1.2 Carbon Storage

Carbon storage refers to the process of removing carbon dioxide (CO_2) from the atmosphere and storing it in various reservoirs, such as forests, oceans, soil, and rocks. Trees are one of the most effective natural systems for carbon storage, as they absorb CO_2 during photosynthesis and store it in their biomass and in the soil.

A mature tree can store a significant amount of carbon, with estimates varying depending on the species and other factors. On average, a mature tree can store between 100 and 1000 kilograms of carbon (IPCC, 2019). Trees also provide a range of other benefits, such as regulating water cycles, providing habitat for wildlife, and supporting human well-being (FAO, 2020).

The overall contribution of trees to global carbon sequestration is significant, but difficult to estimate precisely. According to the Intergovernmental Panel on Climate

Change (IPCC), forests and other vegetation currently absorb about 30% of anthropogenic CO_2 emissions (IPCC, 2019). This makes them one of the largest carbon sinks on Earth, along with the ocean and soil.

However, the contribution of trees to global carbon sequestration is also threatened by deforestation and other land-use changes. Deforestation has been estimated to contribute between 10-15% of total greenhouse gas emissions (IPCC, 2019). Conversely, reforestation and afforestation (planting trees in areas where there were no trees before) can help to sequester carbon and mitigate climate change. One study estimated that global reforestation could sequester up to 205 gigatons of carbon over the next century (Bastin et al., 2019).

In terms of urban trees, estimates suggest that about 8% of the world's tree cover is located in urban areas (Nowak et al., 2018). In the United States, urban trees comprise about 5% of the country's tree cover (Nowak et al., 2019). While urban trees may not sequester as much carbon as forests, they also provide a range of important ecosystem services, such as air pollution reduction, stormwater management, and urban heat island mitigation.

1.3 i-Tree

i-Tree is a suite of software tools developed by the United States Forest Service that provides a range of resources for assessing and managing forests.

One of the most widely used i-Tree modules is i-Tree Eco, which is a tool for assessing the structure and function of inventoried forests. i-Tree Eco uses field data to estimate the amount of carbon sequestered by trees, air pollution removal, and other ecosystem services (Nowak et al., 2008). It also addresses services unique to urban trees, such as reduction in the heat island effect and the savings in building cooling costs that come from the shade thrown by nearby trees.

i-Tree eco only *requires* two inputs: a tree's species identity and its diameter at breast height (dbh), although users can add optional additional information such as crown height, tree condition, or sun exposure. The outputs that are specifically used in this thesis are the composition and structure summary including leaf biomass, and the carbon benefits summary including carbon storage and sequestration and air pollution removal.

1.4 Objectives

The overall objective of this thesis is to evaluate the current and potential carbon benefits produced by the trees of the NJIT campus, as a model of a typical urban campus. A total of 254 trees were used for analysis, comprising almost all the trees within the perimeter of the main campus. Within this overall objective, there are two sub-objectives. One is to examine the i-Tree package by attempting to replicate some of its outputs using independent code based on the provided documentation, e.g., Understanding i-Tree:

2021 Summary of Programs and Methods (Nowak, 2021). The second objective is to use the reports generated by i-Tree Eco to quantify the carbon services provided by the current campus tree community, and to use these to make suggestions for campus management and planning going forward.

CHAPTER 2

UNPACKING THE I-TREE 'BLACK BOX'

2.1 i-Tree Suite

i-Tree is a suite of software tools developed by the United States Forest Service that provides a range of resources for assessing and managing forests. Urban forests are an important component of cities, providing a range of ecosystem services, including air pollution reduction, temperature moderation, and carbon storage (Nowak et al., 2010). However, urban forests face a range of challenges, including fragmentation, pollution, and climate change, which can impact their structure and function (McDonald et al., 2021). The i-Tree suite is designed to help urban forestry professionals and city planners to understand and manage urban forests more effectively.

One of the more commonly used modules among i-Tree suite is i-Tree Eco. It can be used to generate reports that provide information on the value of urban forests in terms of ecosystem services, which can be used to inform policy decisions and management plans.

i-Tree Eco can perform analysis based on either complete inventory or plot samples. The software combines user input of a tree inventory with built-in databases of tree species information, as well as local weather data and pollution levels, to estimate several anatomical and physiological properties of the trees themselves (such as total biomass, growth rate, etc.), and consequently the ecosystem services provided by those trees. These services are also converted to dollar values, which can be used to inform policy decisions and management plans.

i-Tree Eco can also be used to inform a range of management decisions related to urban forests by running ‘what if’ scenarios. For example, the tool can be used to estimate the carbon sequestration potential of alternative tree species or locations, which can be used to inform decisions about where to plant new trees or which trees to retain during development. It can also be used to estimate the impact of tree removal or pruning on ecosystem services.

2.2 The i-Tree Process

The first objective is to examine the i-Tree calculations by attempting to replicate its interior calculations using the information from the publication provided by i-Tree website, Understanding i-Tree: 2021 Summary of Programs and Methods (Nowak, 2021), and references therein. As this is the official reference, it ought to be possible. As i-Tree can perform its calculations using inputs of just species name and dbh, we start with that. Our starting goal was to replicate each stage of the calculations up to the final estimates of carbon storage and sequestration. (We did not try any of the economic conversions.)

Tree biomass is in direct relationship to carbon storage. In general, the more biomass a tree has, the more carbon it will store (wood dry biomass is approximately 50%

carbon, but see below). The i-Tree documentation mentions two biomasses being used for the calculation of carbon storage, tree biomass and leaf biomass.

Tree biomass means the total tree dry weight biomass. Dry weight biomass is a measure of the weight of organic matter in a tree after all water has been removed, and it is closely related to the amount of carbon stored in the tree. The amount of carbon stored in a tree can be estimated by multiplying the dry weight biomass of the tree by a carbon fraction, which is the proportion of carbon in the dry weight biomass. The carbon fraction varies depending on the tree species, but typically ranges from 0.45 to 0.5 (Nowak et al., 2010). The documentation provides allometric equations for the calculation of dry weight biomass for each of a number of species, based on its measured dbh (Appendix A).

Leaf biomass means the total weight of dry leaves. It is calculated from leaf area estimates using species-specific conversion factors (Appendix B). To get the leaf biomass, we just multiply the leaf are by the species-specific conversion constant. Before that, we do need to use other equations in order to get the leaf area first.

Leaf area is defined as the total surface area of leaves on a tree. Leaf area of individual open-grown (high crown light exposure), deciduous trees is calculated using a regression equation (Nowak, 2021):

$$\ln Y = -4.3309 + 0.2942H + 0.7312D + 5.7217S + -0.0148C$$

Where Y is leaf area (m^2),

H is crown height (m),

D is average crown diameter (m),

S is the average shading factor for the individual species, and

C is based on the outer surface area of the tree crown (π D (H + D) / 2).

Therefore, in order to calculate the leaf area (Y), we need to estimate the crown height (H), crown width (D), shading factor (S), and ground surface area (C), which is based on crown width (D). In this case, the shading factor (S) is based on the dbh and species shading coefficient, which is a species-specific constant (Appendix C).

$$S = 0.0617 \ln(dbh) + 0.615 + \text{species-specific shading coefficient}$$

As for the crown height (H) and the crown width (W), we either have to measure the data during sampling, or to use equations that estimate these values from the dbh. These equations are not provided in the documentation, so we requested a copy of the equation sheets that lists the all conversion between dbh and crown height or crown width from the i-Tree staff (Appendix D).

Table 2.1 Summary of which Directly Field-measured Characteristics are Used to Estimate Derived Variables and Ecosystem Services. (D = directly used; I = indirectly used; C = conditionally used.)

	DERIVED VARIABLES		ECOSYSTEM SERVICES										
DIRECT MEASURES	Leaf Area	Leaf Biomass	Carbon Storage	Gross Carbon Sequestration	Net Carbon Sequestration	Energy Effects	Air Pollution Removal	Avoided Runoff	Transpiration	VOC Emissions	Compensatory Value	Wildlife Suitability	UV Effects
Species	D	D	D	D	D	D	I	I	I	D	D		
Diameter at breast height (d.b.h.)			D	D	D						D	D	
Total height	D	D	C	C	C	D	I	I	I	I		D	
Crown base height	D	D	C				I	I	I	I			
Crown width	D	D	C				I	I	I	I			
Crown light exposure			C	D	D								
Percent crown missing	D	D	C	C	C	D	I	I	I	I			
Crown health (condition/ dieback)				D	D						D	D	
Field land use				D							D	D	
Distance to building						D							
Direction to building						D							
Percent tree cover						D	D	D				D	D
Percent shrub cover							D					D	
Percent building cover						D							
Ground cover composition							I					D	

Source: Nowak, D. J. (2021). Understanding i-Tree: 2021 Summary of Programs and Methods. [Brochure]. US Forest Service.

Once we manage to calculate the numbers like crown width and crown height, we can track back to this Table 2.2.1 provided by i-Tree. We can see that all the required measurements, either directly used or conditionally used, we can all manage to calculate based on only species name and dbh.

2.3 Results of Coding Replication

A series of functions were written to replicate the calculations behind i-Tree Eco based on the report published on the i-Tree website, Understanding i-Tree: 2021 Summary of Programs and Methods (Nowak, 2021). These functions were applied to hypothetical trees, such as “Red Maple, dbh 15cm”, and the results compared to the corresponding i-Tree output.

Following the instructions from the documentation, two sets of functions were written; one to calculate the tree biomass, the other to calculate the leaf biomass.

As discussed in the last section tree biomass means the total tree dry weight biomass. A series of allometric equations is provided by the documentation to calculate the dry weight biomass. The codes serve as a way to help find the suited equation in order to calculate the biomass using species name and dbh. In this case, we want to find the right equation in the tree biomass table (Appendix A).

```
dryBiomass[dbh_, species_] := Module[{biomassData, a, b, c, d, e, f, g},
  biomassData = findBestMatch[species, biomassEquationTable];
  (*Print[biomassData];*)
  If[biomassData === {Missing[]}, Missing[],
   Which[
    biomassData[[2]] === "Y=10(A+(B*log(x)))",
    {a, b} = biomassData[[{3, 4}]];
    10^(a + (b * Log[10, dbh])),
    biomassData[[2]] === "Y=10((A*log(x))-B)",
    {a, b} = biomassData[[{3, 4}]];
    10^((a * Log[10, dbh]) - b),
    biomassData[[2]] === "Y=10AxB",
    {a, b} = biomassData[[{3, 4}]];
    (10^a) * (dbh^b),
```

Figure 2.1 Partial codes on the calculation of tree biomass. (Full codes available if requested).

For example, Figure 2.1 shows a function which finds the best match for a species in the table, extracts the corresponding dry biomass scaling equation, and then applies it to the dbh input.

The biggest issue we faced was that the data table does not contain all the species in the US, or even all the species we have in our inventory. What is worse, other calculations reference different tables that have different collections of species. In order to partially fix this issue, we extended our lookup code to allow us to find the closest name choice when the exact species name is not in the species list. For example, in the tree biomass table, if we directly search for *Quercus palustris* (pin oak), there will be no match. With the updated codes it will automatically find the closest match, which is *Quercus spp.* in this case. When looking for the closest match, we follow the sequence of exact species, genus average, family average, and finally similar species in the same genus or family.

However, even this does not solve all the problems. Take the same tree biomass table for example. Even with the help of the filter to find similar species, there still are a number of species for which there isn't even a family match. This includes some of the common species on campus, such as *Ginkgo biloba*, *Pyrus calleryana* (Callery pear) and *Gleditsia triacanthos* (honey locust). Test of the functions therefore yields results like those below (Figure 2.2).

```
dryBiomass[25, "Acer rubrum"]

354.21

dryBiomass[25, "Ginkgo biloba"]

Missing[]

dryBiomass[25, "Fagus sylvatica"]

412.086
```

Figure 2.2 Test result of the functions to calculate the tree dry biomass. The two inputs are dbh in cm and the scientific name of the species. The output is total tree dry weight biomass in kg.

As we can see from Figure 2.2, the result for the search for "*Ginkgo biloba*" is "Missing[]". This means that we can't find the species of *Ginkgo biloba*, of the genus *Ginkgo, the family Ginkgoaceae*, or any other species in those taxa.

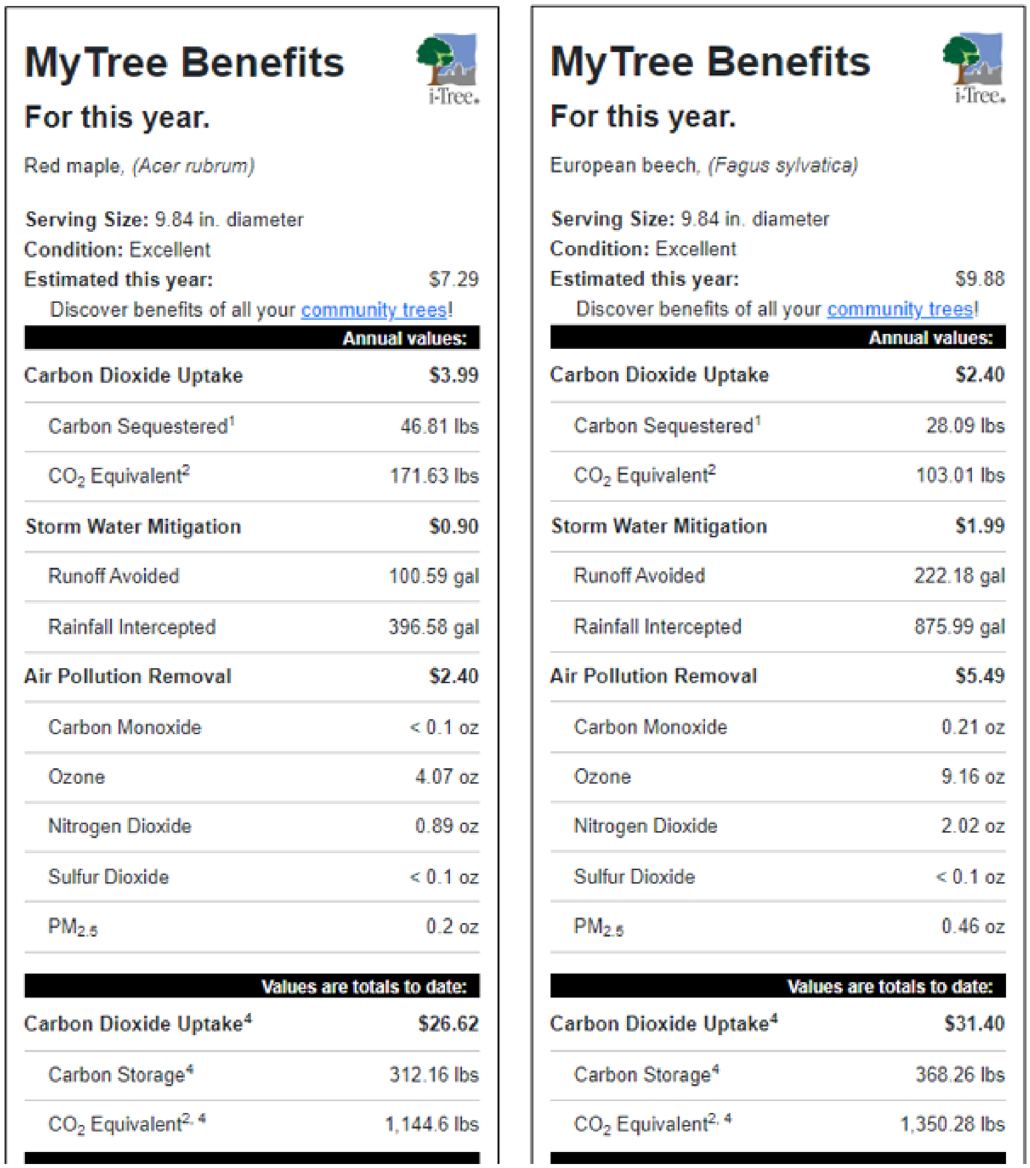
While the calculations for tree biomass is not available, we still have the report from i-Tree Eco to test. i-Tree Eco has its own calculation codes set within the system, some of which are detailed explained in the manuscript (Koeser et al., 2021). As a result, a written report along with detailed individual results were generated by the system. According to the report, with a provided species name and "DBH", i-Tree Eco managed to calculate the result of "Crown height", "Crown width", "Canopy cover", "Leaf area", "Leaf biomass" and other carbon benefits data.

