Assessment of the Environmental Service Benefits of the City of New Haven’s Street Tree Population

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Master’s Project
Spring 2007

Image of street tree canopy in Beaver Hills neighborhood. Suzy Oversvee
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ABSTRACT

Environmental services provided by New Haven’s street tree population including energy conservation, improved air quality, carbon dioxide reduction, stormwater runoff reduction and aesthetic benefits were quantified using the U.S. Forest Service model, STRATUM. The results of this study suggest that New Haven’s street tree population has an estimated economic value of $4,036,796. The energy and aesthetics benefits categories contribute the largest amount of economic value to the overall value. The data was analyzed at the species and neighborhood sub-species scales.

I. INTRODUCTION AND PROJECT OBJECTIVES

In 2006, the United States population surpassed 300 million people (Nelson and Lang, 2007). It is expected that by about 2040, the population will gain another 100 million people (Nelson and Lang, 2007). As our population continues to expand at a rapid rate, many areas in the U.S. landscape are urbanizing at an even faster rate. For example, in Connecticut, it is estimated that the rate of land developed is seven times faster than population growth (NRCS, 2007). As the amount of urbanized land continues to grow in the U.S., the significance of the urban forest as an environmental resource is becoming more prominent (Dwyer et al., 2003).

The concept of the urban forest is shifting from a focus on individual trees to a more holistic concept of the urban forest and its interconnections (Dwyer et al., 2003). With this shift, we may also be seeing a shift in the way city planners and officials consider trees in the city budget. As a set of individual trees, the urban forest has traditionally been considered a line-item expense associated with maintenance and planting costs. However, when considering a broader view of the urban forest, quantifiable ecosystem service benefits may provide reason to consider the urban forest as an asset in city budgets.
The objective of this study is to quantify the ecosystem service benefits for New Haven’s street tree population. The specific project objectives include:

- Determine value of ecosystem services of New Haven’s street tree population for the city as a whole and across its neighborhoods.
- Provide data to the City and the Urban Resources Initiative (URI) on the structure of New Haven’s street tree population to aide these entities in developing better informed tree planting and maintenance plans.
- Examine the relationship between New Haven’s street tree population and New Haven’s human population to determine the potential impact of social forces on the structure and value of the tree population.

II. RELEVANCE OF URBAN FORESTRY TO CITY PLANNING

As the urban forest becomes a more prominent feature of our country’s forested landscape, cities across the country are beginning to consider the benefits of the urban forest and its trees above and beyond the aesthetic value to which they have been traditionally limited. These benefits include the ability of urban trees to conserve energy, improve air quality, reduce atmospheric carbon dioxide, reduce stormwater runoff, and increase property values (Maco and McPherson, 2003). In many cases, these benefits contribute to an improved aesthetic and quality of life for city residents. This study will also demonstrate that these benefits translate to economic savings. These benefits will be explored more thoroughly throughout this paper.
Energy

Trees planted near buildings act as a buffer to the effects of extreme temperatures and weather conditions on indoor heating and cooling systems. In the summer, shade from trees keeps homes and buildings cooler, requiring less energy to be expended on air conditioning. In the winter, trees help to insulate buildings from cold temperatures and strong winter winds, requiring less energy to be expended on heating (McPherson and Simpson, 2003).

As street trees are not usually intentionally placed as close to buildings as yard trees, street trees tend to not contribute significant shade effects on buildings. However, street trees do benefit the urban climate by contributing to lowered ambient air temperatures and wind speeds, thus reducing the need for air conditioning and heating in buildings (McPherson et al., 2006).

Air Quality

Urban trees have the ability to improve and conserve air quality in cities by filtering pollutants from the air through deposition, as well as preventing pollutants from being emitted into the air due to fewer emissions from lowered energy use. Air pollution is of great concern in urban areas due to the associated health risks, including heart disease and respiratory illnesses and the related social costs such as absenteeism and greater medical costs (Smith, 1990 in McPherson et al., 2006).
Improved air quality by urban trees is of particular relevance to New Haven. In 1996, New Haven County was found to have the second highest volume of air pollutants out of all New England counties (City of New Haven, 2004).