In order to test the result from i-Tree Eco, two methods were taken to confirm the calculation.

In the first method, a sensitive test was taken with an extra input of the estimated "Total height" added to the data base. This way allows a comparison between the two sets of end results, one with the system calculated height, the other with the human estimated height. With the first method, a first difference is noticed between the estimated height and system calculated height. In most cases (out of the 254), the system calculated height is way higher than human estimated height, which at the same time also makes other categories higher. One potential explanation of this could be that the i-Tree calculation was initially built on forest data, while the samples in this project was more focused on urban trees.

In the second method, a similar set of code are written. Instead of trying to get the tree biomass, these codes are built to calculate the composition and structure summary such as crown height and width (Appendix D). With the second the method, a comparison is made between the written codes and the i-Tree built-in calculation. There still are quite a variance between the two outcomes with the i-Tree Eco estimates are higher than human function estimates. Therefore, there is not yet a conclusion to made regarding the code replication on i-Tree. The main reason behind this could be that i-Tree is not sharing all the calculation basics. This makes this i-Tree system still somewhat remain as a “black box”.

Back to the original tree biomass calculation (Figure 2.2), in order to test the results of the other two available outcomes, we also compare our calculated values to the ‘carbon’ outcomes from the i-Tree software after putting in the same species name and dbh (Figure 2.3).



	Red maple	European beech
Title	MyTree Benefits – For this year.	MyTree Benefits – For this year.
Species	Red maple, *(Acer rubrum)*	European beech, *(Fagus sylvatica)*
Serving Size:	9.84 in. diameter	9.84 in. diameter
Condition:	Excellent	Excellent
Estimated this year:	$7.29	$9.88
Discover benefits of all your community trees!		
Annual values:		
Carbon Dioxide Uptake	**$3.99**	**$2.40**
Carbon Sequestered[1]	46.81 lbs	28.09 lbs
CO_2 Equivalent[2]	171.63 lbs	103.01 lbs
Storm Water Mitigation	**$0.90**	**$1.99**
Runoff Avoided	100.59 gal	222.18 gal
Rainfall Intercepted	396.58 gal	875.99 gal
Air Pollution Removal	**$2.40**	**$5.49**
Carbon Monoxide	< 0.1 oz	0.21 oz
Ozone	4.07 oz	9.16 oz
Nitrogen Dioxide	0.89 oz	2.02 oz
Sulfur Dioxide	< 0.1 oz	< 0.1 oz
$PM_{2.5}$	0.2 oz	0.46 oz
Values are totals to date:		
Carbon Dioxide Uptake[4]	**$26.62**	**$31.40**
Carbon Storage[4]	312.16 lbs	368.26 lbs
CO_2 Equivalent[2, 4]	1,144.6 lbs	1,350.28 lbs

Figure 2.3 Test results from i-Tree software. The inputs are the same species name and dbh as the previous test.

For our two example inputs, i-Tree gives us the total carbon storage in lb: 312.16lb for the red maple and 368.26lb for the European beech (Figure 2.3). We convert our own tree biomass calculations into carbon storage to compare to the i-Tree outputs. The estimated tree biomass for red maple is 354.21kg; for European beech is 412.086kg.

We convert these two numbers into pounds and then multiply by the carbon fraction rate (the approximate conversion rates between tree biomass and carbon storage discussed earlier) of 0.5. This gives estimated carbon storages of 390.4lb for red maple, and 454.3lb for European beech.

As we can see from the two sets of result, the numbers from the written functions are relatively larger than the outcomes from the i-Tree software. We repeated these tests with various different species and dbh values. The results from our code generally follow the same trend as the results from i-Tree but are always larger.

There are several possible explanations for this outcome. One is that the i-Tree software has done more calculations behind the scenes, such as including the sun exposure (it does require a geographic location at first), or a non-zero crown damage value, and so on. Also, the carbon fraction rate may vary for different species (although it does not seem to vary enough to explain the discrepancies). Meanwhile, Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations (Nowak 1994). Therefore, there should be another factor that would show the difference between urban trees and street trees.

Unfortunately, we are not able to test these hypotheses because those additional calculations, if being performed, are not explained in the i-Tree documentation. Therefore, despite our best efforts, i-Tree remains in large part a “black box”.

CHAPTER 3

NJIT CAMPUS CARBON BENEFITS

Even though we were not able to precisely reproduce the i-Tree calculations, we proceeded to examine the i-Tree Eco reports based on our campus tree inventory. i-Tree is used by professionals all over the country, and we don't feel that we have sufficient evidence (yet) to invalidate it.

3.1 Campus Survey

In order to test the carbon services, along with the economic benefit, of NJIT's trees, a tree survey was performed within the campus area of NJIT. With the help of i-naturalist, the following data were collected for all the tree species within the area, "Scientific name", "Common name", "DBH" (diameter at breast height), and "Location" (latitude and longitude). Where possible "Total height" and "Crown height" were also estimated, sometimes using an inclinometer, and sometimes with dead reckoning. There are two reasons why "Total height" and "Crown height" were not measured precisely. One is because it's relatively harder to precisely measure the height than it is to measure the diameter of a tree. The second reason is because i-Tree can perform its own calculations to convert "DBH" into various height and other morphological measurements for a known tree species. Further comparison and analysis shall be discussed later on.

Altogether, 254 trees were censused within the campus of NJIT, comprising almost all the trees within the main campus boundary (Figure 3.1).

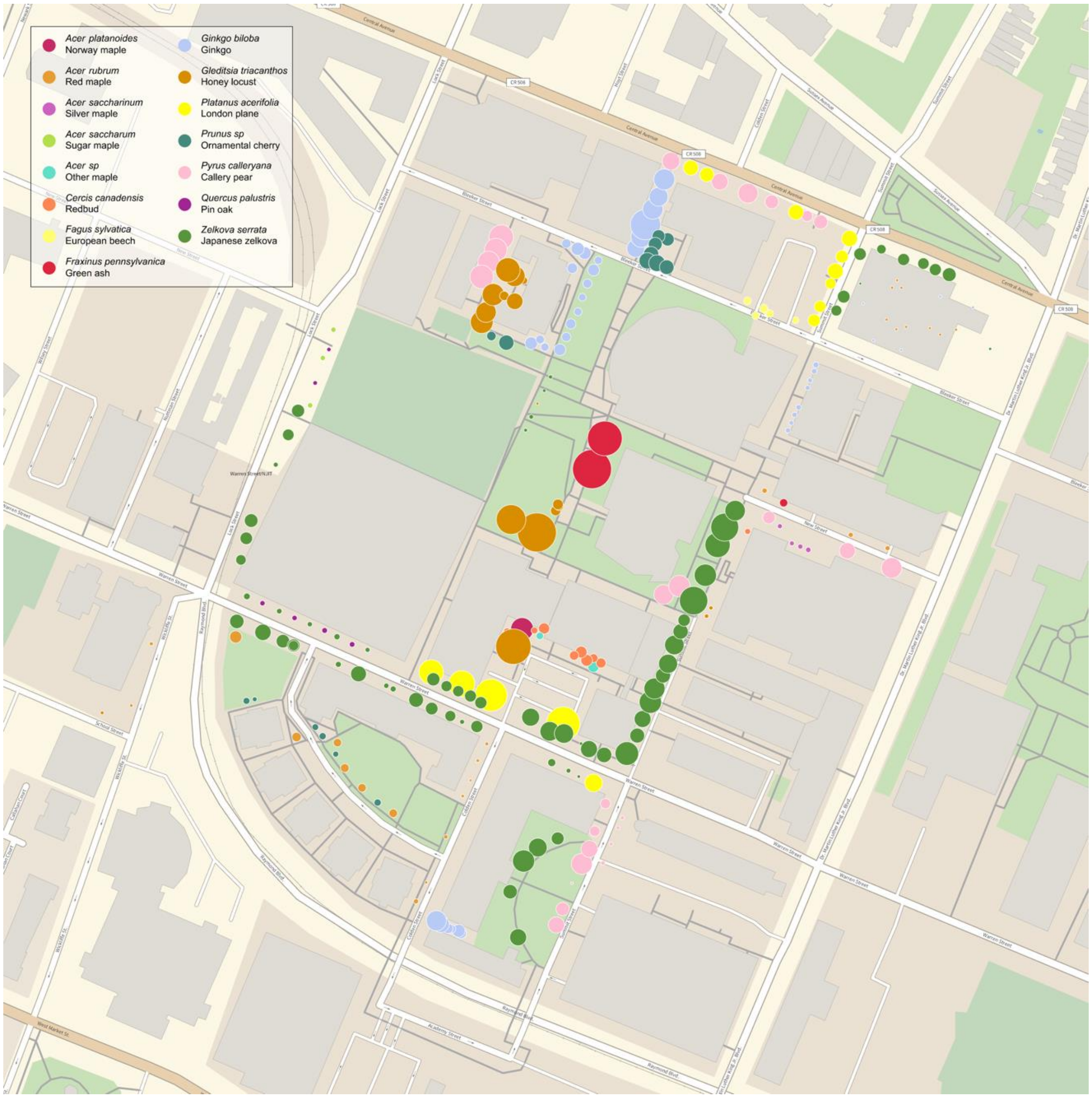


Figure 3.1 All trees included in these analyses, located on a street map of NJIT.

Within that census were thirteen distinct species, with two trees identified only as genus *Acer*, and all types of ornamental cherry recorded only as genus *Prunus*. The thirteen species were *Zelkova serrata* (Japanese zelkova), *Ginkgo biloba*, *Quercus palustris* (pin oak), *Pyrus calleryana* (Callery pear), *Platanus x hybrida* (London plane), *Gleditsia triacanthos* (honey locust), *Fraxinus pennsylvanica* (green ash), *Fagus sylvatica* (European beech), *Cercis canadensis* (eastern redbud), *Acer rubrum* (red maple), *Acer saccharum* (suger maple), *Acer saccharinum* (silver maple) and *Acer platanoides* (Norway maple). The abundance of species varied considerably, with the three most common species being Japanese zelkova (28.7 percent), ginkgo (15.7 percent), and red maple (10.6 percent)(Figure 3.2).

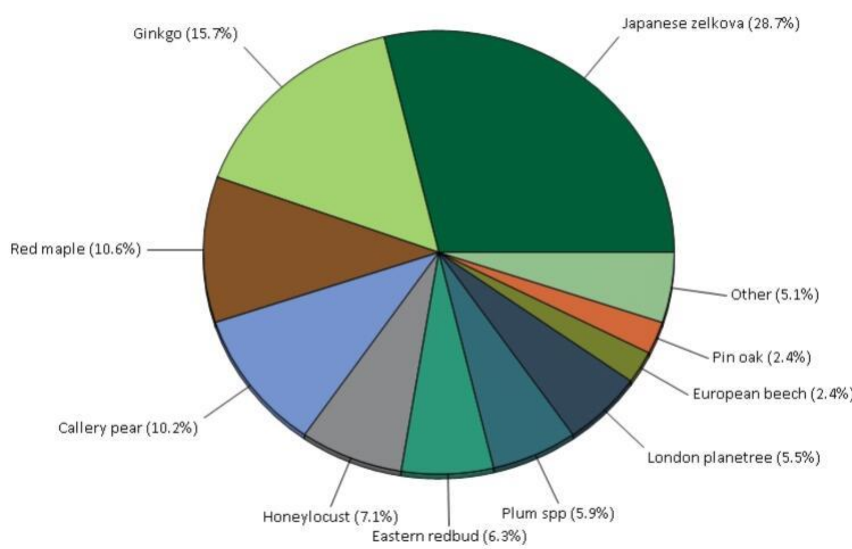


Figure 3.2 Tree species composition in NJIT.

Urban forests are typically composed of a mix of native and non-native tree species, and therefore have the potential for a tree diversity that is higher than surrounding native landscapes. Significant tree diversity can minimize the overall impact or destruction by a species-specific insect or disease. In practice though, trees used in urban settings, especially 'street trees,' are usually selected from a relatively small pool of candidates based on their tolerance for various stressors, and urban tree diversity can also be low. In addition, non-native species can pose a risk to native plants, and local ecosystems more generally, if they are capable of propagating into nearby green spaces. Non-native species are considered invasive if they can out-compete and displace native species. Invasive plant species are often characterized by their vigor, ability to adapt, reproductive capacity, and general lack of natural enemies.

In the NJIT tree inventory (Figure 3.3), about 30 percent of the trees are species native to North America, with 23 percent native specifically to New Jersey. Species non-native to North America make up 70 percent of the population. Most of the non-native tree species have an origin in Asia (55 percent of the species).

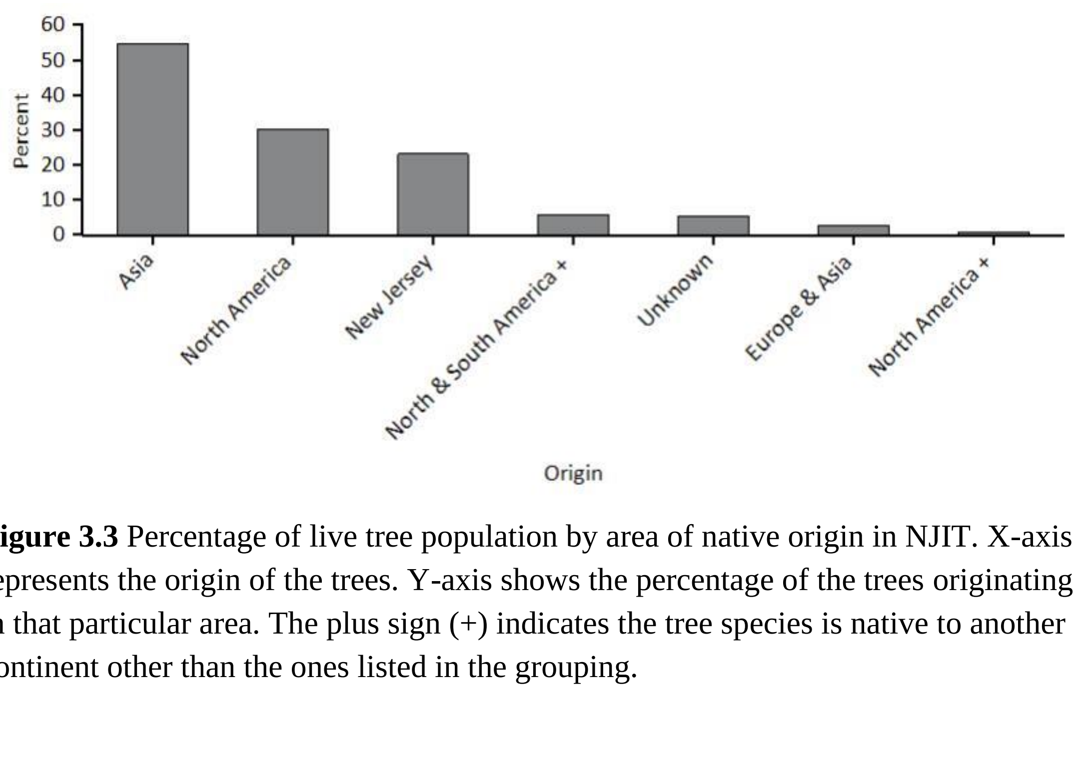


Figure 3.3 Percentage of live tree population by area of native origin in NJIT. X-axis represents the origin of the trees. Y-axis shows the percentage of the trees originating in that particular area. The plus sign (+) indicates the tree species is native to another continent other than the ones listed in the grouping.

Three of the species in NJIT, Japanese zelkova, Callery pear, and Norway maple, are identified as invasive species by the State of New Jersey (New Jersey Invasive Species Strike Team, 2022). In this case, Callery pear and Norway maple are considered more concerning as they are marked as “Widespread,”, while Japanese zelkova is only at “Stage 0”.

Based on the information from the New Jersey Invasive Species Strike Team, a pie figure is made to have a clearer view among native, non-native, and invasive species (Figure 3.4).

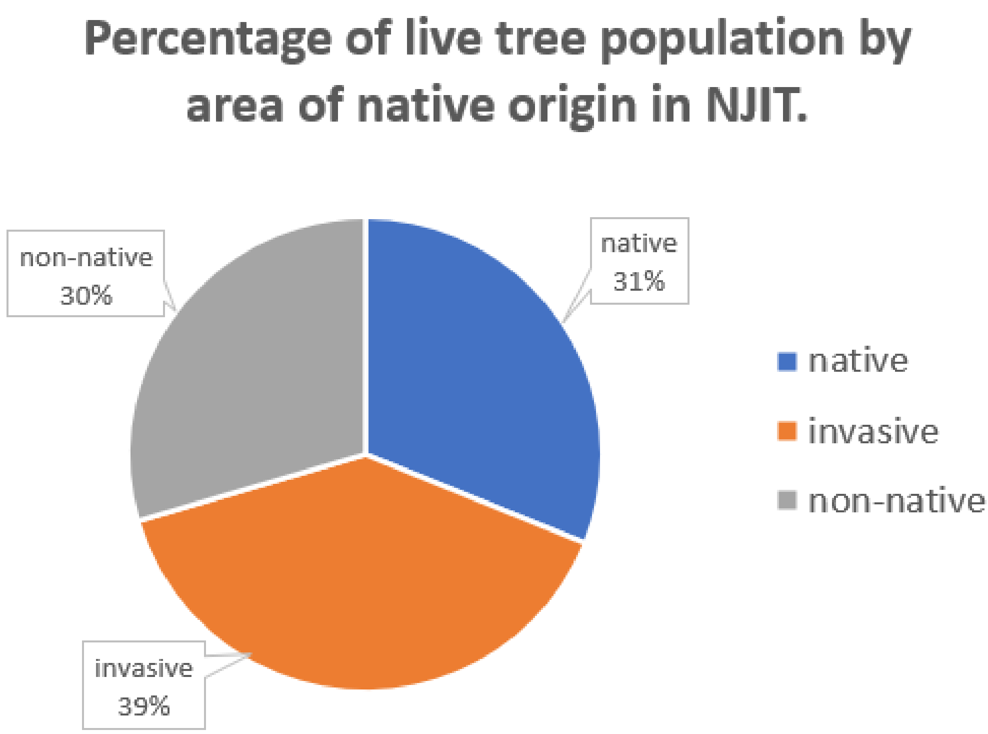


Figure 3.4 Pie graph of percentage of live tree population by area of native origin in NJIT.

3.2 Carbon Storage and Carbon Sequestration

As mentioned earlier, both carbon storage and carbon sequestration are closely tied to overall tree biomass (Figures 3.5 and 3.6). The largest trees store over 1000 times the carbon of the smallest trees, and sequester over 200 times more.

Figure 3.5 NJIT campus map of all species showing the carbon storage (lb) of all trees. The shade of the color shows the carbon storage. The size of the dot is in relation to the square root of the "DBH" of each tree.

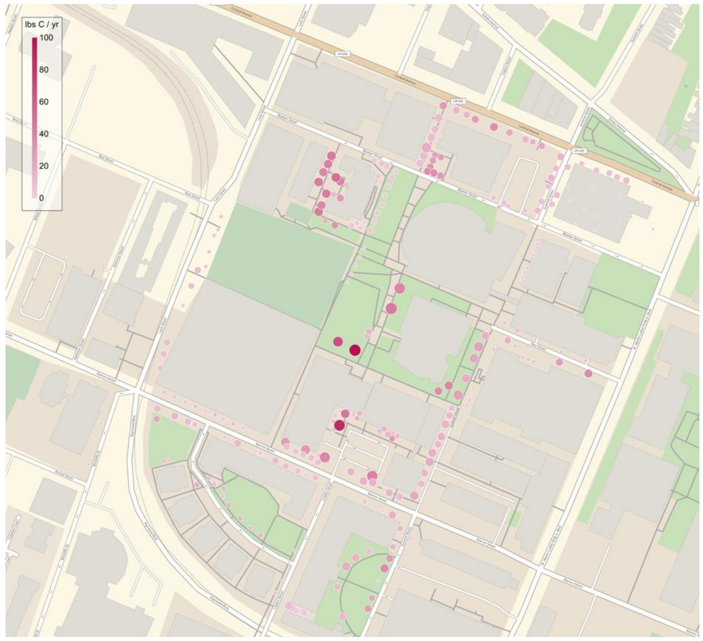


Figure 3.6 NJIT campus map of all species showing the carbon sequestration (lb/yr) of all trees. The shade of the color shows the carbon sequestration. The size of the dot is in relation to the square root of the "DBH" of each tree.

To further examine the difference in size dependence of carbon storage vs annual sequestration, and also look at species-specific differences, we plotted each carbon value against DBH raised to a power that would make the relationship linear. Across all species in this study, carbon storage scales with DBH raised to the power 2.5 (Figure 3.7), which is less than the power of 3 that would be expected if tree volume (and therefore wood biomass) scaled isometrically with DBH. By observation, smaller trees tend to be narrower and proportionally taller than mature trees, in which case they will contain more wood volume relative to the trunk cross-sectional area.

Carbon sequestration, however, scales with DBH raised only to the power 1.5 (Figure 3.8). This is presumably because carbon sequestration is a function of photosynthetic activity, best measured by total leaf area. Since leaf size doesn't change with tree age, total leaf area will be mainly a function of the number of leaves, and as leaves occur on towards the tips of branches, they will scale closer to canopy area than to total tree volume.

Some of the biggest trees on campus are honey locusts, and these also have relatively high carbon storage relative to their trunk diameter (Figure 3.7). Overall, differences in this rate reflect differences in tree shapes.

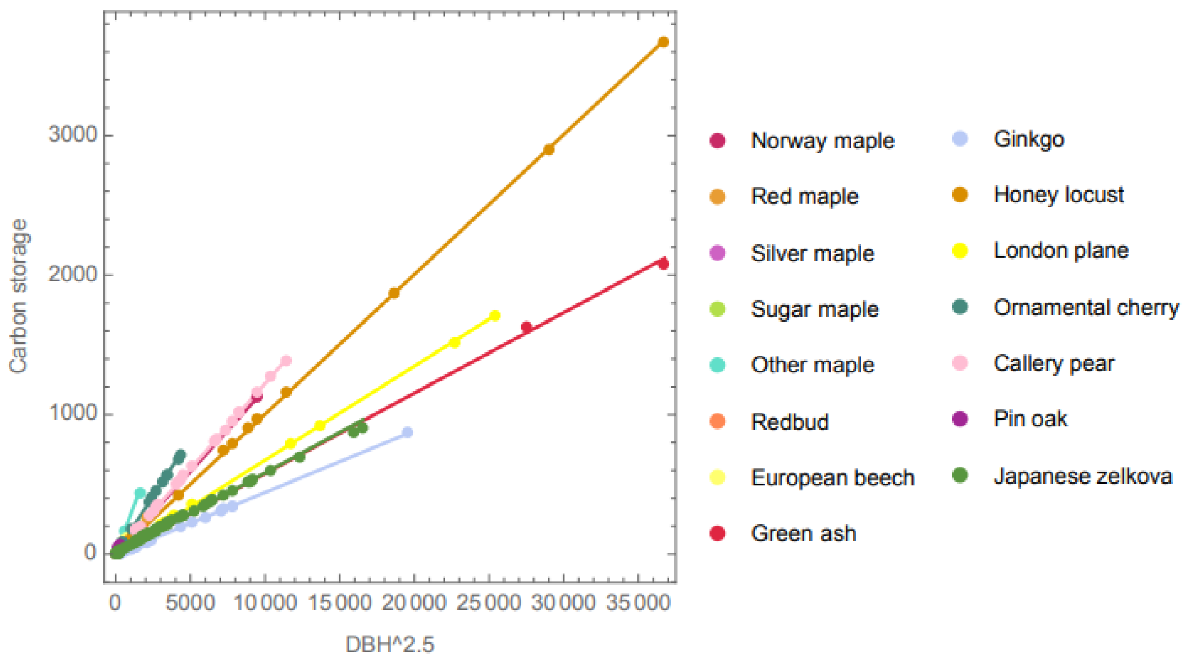


Figure 3.7 Carbon storage for different species versus different "dbh^2.5". Different species are marked with different color.

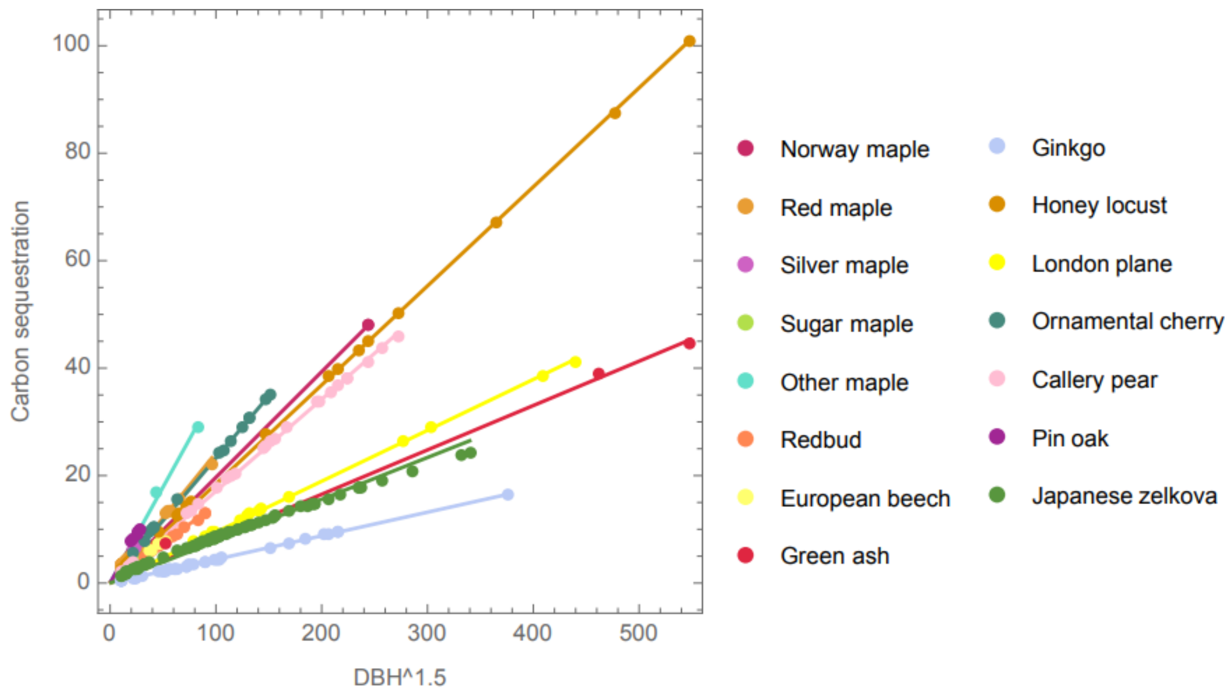


Figure 3.8 Carbon sequestration for different species versus different "dbh^1.5". Different species are marked with different color.

The same is broadly true for annual carbon sequestration (Figure 3.8). Much more interesting would be to plot the carbon values against tree age, as this would reveal expected rates of carbon capture as a function of time. We can do this by applying species-specific growth rate factors gleaned from the literature to convert dbh to age (Figures 3.9 and 3.10).