**Carbon Dioxide Reduction**

Reduction of carbon dioxide through carbon sequestration has become a priority topic in the forestry and environmental communities as the issue of global warming has transitioned from theory to reality. Carbon dioxide, the number one greenhouse gas contributing to global warming, is a primary component in photosynthesis. Plants absorb, or sequester carbon dioxide in the atmosphere during photosynthesis, transforming the gas into stored energy for plant growth. Trees specifically have great ability to sequester carbon dioxide and store large amounts of carbon relative to other plant forms due to their relatively long life spans. As urban centers tend to be large producers of carbon dioxide due to high concentrations of traffic and industry, urban trees can play an important role in sequestering carbon dioxide at the source.

**Stormwater runoff reduction**

Stormwater, particularly water collected on impervious surface during a rain event, has become an issue of major concern when considering water quality. During a rain or storm event, pollutants such as oil, pesticides, fertilizers, fecal matter and litter that have collected on impervious surfaces such as roads and parking lots are washed directly or indirectly through storm sewers, into water bodies such as lakes, streams and rivers. The more impervious surfaces that exist in a watershed, the faster these pollutants enter the water. Vegetation plays an important role in filtering out pollutants before
reaching water bodies. Vegetation also slows water, protecting the hydrology of streams and rivers while preventing flooding.

It is worth noting that a subfield of urban forestry, urban watershed forestry, has recently emerged indicating a growing interest in urban forestry (see sidebar). The Center for Watershed Protection, a national non-profit organization has recently partnered with the U.S. Forest Service to produce manuals urban watershed forestry. This field is particularly applicable to New Haven, with respect to its proximity to Long Island Sound. Using forestry to protect surface waters could also benefit the fishing, oyster and tourism economies in the New Haven region.

Aesthetics

Studies have shown that people value natural features, such as parks, in places where they live. This value has been quantified by examining the difference in real estate prices of houses with yard trees as opposed to similar houses without trees (Anderson and Cordell, 1988 in McPherson and Simpson, 2002).

Stephen Kellert, in *Building for Life: Designing and Understanding the Human Nature Connection* (2005), describes the intrinsic relationship between people and natural features that correspond to better health and improved quality of life. As biological beings, humans tend to respond positively to natural elements, as our species evolved in a non-urban environment (Kellert, 2005). As health concerns continue to rise due to our

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**Sidebar. Urban Watershed Forestry**

“When urban watershed forestry is an integration of the fields of urban and community forestry and watershed planning. Urban and community forestry is the management of the urban forest for environmental, community, and economic benefits, while watershed planning promotes sound land use and resource management to improve water resources within a watershed. Therefore, urban watershed forestry sets watershed-based goals for managing the urban forest as a whole rather than managing forest resources on a site-by-site or jurisdictional basis, and provides strategies for incorporating forests into urban watershed management.” (Cappiella et al., 2005, p.1)
urban lifestyles, there is great opportunity for integrating nature, such as urban forests, into our built environment. Integrating forests into the built landscape may provide a more attractive and comfortable environment for outdoor activity. Trees often improve the streetscape, encouraging social and physical activity, leading to healthier lifestyles.

III. METHODS FOR MODELING URBAN FOREST BENEFITS

The U.S. Forest Service has played a large role in helping communities assess the value of their urban forest. Specifically, research scientists have developed a set of easy-to-use tools and software called i-Tree. i-Tree is a suite of urban forest analysis and data-gathering tools designed for forest managers. For the purposes of this study, a citywide street tree inventory was integrated into STRATUM (Street Tree Resource Analysis Tool for Urban-Forest Managers) to analyze the benefit of New Haven’s street trees.