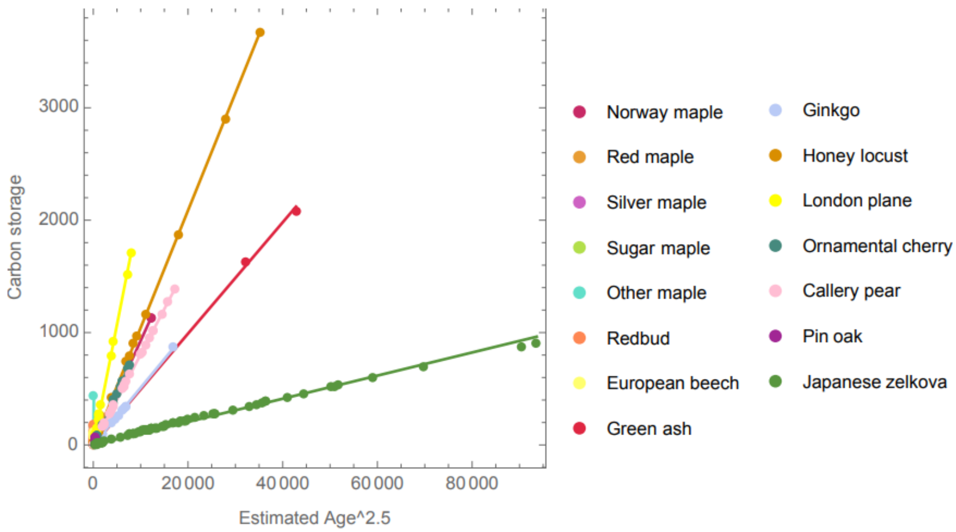


Figure 3.9 Carbon storage for different species versus different “age^2.5”. Different species are marked with different color. Ages were estimated based on measured dbh.

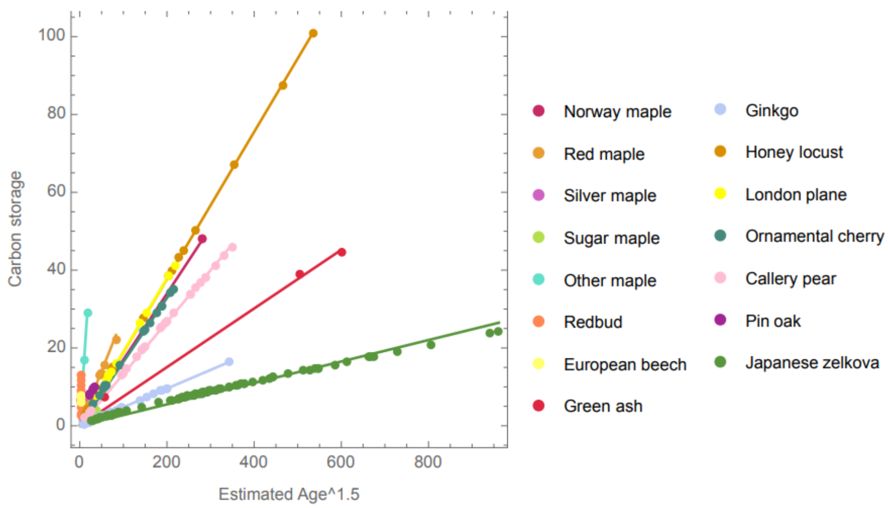


Figure 3.10 Carbon sequestration for different species versus different “age^1.5”. Different species are marked with different color. Ages were estimated based on measured dbh.

Non-native Japanese zelkova seems to have by far the lowest rate rates of overall carbon storage and annual sequestration, with similarly non-native Ginkgo also low in sequestration. Other non-native species such as Callery pear and Norway maple, as well as various native species (e.g., honey locust, red maple and redbud) have much higher rates. One thing worth noting, however, is that the growth rate conversion factors that estimate age from dbh are extremely coarse, with different sources often providing quite different factors. Thus these ‘species rankings’ should be regarded a tentative.

3.3 Carbon Benefits in Invasive Species

Analysis of the tree on the NJIT campus shows that our ‘urban forest’ consists of a mix of both native and non-native tree species. While this arguably increases tree diversity, it might also pose a risk to native plants if non-native species are invasive and out-compete native species. Invasive species sometimes can cause significant harm to the environment, economy, or human health. However, from the carbon storage perspective, there isn’t a clear distinction between native and non-native species (Figure 3.11 and 3.12). Especially when we put the other two invasive species, Norway maple and Callery pear, into consideration, these two species fall right among the rest native species. Therefore, this low carbon benefits of Japanese zelkova are more likely to be an outlier. Even if it is indeed is producing less, it is unlikely due to it being non-native species.

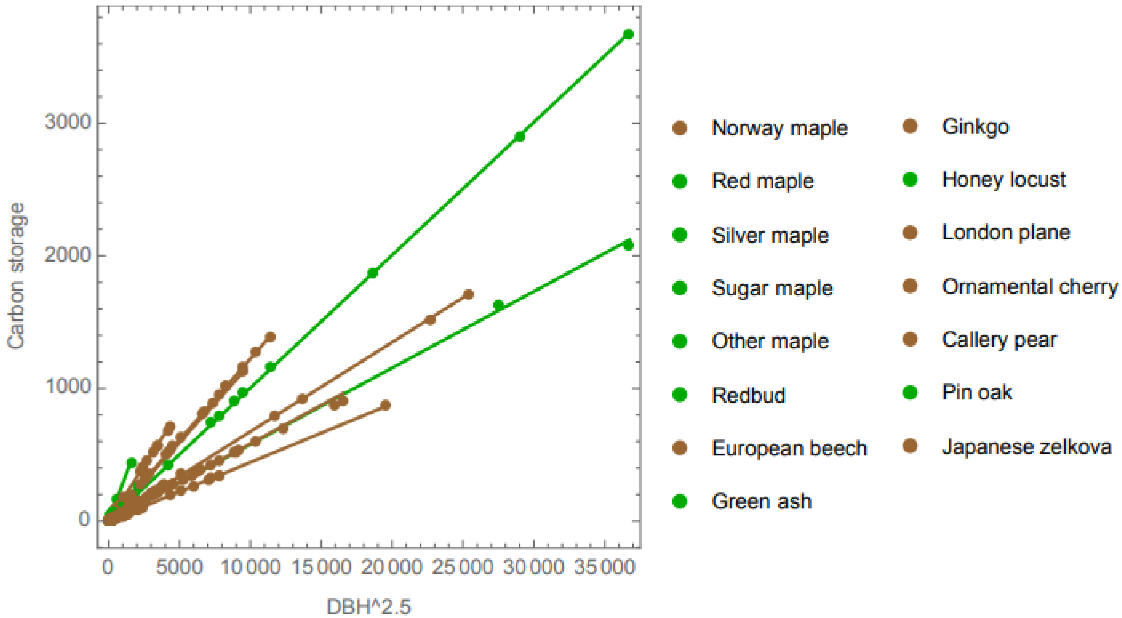


Figure 3.11 Carbon storage for different species in terms of native and non-native. Green represents native species. Brown represents non-native species.

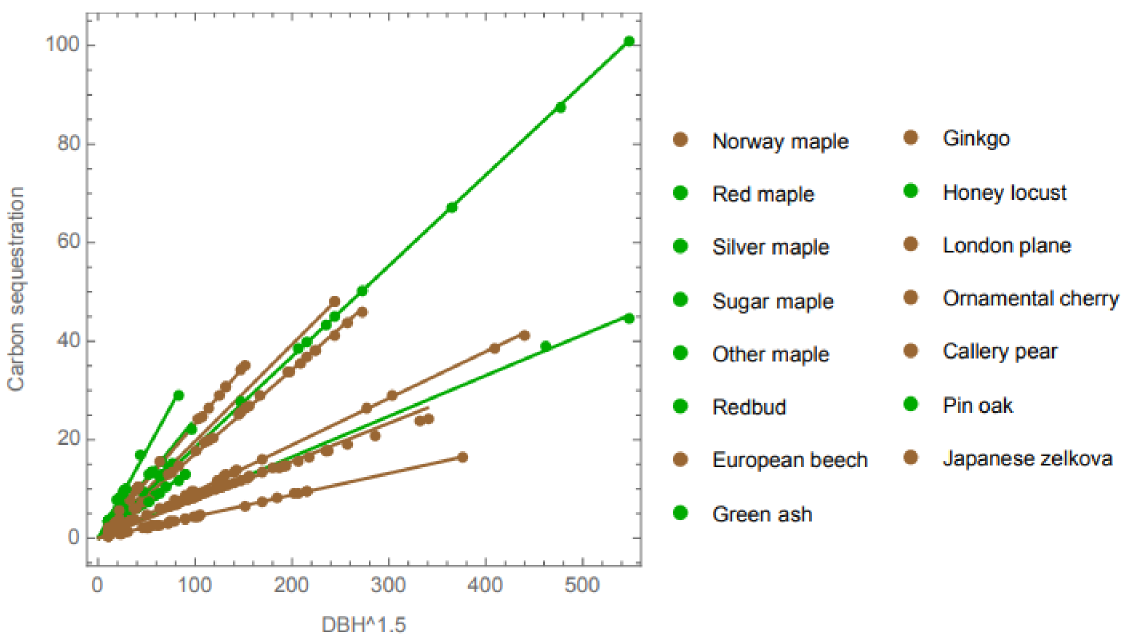


Figure 3.12 Carbon sequestration for different species in terms of native and non-native. Green represents native species. Brown represents non-native species.

3.4 Carbon Benefits in Different Tree Sizes

If the distinction between native and non-native species is inconclusive from a carbon storage perspective, it's a whole different story when it comes to removing or replacing existing trees and adding new ones.

As shown in the previous (Figures 3.5 and 3.6). The largest trees store over 1000 times the carbon of the smallest trees, and sequester over 200 times more. In fact, the twenty-six largest trees (just over ten percent) constitute fifty percent of the total carbon storage, whereas the smallest hundred and eleven trees (~44%) constitute only five percent (Figure 3.13)

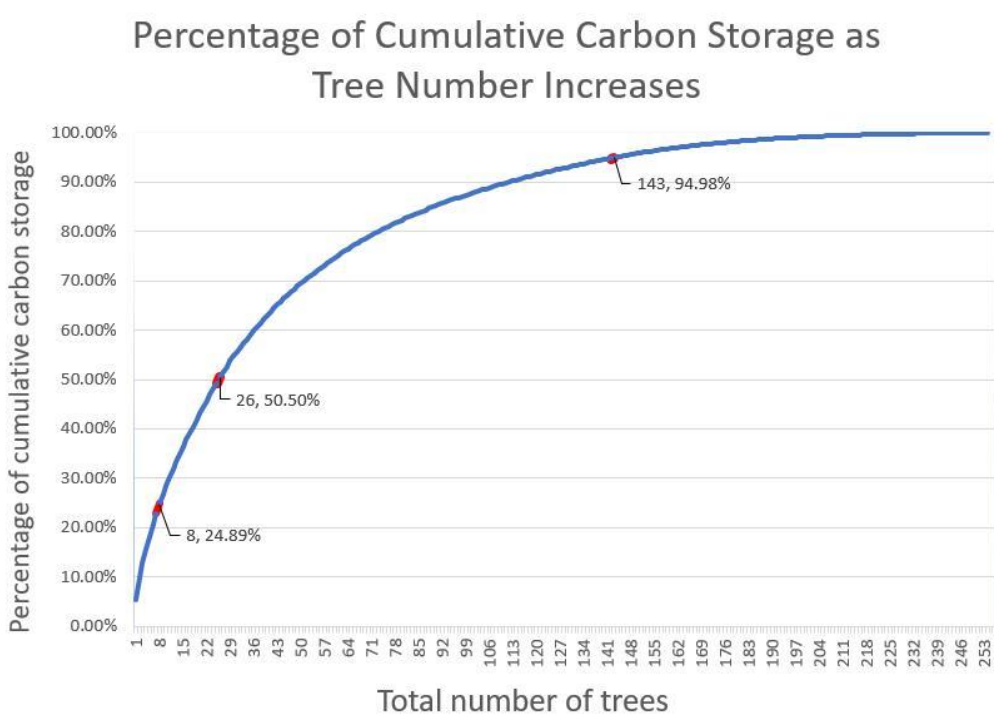


Figure 3.13 Percentage of cumulative carbon storage as tree number increases. X-axis represents the total number of trees starting with the largest. Y-axis represents the percentage of cumulative carbon storage.

For sequestration, the disparity is less dramatic, with the 42 biggest trees providing fifty percent of total carbon sequestration and the smallest 65 small trees providing five percent (Figure 3.14).

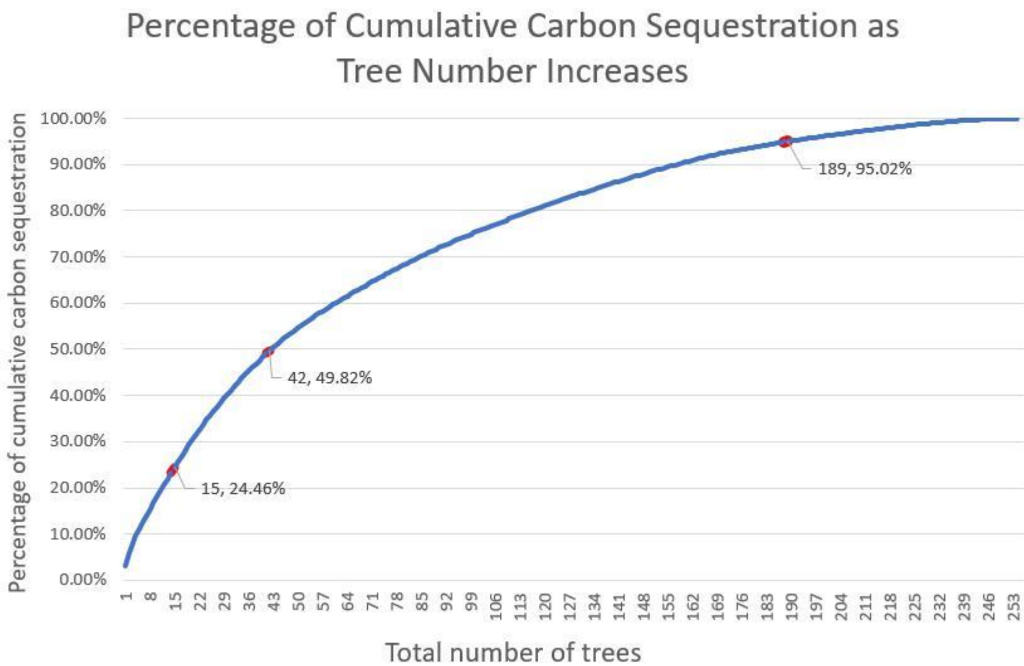


Figure 3.14 Percentage of cumulative carbon sequestration as tree number increases. X-axis represents the total number of trees starting with the largest. Y-axis represents the percentage of cumulative carbon sequestration.

Figure 3.15 is the same curve that was shown previously but with different selected points. From the figure we can tell that the single largest tree on campus, which is a honey locust, contributes 3.18% of the total carbon sequestration. It takes 48 of the smallest trees on campus to match this, or about three of the twentieth largest trees combined. This means that it is more than difficult to replace one of the larger trees on campus if we want to maintain the carbon sequestration each year. Even, if we just want to replace the twentieth biggest tree on campus, which is still one of those honey locusts, we need about a dozen of smaller trees to match its carbon sequestration. Therefore, large trees should not be removed unless it is absolutely necessary; and when it is, it proposes big challenges in find the number and places for small trees to offset the loss.

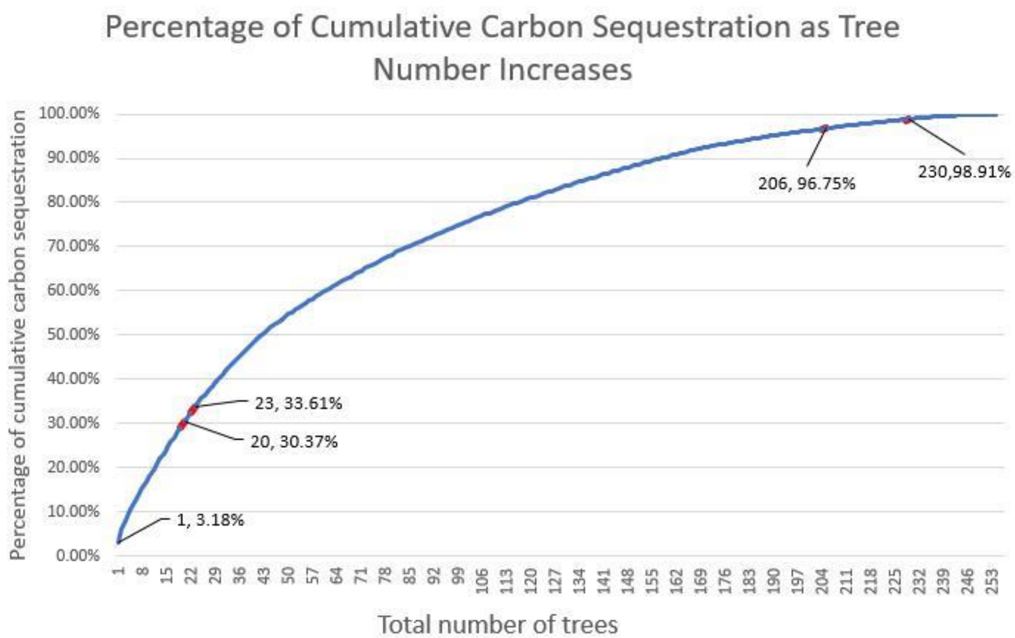


Figure 3.15 New percentage of cumulative carbon sequestration as tree number increases.

3.5 The Economic Value in Carbon

Urban trees 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 sources (Abdollahi et al 2000). Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered increases with the size and health of the trees. According to the calculations of i-Tree Eco, the gross sequestration of the inventoried trees at NJIT is 1.585 tons of carbon per year, which has an associated value (today) of $270 (Figure 3.16).

Carbon storage is another way trees can influence global climate change. As a tree grows, it stores more carbon by holding it in its accumulated tissue. As a tree dies and decays, it releases much of the stored carbon back into the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees, but tree maintenance can contribute to carbon emissions (Nowak et al 2002).

All of the sample trees in NJIT are estimated to store 33.7 tons of carbon, with a value of $5,750 (Figure 3.17). Because it is the most common tree, Japanese zelkova stores and sequesters the most carbon, with an 21.1% of the total stored and 20.6% of the annual sequestration.

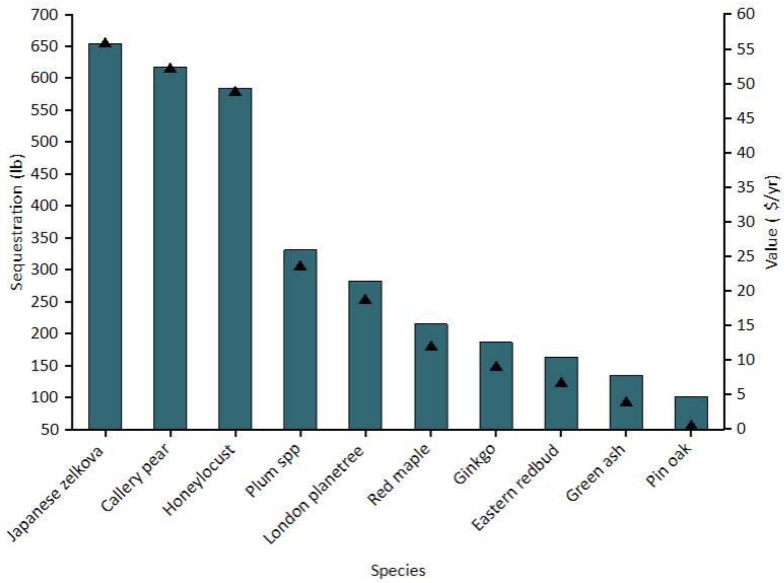


Figure 3.16 Estimated carbon storage (triangles) and values (bars) for urban tree species with the greatest storage in the sample trees in NJIT.

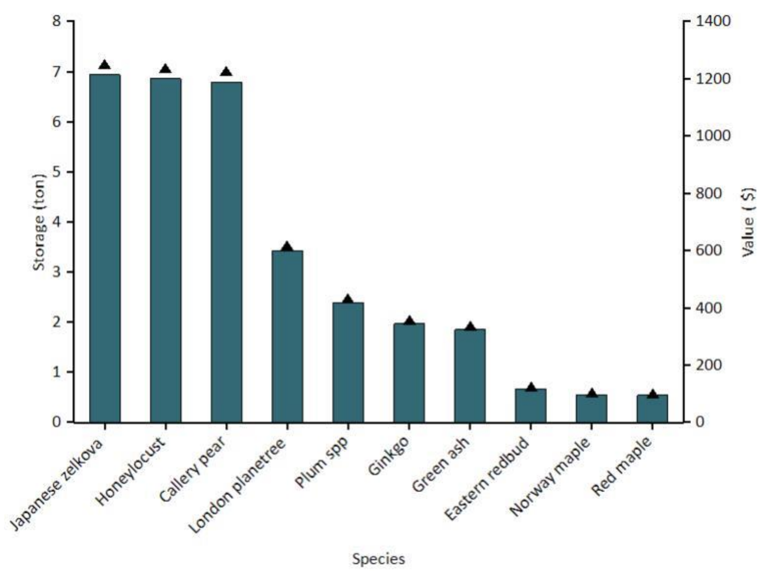


Figure 3.17 Estimated annual gross carbon sequestration (triangles) and values (bars) for urban tree species with the greatest storage in the sample trees in NJIT.

CHAPTER 4

DISCUSSION

This thesis presents two sets of analysis regarding the evaluation of the carbon benefits produced by urban street trees.

The first analysis is on the interior calculation of the software i-Tree. The result proves that i-Tree does involve the calculation from all aspects. While there are some concerning area where the i-Tree calculation is not completely transparent. This includes the extra calculation which is not explained in the documents, and the inconsistent species list where some of the species are not found in some of the reference tables. Also, the difference between urban trees and forest trees are not clearly explained in details (numbers), which also makes it challenging to convert.

The second analysis is based on the campus survey. The result proves the carbon benefits produced by the campus street trees with the economic benefits along with it. The discussion between native species and non-native species shows that there is not a significant different between native species and non-native or invasive species. Therefore, if we were to replace some of the invasive species on our campus due to some other impacts on ecosystem, we will not have to worry about the drop in carbon benefits as long as we replace them with similar sized trees.

However, in case of replacing larger sized trees, it will be more challenging. Sometimes, it’s inevitable when large trees grow old or die. As proven in previous chapters, a large tree would take about forty small trees or three medium trees to balance the carbon loss. Even for a medium sized tree, it still would take about ten small trees to cut the loss. This would require a lot panning ahead of the action as the carbon benefits is also proven to be directly connect to actual money.

APPENDIX A

TREE BIOMASS EQUATIONS

Dry weight biomass equations, by species, used in i-Tree. x = d.b.h. in cm unless otherwise noted; Y= total tree dry weight biomass in kg unless otherwise noted. DHT: x = d.b.h.2 (cm2) x total tree height (m); AGB = aboveground dry weight biomass.

These equations were derived from Understanding i-Tree: 2021 Summary of Programs and Methods (Nowak, 2021).

Species	Equation form	A	B	C	D	E	F	G	x	Y
Abies balsamea	$Y=Ax^B$	0.27965	2.04308							
Acacia auriculaeformis	A	0	-0.0551	0.1401	0.0017	-4.00E-06				
Acacia nilotica	$Y=A+Bx^2$	-21.4868	0.5797							AGB (kg)
Acer macrophyllum	$Y=e^{(A + B * Ln(X) + (C/2))}$	-1.53689	2.24355	0.0315						
Acer rubrum	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.45	-0.6682	0.3529	0.0115	-9.00E-05	6.00E-07	-2.00E-09		
Acer saccharinum	$Y=Ax^B$	0.17789	0.8467						DHT	

Acer saccharum	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.5	-0.7295	0.4155	0.0118	-0.0001	6.00E-07	-2.00E-09		
Adinandra glischroloma	$Y=Ax^B$	0.1142	2.4451							AGB (kg)
Alnus spp.	$Y=Ax^2-B$	0.2896	5.5963						cm^2	AGB (kg)
Alogus nepalensis	$Y=A+Bx+C^2X+D^3x$	0	4.3112	0.2891	-0.0007					
Artocarpus lakoocha	$Y=Ax^B$	0.1245	2.4163							AGB (kg)
Avicennia germinans	$Y=10^Ax^B$	-0.395	1.934							AGB (kg)
Bambusa balcooa	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x$	0.7	-0.9327	0.4542	0.0061	-3.00E-05	1.00E-07			
Bambusa cacharensis	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x$	0.5	-0.5705	0.3208	0.0034	-2.00E-05	6.00E-08			
Bambusa vulgaris	$Y=A+Bx+C^2X+D^3x$	0.31	-0.3542	0.4043	0.0002					
Betula alleghaniensis	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x$	0.8	-1.0119	0.4244	0.0075	-4.00E-05	1.00E-07			
Betula lenta	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.14313	2.4916	0.03467						

Betula papyrifera	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.41197	2.56847	0.03474						
Buddleia megalocephala	$Y=Ax^2-B$	0.2696	3.067						cm^2	AGB (kg)
Carya spp.	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.5	-0.6913	0.342	0.0135	-0.0001	6.00E-07	-2.00E-09		
Cassia siamea	$Y=10^{(A+(B*log(x)))}$	-1.5851	2.4855							
Castanopsis chrysophylla	$Y=e^{(A + B * Ln(X) + (C/2))}$	-1.94995	2.31214	0.04259						
Cecropia schreberiana	$Y=Ax^B$	0.16502	2.3351							AGB (kg)
Ceiba pentandra	$Y=Ax^B$	0.16502	2.3351							AGB (kg)
Cercocarpus ledifolius	$Y=Ax^B$	0.0104	2.7105							AGB (kg)
Cinnamomum camphora	$Y=10^{(A+(B*log(x)))}$	-0.85	2.41							AGB (kg)
Cornus florida	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.4	-0.6022	0.3899	0.009	-8.00E-05	5.00E-07	-1.00E-09		
Cornus spp.	$Y=e^{(A + B * Ln(X) + (C/2))}$	-1.98379	2.38367	0.0381						

Cupressus macrocarpa	$Y=A+Bx+C^2X+D^3x$	8.9	-0.6419	0.5921	-0.00003					
Dalbergia sissoo	$Y=A+Bx+C^2X+D^3x$		2.1774	0.3439	-0.0005					
Daniellia thurifera	$Y=Ax^B$	0.16502	2.3351							AGB (kg)
Eucalyptus brassiana	$Y=10_{((A*log(x))-B)}$	2.39602	1.3933							
Eucalyptus camaldulensis	$Y=10_{((A*log(x))-B)}$	2.39602	1.3933							
Eucalyptus hybrid	$Y=Ax^B$	0.135336	2.416484							AGB (kg)
Eucalyptus tereticornis	$Y=10_{((A*log(x))-B)}$	2.39602	1.3933							
Fagus grandifolia	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.5	-0.7564	0.4552	0.0115	-0.0001	6.00E-07	-2.00E-09		
Fraxinus americana	$Y=e_{(A + B * Ln(X) + (C/2))}$	-1.8446	2.3762	0.05731						
Fraxinus nigra	$Y=e_{(A + B * Ln(X) + (C/2))}$	-1.905	2.29776	0.08518						
Fraxinus pennsylvanica	$Y=e_{(A + B * Ln(X) + (C/2))}$	-2.19052	0.8403	0.13692					DHT	
Hopea odorata	$Y=Ax^B$	0.1277	2.3944							
Juniperus virginiana	$Y=Ax^B$	0.1632	2.2454							AGB (kg)

Lagerstroemia calyculata	$Y=Ax^B$	0.1277	2.3943							AGB (kg)
Laguncularia racemosa	$Y=10^Ax^B$	0.112	1.731							AGB (kg)
Liquidambar styraciflua	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.2	-0.1931	0.1408	0.0067	-5.00E-05	3.00E-07	-9.00E-10		
Liriodendron tulipifera	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.4	-0.495	0.2491	0.0091	-7.00E-05	4.00E-07	-1.00E-09		
Mangifera minitifolia	$Y=Ax^B$	0.14	2.31							AGB (kg)
Nauclea diderrichii	$Y=Ax^B$	0.16502	2.3351							AGB (kg)
Nyssa sylvatica	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.4	-0.5542	0.304	0.009	-8.00E-05	5.00E-07	-1.00E-09		
Olneya tesota	$Y=A((x^2)^B)$	2.50008	1.19431						in^2	AGB (lb)
Ostrya virginiana	Y=e(A + B * Ln(X) + (C/2))	-2.28196	2.42731	0.08647						
Oxydendrum arboreum	$Y=A((x^2)^B)$	2.37722	1.21022						in^2	AGB (lb)
Picea abies	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x$	10	-1.3638	0.4216	0.0041	-3.00E-05	1.00E-07			

Picea glauca	$Y=e^{(A + B * Ln(X) + (C/2))}$	-1.73798	2.22809	0.05189						
Picea rubens	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.25	-0.3531	0.2983	0.0041	-4.00E-05	3.00E-07	-7.00E-10		
Picea spp.	$Y=e^{(A + B * Ln(X) + (C/2))}$	-1.87821	2.25867	0.04823						
Pinus banksiana	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.21	-0.1925	0.1914	0.0051	-5.00E-05	3.00E-07	-9.00E-10		
Pinus caribaea	$Y=Ax^B$	0.07035	2.56							AGB (kg)
Pinus contorta	$Y=Ax^B$	0.11886	2.2333							
Pinus echinata	$Y=Ax^B$	0.01512	0.99415						DHT	
Pinus elliottii	$Y=Ax^B$	0.01865	0.97777						DHT	
Pinus palustris	$Y=Ax^B$	0.02455	0.95612						DHT	
Pinus resinosa	$Y=e^{(A + B * Ln(X) + (C/2))}$	-1.9363	2.2825	0.0573						
Pinus strobus	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.82175	2.42377	0.02545						
Pinus sylvestris	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x$	1.5	-0.8569	0.3074	0.003	-3.00E-05	1.00E-07			
Populus balsamifera	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.52684	2.43482	0.08914						
Populus deltoides	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.5	-0.5403	0.2447	0.0118	-9.00E-05	5.00E-07	-1.00E-09		