Site Description

New Haven, Connecticut is a city of approximately 124,000 people (DataHaven, 2007) situated in south-central Connecticut along the Long Island Sound. Three rivers (West River, Mill River and Quinnipiac River) flow through New Haven into Long Island Sound. The city takes up an area of approximately 20 square miles and is comprised of 20 unofficial neighborhoods. Approximately 17% of the city is dedicated to public park space (City of New Haven, 2007).
New Haven’s Street Tree Inventory

In 2000, the City of New Haven hired the consulting firm ACRT to conduct a complete street tree inventory for the city. New Haven Parks received funding from the mayor to conduct the inventory for planning purposes. Hazards posed by street trees have been a major concern for New Haven’s residents (falling branches, root interferences with sidewalks and underground pipes), and therefore are also a major concern for the city’s Aldermanic board. (pers comm. Christy Hass, 2006).

The data collected by ACRT for the inventory included:

- Tree species
- Location (building addresses and lot sides, and GPS survey point)
- Condition
- Size (DBH)
- Maintenance observations

The inventory is comprised of over 30,000 entries that include live trees, dead trees, stumps and potential planting sites.

The data was provided by ACRT to the City of New Haven as multiple GPS point files and a database file containing the inventory information. Each entry in the database was assigned a unique value by ACRT which corresponds to records in the GPS point files. The GPS data format as provided required conversion using GPS Pathfinder Office v2.9. The data was converted to shapefiles files usable in ArcGIS. When viewed in ArcGIS, it was apparent that the data had many inconsistencies. The data was compartmentalized into four subsets that overlapped considerably with each other. In total, the original GPS data as provided by ACRT was comprised of 52,054 points corresponding to the database comprised of 30,508 records. With the help of an outside consultant, a strategy using ArcGIS was devised to eliminate duplicate points and fill in missing points where possible using the inventory data to guide this process. The major assumption made in order to make this exercise possible was that the data points were generally collected in numeric order. In the end, 29,558 points were recovered from the GPS data that correspond to the database inventory which includes 30,508 entries. Thus, 950 points are not included in the map that are included in the inventory. The gap in the data sets may be explained in the absence of trees in the Downtown neighborhood surrounding the town green (Appendix 1).
In order to assign neighborhood information to the inventory data, a roads layer and neighborhood layer were imported into ArcGIS from the City of New Haven Green Map v. 2 (2006). This exercise provided a base map of New Haven that incorporated the street tree inventory database, tree locations, neighborhoods, and streets.

**STRATUM**

STRATUM is a computer model developed by a team of research scientists at the U.S. Forest Service Pacific Southwest Research Station’s Center for Urban Forest Research. The model is described by the Forest Service as “an easy-to-use, computer-based tool that enables any community to assess its street tree resource (*i-Tree Software Suite User’s Manual*, p 26).”

STRATUM analyzes street tree inventories to quantify the following benefits:

- **Energy conservation** - Energy benefits are broken down into total electricity savings in Megawatt Hours (MWh) and dollars and total natural gas savings measured in therms and dollars.

- **Air quality improvement** - Air quality benefits are measured in terms of pounds of pollutants deposited on street trees, including Ozone (O$_3$), Nitrogen Dioxide (NO$_2$), Particulate Matter (PM$_{10}$) and Sulfur Dioxide (SO$_2$) and the related economic value. Air quality benefits are also measured in terms of pounds of pollutants avoided from being released into the atmosphere through energy savings and the related economic value. These avoided pollutants include NO$_2$, PM$_{10}$, VOCs and SO$_2$. Trees also contribute pollutants into the atmosphere in the form of biogenic volatile organic compounds (BVOCs) that contribute to the
formation of smog. These estimated negative emissions are included in the results.

- **Carbon dioxide reduction** - Benefits related to carbon dioxide reduction by street trees are measured and reported in terms of pounds sequestered, pounds avoided, pounds stored and the related economic value. The cost of ?? is also taken into account. Street trees release carbon dioxide into the atmosphere through decomposition and maintenance activities.

- **Stormwater runoff reduction** – Stormwater runoff reduction is measured in terms of gallons of stormwater intercepted by trees and the related economic value in dollars.

- **Aesthetics** - Aesthetic value is estimated based on the capability of street trees to raise real estate values and is reported in dollars.