Populus grandidentata	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.88716	2.56202	0.0665						
Populus spp.	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.28909	2.44837	0.01442						
Populus tremuloides	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.51459	2.4573	0.06754						
Prunus pensylvanica	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.0349	2.42467	0.05423						
Prunus serotina	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.00442	2.44771	0.03475						
Pseudotsuga menziesii	$Y=e^{(A + B * Ln(X) + (C/2))}$	-4.4135	1.0038	0.00016					DHT	
Quercus agrifolia	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.22479	2.51969	0.06469						
Quercus alba	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x$	0.8	-0.9828	0.3346	0.01	-4.00 E-05	1.00 E-07			
Quercus chrysolepis	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.21701	2.52856	0.0725						
Quercus coccinea	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.31062	2.49694	0.06724						
Quercus douglasii	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.31817	2.49223	0.06008						
Quercus ilex	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.5	-0.7625	0.5314	0.0099	-9.00 E-05	6.00 E-07	-2.00 E-09		
Quercus lyrata	$Y=Ax^B$	0.0363	0.97662						DHT	

Quercus macrocarpa	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.38644	2.49236	0.06595						
Quercus phellos	$Y=Ax^B$	0.05652	0.94267						DHT	
Quercus prinus	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x$	0.9	-1.1889	0.3977	0.0127	-6.00E-05	2.00E-07			
Quercus rubra	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.0755	2.42949	0.07839						
Quercus spp.	$Y=Ax2+^B$	0.6048	4.3198						cm^2	AGB (kg)
Quercus stellata	$Y=A((x^2)^B)$	2.23774	1.21527						in^2	AGB (lb)
Quercus velutina	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x+G^6x$	0.5	-0.6353	0.4673	0.0134	-0.0001	6.00E-07	-2.00E-09		
Quercus wislizeni	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.17185	2.50939	0.07789						
Rhizophora mangle	$Y=10^Ax^B$	-0.441	1.93							AGB (kg)
Tectona grandis	$Y=Ax^B$	0.202	2.353							
Terminalia superba	$Y=Ax^B$	0.066	2.565							
Thuja occidentalis	$Y=A+Bx+C^2X+D^3x+E^4x+F^5x$		0.3581	0.5396	-0.0011	8.00E-06	-2.00E-08			
Thuja plicata	$Y=e^{(A + B * Ln(X) + (C/2))}$	-4.88072	1.00448	0.00076					DHT	

Tilia americana	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.42943	2.35806	0.25912						
Tsuga canadensis	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.25566	2.32302	0.04002						
Tsuga heterophylla	$Y=e^{(A + B * Ln(X) + (C/2))}$	-4.19825	1.00526	0.00198					DHT	
Ulmus americana	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.22755	2.39866	0.0602						
Vitellaria paradoxa	$Y=Ax^B$	0.08	2.46							

APPENDIX B

CONVERSION FACTORS FOR LEAF AREA TO BIOMASS

Conversion factors used to estimate leaf biomass (g) from leaf area (m^2) for individual species are shown in below. Values are based on averages from numerous unpublished field studies.

Species	g/m^2
Abies balsamea	104.17
Abies lasiocarpa	217.39
Acacia aneura	476.19
Acacia melanoxylon	161.94
Acer buergerianum	123.46
Acer mono	37.17
Acer negundo	91.48
Acer pensylvanicum	32.57
Acer platanoides	53.97
Acer pseudoplatanus	69.93
Acer rubrum	67.34
Acer saccharinum	52.63
Acer saccharum	60.24
Aesculus californica	88.11
Aesculus flava	65.15
Aesculus hippocastanum	69.93
Albizia julibrissin	43.48
Alnus incana ssp. Rugosa	85.84
Alnus rhombifolia	87.72
Alnus species	55.25
Amelanchier alnifolia	100
Amelanchier arborea	60.98
Arecastrum romanzoffianum	183.49

Artemisia tridentata	312.5
Asimina triloba	167.76
Atriplex canescens	119.05
Atriplex polycarpa	253.16
Baccharis pilularis	192.31
Betula alleghaniensis	41.41
Betula nigra	77.51
Betula papyrifera	69.93
Betula species	62.5
Bischofia polycarpa	178.57
Brachychiton populneus	87.53
Broussonetia papyrifera	57.47
Caesalpinia gilliesii	89.29
Carpinus caroliniana	60.24
Carya alba	57.31
Carya aquatica	232.27
Carya cordiformis	62.86
Carya glabra	19.06
Carya illinoinensis	69.54
Carya ovata	73.24
Carya pallida	59.88
Carya species	56.26
Cassia nemophila	259.74
Castanea dentata	45.66
Castanea pumila	150.86
Catalpa bignonioides	53.33
Catalpa species	70.92
Celtis laevigata	67.99
Celtis occidentalis	52.03
Cercis canadensis	64.04
Cercocarpus montanus	123.46
Chamaecyparis obtusa	250
Chamaedaphne calyculata	84.75
Cinnamomum camphora	67.57
Citrullus lanatus	85.47
Citrus limon	147.06
Citrus sinensis	124.61
Cornus alternifolia	66.67
Cornus florida	58.1
Cornus mas	66.23

Cornus racemosa	47.73
Cornus sericea	57.22
Corylus cornuta	69.44
Crataegus marshallii	245.23
Crataegus monogyna	125.79
Crataegus species	35.97
Ericameria nauseosa	180.51
Eucalyptus camaldulensis	138.41
Eucalyptus grandis	115.61
Eucalyptus sideroxylon	136.99
Euryops pectinatus	224.72
Fagus crenata	60.61
Fagus grandifolia	42.61
Fraxinus americana	56.82
Fraxinus excelsior	106.38
Fraxinus nigra	59.52
Fraxinus pennsylvanica	65.22
Fraxinus species	90.09
Garrya flavescens	217.39
Ginkgo biloba	44.09
Gleditsia triacanthos	104.71
Gossypium hirsutum	69.32
Grevillea robusta	121.58
Hamamelis virginiana	58.82
Hibiscus rosa-sinensis	85.11
Hibiscus syriacus	48.31
Ilex opaca	133.69
Juglans nigra	80.14
Juglans regia	42.15
Juniperus species	277.78
Kalmia latifolia	120.48
Koelreuteria paniculata	80.81
Larix laricina	46.3
Larix leptolepis	64.52
Ledum groenlandicum	107.53
Ligustrum lucidum	90.91
Liquidambar styraciflua	45.91
Liriodendron tulipifera	58.95
Lonicera x bella	49.26
Lycopersicon esculentum	79.21
Lysiloma watsonii	105.82

Maclura pomifera	100.53
Magnolia acuminata	32.79
Magnolia grandiflora	135.04
Magnolia virginiana	142.92
Mahonia bealei	86.21
Malus pumila	86.21
Metasequoia glyptostroboides	56.5
Morella cerifera	344.09
Morus alba	73.15
Morus rubra	99.32
Nerium oleander	148.7
Nyssa sylvatica	34.59
Osmanthus fragrans	86.96
Ostrya virginiana	65.28
Oxydendrum arboreum	30.44
Parthenocissus tricuspidata	49.18
Photinia serratifolia	102.04
Picea abies	166.67
Picea abies x asperata	178.57
Picea asperata	99.5
Picea bicolor	194.17
Picea engelmannii	212.77
Picea glauca	160.64
Picea glehnii	229.89
Picea jezoensis	487.8
Picea koraiensis	95.24
Picea koyamai	204.08
Picea mariana	188.68
Picea montigena	153.85
Picea omorika	188.68
Pinus banksiana	83.33
Pinus contorta	192.31
Pinus resinosa	147.06
Pinus strobus	64.31
Pinus taeda	81.11
Pistacia chinensis	76.34
Pistacia vera	155.04
Platanus hybrida	43.67
Platanus occidentalis	48.45
Populus alba	86.96

Populus angustifolia	87.72
Populus balsamifera trichoca	54.05
Populus fremontii	86.58
Populus grandidentata	51.02
Populus nigra	72.12
Populus species	67.57
Populus tremuloides	78.74
Populus x canadensis	92.42
Prunus alleghaniensis	212.77
Prunus cerasifera	60.75
Prunus dulcis	101.27
Prunus pensylvanica	48.27
Prunus serotina	77.55
Prunus virginiana	77.52
Pterocarya stenoptera	80
Pueraria lobata	30.03
Quercus agrifolia	141.68
Quercus alba	72.74
Quercus berberidifolia	149.32
Quercus chrysolepis	168.94
Quercus coccinea	72.87
Quercus douglasii	121.41
Quercus ellipsoidalis	103.09
Quercus engelmannii	151.16
Quercus falcata	77.98
Quercus gambelii	133.33
Quercus kelloggii	102.89
Quercus lobata	101.12
Quercus michauxii	60.21
Quercus nigra	94.56
Quercus pagoda	112.82
Quercus palustris	90.5
Quercus phellos	88.71
Quercus prinus	78.59
Quercus robur	66.58
Quercus rubra	79.68
Quercus stellata	85.11
Quercus suber	177.78
Quercus velutina	70.67
Quercus virginiana	209.93

Quercus wislizeni	148.36
Rhamnus cathartica	44.44
Rhododendron maximum	200
Rhus glabra	55.14
Rhus lancea	122.7
Rhus ovata	320
Rhus species	80
Robinia pseudoacacia	53.84
Rosmarinus officinalis	275.86
Rubus species	37.31
Salix sericea	65.05
Salix species	61.73
Salvia leucophylla	246.91
Sassafras albidum	49.18
Senna artemisioides	186.05
Sophora japonica	113.64
Sorbus species	79.37
Spartium junceum	291.97
Symphoricarpos occidentalis	55.87
Syringa vulgaris	96.46
Thuja occidentalis	192.31
Tilia americana	29.2
Tilia cordata	74.91
Tilia platyphyllos	59.17
Tsuga canadensis	92.88
Tsuga heterophylla	55.25
Ulmus alata	72.25
Ulmus americana	72.73
Ulmus parvifolia	113.64
Ulmus rubra	44.77
Vitex agnus-castus	133.78
Vitis vinifera	66.67
Washingtonia robusta	154.44

APPENDIX C

SHADING COEFFICIENTS

The shading coefficient (y) is based species-specific coefficients (Table 11) and d.b.h., based on the formula: $y = 0.0617 * \ln(x) + 0.615$ + species-specific shading coefficient Where: x = d.b.h in cm.

Species	Coefficient
Acacia farnesiana	0.006476
Acacia melanoxylon	0.033203
Acacia salicina	0.036297
Acer macrophyllum	0.00733
Acer negundo	0.0136
Acer palmatum	0.01986
Acer platanoides	0.038195
Acer rubrum	0.009591
Acer saccharinum	0.017403
Acer saccharum	0.024004
Bauhinia blakeana	0.148861
Betula nigra	0.018711
Betula pendula	0.001379
Brachychiton populneus	0.001286
Callistemon citrinus	0.000129
Calocedrus decurrens	0.030777
Calophyllum inophyllum	0.066124
Carpinus betulus	0.064152
Carya illinoinensis	0.015547
Cassia x nealiae	0.052799
Casuarina equisetifolia	0.187445
Catalpa speciosa	0.008864
Cedrus deodara	0.021595
Celtis laevigata	0.007073
Celtis occidentalis	0.018599
Celtis sinensis	0.02589
Ceratonia siliqua	0.020249
Chilopsis linearis	0.006679
Cinnamomum camphora	0.017635

Citharexylum spinosum	0.042121
Cocos nucifera	0.212762
Conocarpus erectus	0.064823
Cordia subcordata	0.034285
Cornus florida	0.041082
Crataegus spp	0.005855
Crataegus x lavallei	0.044633
Cupaniopsis anacardioides	0.032094
Delonix regia	0.10831
Elaeagnus angustifolia	0.000679
Elaeodendron orientale	0.02149
Eriobotrya japonica	0.031987
Eucalyptus ficifolia	0.008154
Eucalyptus globulus	0.013452
Eucalyptus microtheca	0.005495
Eucalyptus sideroxylon	0.004389
Fagus sylvatica	0.007078
Ficus benjamina	0.005748
Ficus thonningii	0.019105
Filicium decipiens	0.036698
Fraxinus americana	0.040826
Fraxinus angustifolia	0.055648
Fraxinus excelsior	0.039979
Fraxinus holotricha	0.021817
Fraxinus latifolia	0.017034
Fraxinus pennsylvanica	0.031117
Fraxinus uhdei	0.006909
Fraxinus velutina	0.00131
Ginkgo biloba	0.014228
Gleditsia triacanthos	0.009429
Gymnocladus dioicus	0.048339
Ilex opaca	0.030095
Ilex paraguayensis	0.114463
Jacaranda mimosifolia	0.005707
Juglans nigra	0.003086
Juniperus virginiana	0.030798
Koelreuteria elegans	0.016586
Koelreuteria paniculata	0.02735
Lagerstroemia indica	0.014415
Lagerstroemia sp	0.076014
Liquidambar styraciflua	0.021253
Liriodendron tulipifera	0.027576
Magnolia grandiflora	0.006197

Malus sp	0.013821
Melaleuca quinquenervia	0.045497
Metrosideros excelsa	0.035613
Morus alba	0.00113
Olea europaea	0.012154
Parkinsonia aculeata	0.061333
Parkinsonia florida	0.025384
Phoenix canariensis	0.0817
Phoenix dactylifera	0.175857
Picea pungens	0.02344
Pinus brutia	0.00855
Pinus canariensis	0.012044
Pinus contorta	0.012737
Pinus echinata	0.039363
Pinus edulis	0.032428
Pinus elliottii	0.059779
Pinus halepensis	0.017895
Pinus nigra	0.033034
Pinus ponderosa	0.040393
Pinus radiata	0.002821
Pinus sylvestris	0.014577
Pinus taeda	0.015568
Pinus thunbergii	0.010467
Pistacia chinensis	0.03091
Pittosporum undulatum	0.004301
Platanus occidentalis	0.001356
Platanus racemosa	0.029835
Platanus x acerifolia	0.0135
Platycladus orientalis	0.036982
Podocarpus macrophyllus	0.036235
Populus angustifolia	0.018432
Populus fremontii	0.011781
Prosopis chilensis	0.05035
Prunus caroliniana	0.000254
Prunus cerasifera	0.00276
Prunus serrulata	0.075394
Prunus sp	0.011707
Prunus yedoensis	0.023468
Pseudotsuga menziesii	0.017942
Pyrus calleryana	0.028712
Pyrus kawakamii	0.056219
Quercus alba	0.018694
Quercus laurifolia	0.003916

Quercus lobata	0.000927
Quercus macrocarpa	0.028163
Quercus nigra	0.006829
Quercus palustris	0.011858
Quercus phellos	0.005547
Quercus rubra	0.022225
Quercus shumardii	0.009522
Quercus agrifolia	0.021636
Quercus ilex	0.024552
Quercus virginiana	0.01608
Rhus lancea	0.031603
Robinia pseudoacacia	0.023624
Samanea saman	0.048322
Schinus molle	0.027216
Schinus terebinthifolia	0.019735
Sequoia sempervirens	0.003386
Swietenia mahogani	0.03224
Tabebuia aurea	0.048674
Tabebuia heterophylla	0.061165
Tabebuia ochracea ssp. Neochrysantha	-0.081893
Tilia americana	0.043399
Tilia cordata	0.044529
Triadica sebifera	0.031487
Tristaniopsis conferta	0.03676
Ulmus alata	0.010829
Ulmus americana	0.016822
Ulmus parvifolia	0.02481
Ulmus pumila	0.009616
Veitchia merrillii	0.105305
Washingtonia filifera	0.144123
Washingtonia robusta	0.085184
Zelkova serrata	0.016636

APPENDIX D

CROWN PARAMETERS

*If there is no equation for the species use an equation for the genus, then family, then order.

*Results are in feet

D1 Crown Height Equations

crwht= dbh	***CrownHeight = B0 + (DBH * B1)***
crwht = dbh dbh*dbh	***CrownHeight = B0 + (DBH * B1) + (DBH^2 * B2)***
crwht = ldbh	***CrownHeight = B0 + (log(DBH) * B1)***
lcrwht = ldbh	***CrownHeight = exp(B0 + (log(DBH) * B1)))***

Scientifi nName	Model	B0	B1	B2	SpeciesType
Acer negundo	crwht = dbh dbh*dbh	4.4778	3.1358	-0.0742	Species
Acer palmatum	crwht = dbh	4.8807	1.1865		Species
Acer platanoides	lcrwht = ldbh	2.0734	0.5317		Species
Acer pseudoplatanus	lcrwht = ldbh	2.1447	0.5258		Species
Acer rubrum	lcrwht = ldbh	1.9422	0.6517		Species
Acer saccharinum	lcrwht = ldbh	2.0482	0.5967		Species
Acer saccharum	crwht = ldbh	4.3008	13.1534		Species
Betula papyrifera	crwht = ldbh	8.6195	8.8565		Species
Betula pendula	crwht = ldbh	13.2422	9.4508		Species
Betula populifolia	lcrwht = ldbh	2.331	0.4096		Species
Carpinus caroliniana	crwht = dbh dbh*dbh	3.9616	4.5169	-0.3409	Species
Carya cordiformis	lcrwht = ldbh	1.8466	0.7115		Species
Carya glabra	lcrwht = ldbh	1.9634	0.7264		Species
Carya illinoinensis	lcrwht = ldbh	2.2766	0.4262		Species
Carya ovata	crwht = dbh	5.8375	2.4594		Species
Catalpa speciosa	lcrwht = ldbh	1.6645	0.6539		Species
Celtis laevigata	lcrwht = ldbh	2.158	0.4732		Species
Celtis occidentalis	lcrwht = ldbh	1.5917	0.7817		Species
Cornus florida	lcrwht = ldbh	1.6619	0.5154		Species

Eucalyptus globulus	lcrwht = ldbh	0.3438	1.2775		Species
Fagus grandifolia	crwht = dbh dbh*dbh	3.858	4.9592	-0.0939	Species
Fraxinus americana	crwht = dbh dbh*dbh	4.9291	2.9204	-0.0554	Species
Fraxinus pennsylvanica	lcrwht = ldbh	2.0069	0.567		Species
Ilex opaca	crwht = dbh	4.6572	2.3151		Species
Juglans nigra	crwht = dbh dbh*dbh	2.9058	2.8986	-0.038	Species
Juniperus virginiana	lcrwht = ldbh	2.0926	0.5665		Species
Lagerstroemia indica	crwht = dbh	4.8082	1.6692		Species
Liquidambar styraciflua	crwht = dbh dbh*dbh	4.9091	3.1597	-0.0576	Species
Liriodendron tulipifera	lcrwht = ldbh	2.1078	0.6018		Species
Magnolia grandiflora	lcrwht = ldbh	2.3096	0.496		Species
Malus pumila	lcrwht = ldbh	2.1383	0.2531		Species
Morus alba	crwht = dbh dbh*dbh	5.0542	2.4817	-0.0524	Species
Morus rubra	lcrwht = ldbh	1.9783	0.5286		Species
Picea abies	crwht = dbh	8.2522	2.0189		Species
Picea glauca	lcrwht = ldbh	2.0261	0.6099		Species
Picea pungens	crwht = dbh dbh*dbh	3.4727	2.8321	-0.0441	Species
Pinus elliottii	crwht = dbh	9.5228	1.3195		Species
Pinus nigra	crwht = dbh dbh*dbh	7.2858	1.7886	-0.0379	Species
Pinus radiata	lcrwht = ldbh	2.055	0.4619		Species
Pinus strobus	crwht = dbh dbh*dbh	3.2668	3.0301	-0.0485	Species
Pinus taeda	lcrwht = ldbh	1.6624	0.6361		Species
Pinus virginiana	lcrwht = ldbh	1.4992	0.6753		Species
Platanus occidentalis	crwht = dbh dbh*dbh	4.9825	2.5967	-0.0176	Species
Platanus hybrida	lcrwht = ldbh	1.6125	0.6897		Species
Populus balsamifera	crwht = dbh dbh*dbh	6.8646	1.0936	0.133	Species
Populus deltoides	lcrwht = ldbh	2.2951	0.4959		Species
Populus tremuloides	crwht = dbh dbh*dbh	1.4702	4.3657	-0.2558	Species
Prunus avium	lcrwht = ldbh	2.0145	0.4617		Species
Prunus serotina	crwht = dbh dbh*dbh	3.8327	2.7042	-0.0492	Species
Prunus virginiana	crwht = ldbh	5.6824	7.617		Species

Pyrus calleryana	crwht = dbh	7.677	1.18		Species
Quercus alba	crwht = dbh dbh*dbh	5.8887	3.1019	-0.0483	Species
Quercus falcata	crwht = dbh dbh*dbh	4.4512	3.0397	-0.0464	Species
Quercus nigra	crwht = dbh dbh*dbh	4.2006	3.2994	-0.0609	Species
Quercus palustris	lcrwht = ldbh	1.8501	0.6992		Species
Quercus phellos	crwht = dbh	9.6871	1.9065		Species
Quercus prinus	lcrwht = ldbh	2.2264	0.4799		Species
Quercus rubra	crwht = ldbh	0.4641	13.7235		Species
Quercus stellata	lcrwht = ldbh	1.5045	0.7604		Species
Quercus velutina	crwht = ldbh	-1.6038	14.3242		Species
Quercus/live virginiana	lcrwht = ldbh	1.8411	0.4913		Species
Rhamnus cathartica	lcrwht = ldbh	1.6648	0.2501		Species
Robinia pseudoacacia	crwht = dbh dbh*dbh	5.9067	2.2067	-0.0245	Species
Salix nigra	lcrwht = ldbh	1.9764	0.5817		Species
Salix sericea	crwht = dbh dbh*dbh	3.9912	2.1772	-0.0543	Species
Syringa vulgaris	crwht = dbh	2.9685	1.14		Species
Thuja occidentalis	crwht = dbh	4.8903	1.4952		Species
Tilia americana	crwht = dbh dbh*dbh	5.3963	2.3592	-0.0274	Species
Tilia cordata	lcrwht = ldbh	1.4554	0.6788		Species
Tsuga canadensis	crwht = dbh dbh*dbh	3.0025	2.5558	-0.0221	Species
Ulmus alata	crwht = dbh	4.74	2.2668		Species
Ulmus americana	lcrwht = ldbh	1.8999	0.6114		Species
Ulmus crassifolia	lcrwht = ldbh	1.7337	0.7143		Species
Ulmus pumila	lcrwht = ldbh	1.7744	0.6095		Species
Ulmus rubra	crwht = dbh dbh*dbh	3.1371	3.1945	-0.0578	Species
Carya alba	crwht = dbh dbh*dbh	3.4081	4.5112	-0.1021	Species
Betula	lcrwht = ldbh	2.3223	0.4633		Genus
Carpinus	lcrwht = ldbh	2.1483	0.4204		Genus
Carya	crwht = dbh dbh*dbh	4.036	3.5895	-0.067	Genus
Catalpa	lcrwht = ldbh	1.6694	0.6537		Genus
Celtis	lcrwht = ldbh	1.7516	0.6714		Genus
Crataegus	lcrwht = ldbh	1.6385	0.407		Genus
Cupressus	crwht = ldbh	8.473	4.8715		Genus
Eucalyptus	lcrwht = ldbh	0.4193	1.221		Genus

Fagus	crwht = dbh dbh*dbh	3.8856	4.9363	-0.0931	Genus
Fraxinus	crwht = dbh dbh*dbh	5.211	2.872	-0.0567	Genus
Gleditsia	crwht = dbh dbh*dbh	6.98	1.7483	-0.0227	Genus
Juglans	crwht = dbh dbh*dbh	3.6877	2.6559	-0.0291	Genus
Juniperus	crwht = dbh dbh*dbh	0.9801	3.8464	-0.096	Genus
Liquidambar	crwht = dbh dbh*dbh	4.8531	3.1701	-0.058	Genus
Liriodendron	lcrwht = ldbh	2.1066	0.6022		Genus
Magnolia	lcrwht = ldbh	2.2992	0.4318		Genus
Malus	lcrwht = ldbh	2.0303	0.304		Genus
Morus	crwht = dbh dbh*dbh	4.628	2.4977	-0.053	Genus
Ostrya	lcrwht = ldbh	1.9715	0.5583		Genus
Phellodendron	lcrwht = ldbh	1.8867	0.3916		Genus
Picea	crwht = dbh dbh*dbh	4.1574	3.1523	-0.0524	Genus
Pinus	crwht = dbh dbh*dbh	4.7157	2.216	-0.0326	Genus
Populus	crwht = dbh dbh*dbh	3.3049	3.0906	-0.0431	Genus
Prunus	crwht = dbh dbh*dbh	3.9189	2.544	-0.0486	Genus
Pyrus	crwht = dbh	7.5071	1.1779		Genus
Quercus	crwht = dbh dbh*dbh	5.4554	2.9539	-0.0445	Genus
Rhus	lcrwht = ldbh	1.0038	0.1913		Genus
Robinia	crwht = dbh dbh*dbh	5.9049	2.1987	-0.0235	Genus
Salix	lcrwht = ldbh	1.6529	0.6577		Genus
Sapium	crwht = dbh dbh*dbh	3.9912	2.1772	-0.0543	Genus
Sassafras	lcrwht = ldbh	1.5928	0.6384		Genus
Syringa	crwht = dbh	3.5307	1.0628		Genus
Thuja	crwht = dbh	4.7348	1.5925		Genus
Tsuga	crwht = dbh dbh*dbh	2.9814	2.552	-0.0218	Genus
Ulmus	crwht = dbh dbh*dbh	4.0399	2.9476	-0.055	Genus
Viburnum	lcrwht = ldbh	1.8853	0.264		Genus
Aceraceae	lcrwht = ldbh	1.9873	0.6217		Family
Anacardiaceae	lcrwht = ldbh	1.0007	0.2096		Family
Betulaceae	crwht = ldbh	6.6649	8.3355		Family
Bignoniaceae	lcrwht = ldbh	1.6777	0.6401		Family
Cornaceae	lcrwht = ldbh	1.6482	0.5246		Family
Cupressaceae	crwht = dbh dbh*dbh	3.2638	2.4467	-0.0432	Family

Euphorbiaceae	crwht = dbh dbh*dbh	3.9912	2.1772	-0.0543	Family
Fagaceae	crwht = dbh dbh*dbh	6.2166	3.0477	-0.0471	Family
Hamamelidaceae	crwht = dbh dbh*dbh	4.7545	3.1914	-0.0588	Family
Juglandaceae	crwht = dbh dbh*dbh	4.3297	3.3204	-0.0576	Family
Lythraceae	lcrwht = ldbh	1.768	0.5216		Family
Magnoliaceae	lcrwht = ldbh	2.1336	0.5797		Family
Moraceae	crwht = dbh dbh*dbh	4.7656	2.3386	-0.0389	Family
Myrtaceae	lcrwht = ldbh	0.5289	1.1629		Family
Nyssaceae	crwht = dbh dbh*dbh	1.4715	4.0894	-0.0836	Family
Oleaceae	crwht = dbh dbh*dbh	4.8348	2.7724	-0.052	Family
Pinaceae	crwht = dbh dbh*dbh	4.6229	2.4388	-0.0374	Family
Platanaceae	crwht = dbh dbh*dbh	6.0828	2.2526	-0.0187	Family
Rhamnaceae	lcrwht = ldbh	1.6577	0.2885		Family
Rosaceae	crwht = dbh dbh*dbh	4.2315	2.1904	-0.0393	Family
Rutaceae	lcrwht = ldbh	1.8781	0.3425		Family
Salicaceae	crwht = dbh dbh*dbh	3.2686	3.101	-0.0535	Family
Scrophulariaceae	lcrwht = ldbh	2.2526	0.2133		Family
Simaroubaceae	crwht = dbh dbh*dbh	3.0956	2.6435	-0.0636	Family
Tiliaceae	crwht = dbh dbh*dbh	6.2999	1.822	-0.0177	Family
Ulmaceae	crwht = dbh dbh*dbh	3.9563	2.9598	-0.0582	Family
Cornales	crwht = dbh dbh*dbh	2.4896	2.7215	-0.0273	Order
Dipsacales	lcrwht = ldbh	1.8437	0.3054		Order
Ebenales	lcrwht = ldbh	1.2836	0.8609		Order
Ericales	lcrwht = ldbh	1.8445	0.5589		Order
Euphorbiales	crwht = dbh dbh*dbh	4.041	2.1568	-0.0534	Order
Fabales	crwht = dbh dbh*dbh	5.8865	2.1033	-0.026	Order
Fagales	crwht = dbh dbh*dbh	6.0957	3.0274	-0.0467	Order
Gentianales	crwht = dbh	7.2447	1.775		Order
Hamamelidales	crwht = dbh dbh*dbh	5.6684	2.8264	-0.0398	Order
Juglandales	crwht = dbh dbh*dbh	4.3297	3.3204	-0.0576	Order