STRATUM also has the ability to analyze the structure (species composition, size distribution, and condition) of the street tree population, provide a cost-benefit analysis taking into account the benefits provided by street trees as well as their management costs, and provide maintenance recommendations (*i-Tree Software Suite User’s Manual*, 2006). To fulfill the objectives of this study, STRATUM was used to characterize the structure of New Haven’s street tree population, quantify the environmental benefits provided by the population, and analyze this data for the city as a whole as well as at a neighborhood scale.

Data from the re-worked New Haven street tree inventory that included neighborhood data was imported into STRATUM. This required an MSAccess database to be developed that included tree names, size, condition and neighborhoods.
Various STRATUM models have been developed to correspond to 10 of 19 different climate zones throughout the country. The *i-Tree Software User’s Manual* places New Haven in the Northeast climate zone, which extends from the southwest corner of Pennsylvania northeast to Portland, Maine. Although the valuation approach to calculating benefits in STRATUM is consistent across the different models, each model is specific to its climate region (pers. com., Maco, 2007). For example, the rate at which a tree grows is partly dependent on climate. Therefore, street trees in different climate zones are likely to grow at different rates, which will affect the amount of carbon they are able to sequester in a year. Likewise, many of the specific economic values in this study vary from region to region. For example, the economic value of energy savings in a particular climate zone is based on the prices of energy in that region (McPherson et al., 2006).

The Forest Service Pacific Southwest Research Station has written a number of “tree guides” that correspond to the various climatic zones and explain the methodology behind estimating the street tree benefits and costs in STRATUM for each region. Unfortunately, at the time of this writing, the “tree guide” for the Northeast climate zone has not been released. Because the “tree guide” for the Northeast climate zone is not available, the Piedmont climate zone was used for this study. An excerpt from the “tree guide” that corresponds to the Piedmont climate zone explaining the approach to estimating benefits and costs in that zone is presented in Appendix 3.


**Standardizing STRATUM data**

Since New Haven’s neighborhoods vary in size and in the amount of streets present, an attempt to standardize the STRATUM data was made by dividing the total benefits of each neighborhood tree sub-population by the total street length in each neighborhood (excluding interstates and interstate ramps). The number of street trees per street mile was also calculated to see if this parameter corresponds to total benefits per street foot.

**Social Science Research**

The potential social forces effecting the structure and value of New Haven’s street tree population were examined using the following methods:

1. As neighborhoods often help define a certain social identity for different sections of a city, the tree data for the city was examined at the neighborhood scale. New Haven is partitioned into 20 neighborhoods as defined by the City of New Haven City Plan Department (DataHaven, 2007) which were used in this study.

2. Household income and poverty data from the 2000 U.S. Census was used as a measurement for the level of socioeconomic resources available to each neighborhood. This data was obtained from DataHaven, an online research tool that provides demographic information for south central Connecticut. DataHaven is the only source that provides this information at the neighborhood scale for New Haven (DataHaven, 2007).

3. The neighborhoods used as case studies in the discussion section were visited to ground truth research findings through qualitative visual observation.
IV. RESULTS

The results reported from the STRATUM analysis are organized as follows:

- Resource Structural Analysis
  - Population summary
  - Species distribution
  - Relative age/diameter distribution, and
  - Condition

  (Each of the above structural components are reported at the city, species and neighborhood scales.)

- Annual Benefits Analysis
  - Annual economic value summary
    - By neighborhood
    - By species
  - Analysis by STRATUM benefits categories
    - Energy savings
    - Air quality improvements
    - Carbon dioxide reduction
    - Stormwater runoff reduction
    - Aesthetics

Results from social research data gathering include household income and poverty statistics by neighborhood, and photographs from the site visits.
Resource Structural Analysis

Population Summary

Ninety-nine percent of New Haven’s street tree population falls under STRATUM’s Broadleaf Deciduous category, with 78% classified as Broadleaf Deciduous Large. New Haven has very few evergreen species within its street tree population.

A detailed list of the quantity of each species falling under each of these categories in New Haven’s street tree population can be found in Appendix 4. Population summaries for each neighborhood are also included in Appendix 4.