Laurales	lcrwht = ldbh	1.6941	0.5866		Order
Magnoliales	lcrwht = ldbh	2.1285	0.5819		Order
Malvales	crwht = dbh dbh*dbh	6.0404	1.8306	-0.0177	Order
Myrtales	lcrwht = ldbh	0.8289	1.0357		Order
Pinales	crwht = dbh dbh*dbh	3.8501	2.5431	-0.0416	Order
Rhamnales	lcrwht = ldbh	1.6555	0.2883		Order
Rosales	crwht = dbh dbh*dbh	4.2315	2.1881	-0.0391	Order
Salicales	crwht = dbh dbh*dbh	3.2686	3.101	-0.0535	Order
Sapindales	crwht = ldbh	3.1398	11.1885		Order
Scrophulariales	crwht = dbh dbh*dbh	4.9344	2.6714	-0.0488	Order
Urticales	crwht = dbh dbh*dbh	4.1929	2.7889	-0.0523	Order

D2 Crown Width Equations

crw= dbh	CrownWidth = B0 + (DBH * B1)
crw = dbh dbh*dbh	CrownWidth = B0 + (DBH * B1) + (DBH^2 * B2)
crw = ldbh	CrownWidth = B0 + (log(DBH) * B1)
lcrw = ldbh	CrownWidth = exp(B0 + (log(DBH) * B1)))

Scientific Name	Model	B0	B1	B2	Type
Acer_negundo	crw = dbh dbh*dbh	5.854	1.9553	-0.0275	Species
Acer_palmatum	crw = dbh	6.61	1.7147		Species
Acer_platanoides	crw = dbh dbh*dbh	5.8975	2.1666	-0.0274	Species
Acer_pseudoplatanus	lcrw = ldbh	1.9314	0.5685		Species
Acer_rubrum	crw = dbh dbh*dbh	6.8474	2.1853	-0.0335	Species
Acer_saccharinum	lcrw = ldbh	1.9519	0.5629		Species
Acer_saccharum	crw = dbh dbh*dbh	6.4681	2.2287	-0.0351	Species
Betula_papyrifera	crw = dbh dbh*dbh	5.064	1.2265	0.0395	Species
Betula_pendula	lcrw = ldbh	1.5123	0.571		Species
Betula_populifolia	lcrw = ldbh	1.9078	0.5326		Species
Carpinus_caroliniana	crw = ldbh	9.0348	6.7159		Species
Carya_cordiformis	lcrw = ldbh	1.946	0.5517		Species
Carya_glabra	lcrw = ldbh	2.0043	0.4994		Species
Carya_illinoinensis	lcrw = ldbh	1.7231	0.6653		Species
Carya_ovata	crw = dbh	6.7211	1.6122		Species
Catalpa_speciosa	lcrw = ldbh	2.0308	0.5362		Species
Celtis_laevigata	lcrw = ldbh	1.7738	0.6299		Species
Celtis_occidentalis	crw = dbh dbh*dbh	5.0384	2.3903	-0.0527	Species
Cornus_florida	lcrw = ldbh	2.1047	0.4727		Species
Eucalyptus_globulus	lcrw = ldbh	-0.0593	1.233		Species
Fagus_grandifolia	crw = dbh dbh*dbh	7.8252	2.4359	-0.0335	Species
Fraxinus_americana	crw = dbh dbh*dbh	4.8708	2.221	-0.0295	Species
Fraxinus_pennsylvanica	lcrw = ldbh	1.759	0.6078		Species
Ilex_opaca	lcrw = ldbh	1.7641	0.4682		Species
Juglans_nigra	lcrw = ldbh	1.8653	0.5878		Species
Juniperus_virginiana	crw = dbh	3.6967	1.2866		Species
Lagerstroemia_indica	lcrw = ldbh	1.9526	0.3644		Species
Liquidambar_styraciflua	crw = dbh dbh*dbh	5.0207	1.5969	-0.0074	Species

Liriodendron_tulipifera	crw = dbh dbh*dbh	5.6119	1.9934	-0.0186	Species
Magnolia_grandiflora	lcrw = ldbh	1.9737	0.4751		Species
Malus_pumila	lcrw = ldbh	2.2312	0.3735		Species
Morus_alba	crw = ldbh	5.5645	7.96		Species
Morus_rubra	lcrw = ldbh	2.0067	0.5491		Species
Picea_abies	crw = dbh	5.0275	1.3419		Species
Picea_glauca	lcrw = ldbh	1.3573	0.5622		Species
Picea_pungens	crw = dbh dbh*dbh	3.1772	1.3664	-0.0162	Species
Pinus_elliottii	lcrw = ldbh	1.2235	0.7611		Species
Pinus_nigra	crw = dbh dbh*dbh	5.6682	1.6952	-0.036	Species
Pinus_radiata	lcrw = ldbh	1.4297	0.5938		Species
Pinus_strobus	crw = dbh dbh*dbh	3.3445	1.5814	-0.0142	Species
Pinus_taeda	lcrw = ldbh	1.1535	0.7313		Species
Pinus_virginiana	lcrw = ldbh	1.5891	0.6557		Species
Platanus_occidentalis	lcrw = ldbh	1.9074	0.5682		Species
Platanus_hybrida	crw = dbh dbh*dbh	3.9088	2.6747	-0.0329	Species
Populus_balsamifera	crw = dbh	4.1386	1.1984		Species
Populus_deltoides	crw = dbh	4.3047	1.6294		Species
Populus_tremuloides	crw = dbh dbh*dbh	1.2786	2.3693	-0.1346	Species
Prunus_avium	lcrw = ldbh	1.9615	0.5056		Species
Prunus_serotina	crw = dbh dbh*dbh	6.1133	2.0116	-0.0355	Species
Prunus_virginiana	lcrw = ldbh	1.7052	0.5541		Species
Pyrus_calleryana	crw = dbh	3.3114	1.7738		Species
Quercus_alba	crw = dbh dbh*dbh	5.5617	1.8924	-0.0109	Species
Quercus_falcata	crw = dbh dbh*dbh	3.2783	2.3124	-0.0246	Species
Quercus_nigra	crw = dbh dbh*dbh	4.1202	2.269	-0.0263	Species
Quercus_palustris	crw = dbh dbh*dbh	7.7679	1.7229	-0.011	Species
Quercus_phellos	crw = dbh dbh*dbh	3.8672	2.1683	-0.0297	Species
Quercus_prinus	lcrw = ldbh	2.1046	0.4575		Species
Quercus_rubra	crw = dbh dbh*dbh	6.5916	1.7597	-0.011	Species
Quercus_stellata	lcrw = ldbh	1.1202	0.8338		Species
Quercus_velutina	crw = dbh dbh*dbh	4.7156	1.8432	-0.0116	Species
Quercus/live_virginiana	crw = dbh dbh*dbh	4.905	1.959	-0.0166	Species
Rhamnus_cathartica	lcrw = ldbh	1.6671	0.5227		Species

Robinia_pseudoacacia	crw = dbh dbh*dbh	6.4707	2.0431	-0.0381	Species
Salix_nigra	lcrw = ldbh	1.6136	0.6141		Species
Salix_sericea	lcrw = ldbh	1.5732	0.6126		Species
Syringa_vulgaris	lcrw = ldbh	1.6104	0.454		Species
Thuja_occidentalis	crw = dbh dbh*dbh	1.8741	1.0552	-0.0141	Species
Tilia_americana	crw = dbh dbh*dbh	5.2194	1.8045	-0.0195	Species
Tilia_cordata	crw = ldbh	-11.1093	14.6509		Species
Tsuga_canadensis	crw = dbh dbh*dbh	2.9619	1.7751	-0.0242	Species
Ulmus_alata	lcrw = ldbh	1.5054	0.7179		Species
Ulmus_americana	crw = dbh dbh*dbh	5.642	2.0847	-0.0193	Species
Ulmus_crassifolia	crw = dbh dbh*dbh	3.8747	1.9785	-0.0015	Species
Ulmus_pumila	crw = dbh	2.7381	1.6825		Species
Ulmus_rubra	lcrw = ldbh	2.1143	0.4987		Species
Carya_alba	lcrw = ldbh	1.9301	0.5499		Species
Rhus_hirta	lcrw = ldbh	1.6611	0.4203		Species
Cornales	crw = dbh dbh*dbh	5.8018	2.4278	-0.0473	Order
Dipsacales	crw = dbh	9.104	0.6597		Order
Ebenales	lcrw = ldbh	1.7794	0.6205		Order
Ericales	lcrw = ldbh	1.9878	0.4638		Order
Euphorbiales	lcrw = ldbh	1.5739	0.6114		Order
Fabales	crw = dbh dbh*dbh	6.5789	2.0282	-0.0344	Order
Fagales	crw = dbh dbh*dbh	7.1598	1.8053	-0.013	Order
Gentianales	lcrw = ldbh	1.9985	0.3371		Order
Hamamelidales	crw = dbh	5.3249	1.5446		Order
Juglandales	crw = dbh dbh*dbh	5.9877	2.0752	-0.0236	Order
Laurales	crw = dbh dbh*dbh	5.4106	2.023	-0.0303	Order
Magnoliales	crw = dbh dbh*dbh	5.9132	1.9798	-0.019	Order
Malvales	crw = dbh dbh*dbh	4.76	1.7351	-0.0141	Order
Myrtales	lcrw = ldbh	0.7593	0.8744		Order
Pinales	crw = dbh dbh*dbh	1.786	1.732	-0.0221	Order
Rhamnales	lcrw = ldbh	1.6669	0.5314		Order
Rosales	crw = dbh dbh*dbh	5.4942	1.9993	-0.0357	Order
Salicales	crw = dbh	2.6658	1.54		Order

Sapindales	crw = dbh dbh*dbh	5.775	2.1928	-0.0294	Order
Scrophulariales	crw = dbh dbh*dbh	4.4295	2.2431	-0.0344	Order
Urticales	crw = dbh dbh*dbh	5.4569	2.192	-0.0296	Order
Betula	crw = dbh	6.2408	1.5854		Genus
Carpinus	lcrw = ldbh	2.303	0.4174		Genus
Carya	crw = dbh dbh*dbh	6.035	2.0755	-0.0255	Genus
Catalpa	lcrw = ldbh	2.1204	0.4598		Genus
Celtis	crw = dbh dbh*dbh	4.3952	2.6692	-0.0625	Genus
Crataegus	lcrw = ldbh	1.8242	0.4338		Genus
Cupressus	crw = dbh	3.2457	0.6505		Genus
Eucalyptus	lcrw = ldbh	-0.0023	1.1862		Genus
Fagus	crw = dbh dbh*dbh	7.7776	2.4516	-0.0348	Genus
Fraxinus	crw = dbh dbh*dbh	4.5348	2.3021	-0.0356	Genus
Gleditsia	crw = ldbh	1.3613	11.2361		Genus
Juglans	crw = dbh	7.01	1.6792		Genus
Juniperus	crw = dbh dbh*dbh	2.3613	1.764	-0.0299	Genus
Liquidambar	crw = dbh dbh*dbh	4.9881	1.6033	-0.0076	Genus
Liriodendron	crw = dbh dbh*dbh	5.5748	1.9963	-0.0186	Genus
Magnolia	lcrw = ldbh	2.0499	0.4761		Genus
Malus	lcrw = ldbh	1.9915	0.4699		Genus
Morus	crw = ldbh	5.0899	8.2704		Genus
Ostrya	lcrw = ldbh	1.9482	0.5244		Genus
Phellodendron	lcrw = ldbh	2.2625	0.4344		Genus
Picea	crw = dbh dbh*dbh	2.8875	1.4568	-0.0125	Genus
Pinus	lcrw = ldbh	1.3312	0.6651		Genus
Populus	crw = dbh	2.4739	1.5565		Genus
Prunus	crw = dbh dbh*dbh	5.9632	1.9593	-0.0327	Genus
Pyrus	crw = dbh	4.1849	1.5245		Genus
Quercus	crw = dbh dbh*dbh	5.6153	1.9184	-0.0148	Genus
Rhus	lcrw = ldbh	1.6641	0.4392		Genus
Robinia	crw = dbh dbh*dbh	6.7187	1.9207	-0.035	Genus
Salix	lcrw = ldbh	1.6602	0.5908		Genus
Sassafras	crw = dbh dbh*dbh	4.8868	2.1566	-0.0339	Genus

Syringa	lcrw = ldbh	1.5839	0.4015		Genus
Thuja	crw = dbh dbh*dbh	1.7205	1.1558	-0.019	Genus
Tsuga	crw = dbh dbh*dbh	2.9363	1.7714	-0.0239	Genus
Ulmus	crw = dbh dbh*dbh	5.66	1.9969	-0.0177	Genus
Viburnum	crw = dbh	11.0379	0.189		Genus
Aceraceae	crw = dbh dbh*dbh	6.3661	2.102	-0.0267	Family
Anacardiaceae	lcrw = ldbh	1.6627	0.4459		Family
Arecaceae	crw = ldbh	0.2355	3.7689	0	Family
Betulaceae	crw = dbh dbh*dbh	7.0333	1.9312	-0.0309	Family
Bignoniaceae	lcrw = ldbh	2.1261	0.4604		Family
Cornaceae	lcrw = ldbh	2.0322	0.5071		Family
Cupressaceae	lcrw = ldbh	1.0354	0.6262		Family
Euphorbiaceae	lcrw = ldbh	1.5732	0.6126		Family
Fagaceae	crw = dbh dbh*dbh	7.122	1.8167	-0.0132	Family
Hamamelidaceae	crw = dbh	5.5438	1.4528		Family
Lythraceae	lcrw = ldbh	1.917	0.4138		Family
Magnoliaceae	crw = dbh dbh*dbh	5.906	1.9807	-0.0191	Family
Moraceae	crw = ldbh	4.9539	8.2482		Family
Myrtaceae	lcrw = ldbh	0.0761	1.1534		Family
Nyssaceae	crw = dbh dbh*dbh	5.9613	2.0986	-0.0233	Family
Oleaceae	crw = dbh dbh*dbh	4.3871	2.2158	-0.0317	Family
Pinaceae	lcrw = ldbh	1.3208	0.664		Family
Platanaceae	crw = dbh dbh*dbh	6.3993	2.0634	-0.017	Family
Rhamnaceae	lcrw = ldbh	1.6555	0.5428		Family
Rosaceae	crw = dbh dbh*dbh	5.4745	2.0111	-0.0362	Family
Rutaceae	lcrw = ldbh	2.2451	0.3713		Family
Scrophulariaceae	crw = ldbh	4.1441	7.1404		Family
Simaroubaceae	crw = dbh dbh*dbh	4.6508	2.5085	-0.0456	Family
Tiliaceae	crw = dbh dbh*dbh	4.8669	1.7481	-0.0148	Family
Ulmaceae	crw = dbh dbh*dbh	5.4986	2.0888	-0.0227	Family

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