Species Distribution

New Haven’s street tree population is comprised of 97 different tree species. The ten most abundant species representing 77% of the total population are listed in Table 1.

Table 1. Percentage population of New Haven street trees.

<table>
<thead>
<tr>
<th>Species</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway maple</td>
<td>21.3</td>
</tr>
<tr>
<td>Pin oak</td>
<td>12.5</td>
</tr>
<tr>
<td>London planetree</td>
<td>9.2</td>
</tr>
<tr>
<td>Sugar maple</td>
<td>6.0</td>
</tr>
<tr>
<td>Northern red oak</td>
<td>5.8</td>
</tr>
<tr>
<td>Honeylocust</td>
<td>5.1</td>
</tr>
<tr>
<td>Littleleaf linden</td>
<td>4.9</td>
</tr>
<tr>
<td>Red maple</td>
<td>4.8</td>
</tr>
<tr>
<td>Callery pear</td>
<td>4.2</td>
</tr>
<tr>
<td>Japanese zelkova</td>
<td>3.5</td>
</tr>
<tr>
<td>Other species</td>
<td>22.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>
Of the 20 New Haven neighborhoods defined in this study, Norway maple is the most abundant species in 11 of these neighborhoods. The five most abundant species in each neighborhood and their proportions are listed in Appendix 4.

Relative Age/Diameter Distribution

The largest proportion of New Haven’s ten most abundant street tree species are within the 6-12 inch (22.0%) and 12-18 inch (22.1%) diameter classes. The smallest proportion of these species fall within the 36-42 inch (2.9%) and >42 inch (2.3%) diameter classes.

The relative age distributions of the ten most abundant species in New Haven are reported in Appendix 4. Highlights from this report are as follows:

- London planetree comprises the highest relative proportion of the two largest diameter classes, 36-42 inches and >42 inches.
- Callery pear comprises the highest relative proportion of the two smallest diameter classes, 0-3 inches and 3-6 inches.

The relative age distributions of the ten most abundant species in each neighborhood are reported in Appendix 4.

Condition

Observations on tree condition were made on all street trees in the inventory according to the following scale: Excellent, Good, Fair, Poor, Critical, or Dead.

Overall, 50% of the total population was rated as being in Good condition. The remaining half of the population was mostly in Fair condition (35%). A summary of the
species and neighborhood sub-populations with the highest proportion of trees in each category is described in Table 2:

### Table 2. Proportions of tree population and sub-populations by condition ratings.

<table>
<thead>
<tr>
<th>Condition</th>
<th>% of total population</th>
<th>Species with highest proportion of each condition (% of sub-population)</th>
<th>Neighborhood with highest proportion of each condition (% of sub-population)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>1.8%</td>
<td>Elm(^1) (5%)</td>
<td>Prospect Hill (6.3%)</td>
</tr>
<tr>
<td>Good</td>
<td>50.3%</td>
<td>Callery pear (72%)</td>
<td>Westville (72.8%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ash(^1) (72%)</td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td>35.2%</td>
<td>American elm (45.5%)</td>
<td>Long Wharf (51.5%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Norway maple (43.5%)</td>
<td>Dwight (49.6%)</td>
</tr>
<tr>
<td>Poor</td>
<td>9.5%</td>
<td>Sugar maple (18.8%)</td>
<td>West River (14.3%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Norway maple (18.2%)</td>
<td></td>
</tr>
<tr>
<td>Critical</td>
<td>0.4%</td>
<td>American elm (1.5%)</td>
<td>Long Wharf (2.4%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sugar maple (1.5%)</td>
<td></td>
</tr>
<tr>
<td>Dead</td>
<td>2.7%</td>
<td>Sugar maple (10.6%)</td>
<td>Edgewood (6.1%)</td>
</tr>
</tbody>
</table>

\(^1\) Some species of Elm and Ash were not recognized by STRATUM for the Northeast climate region. These undefined species are collectively referred to by their genus designations.

Tree condition details for species and neighborhood sub-populations are reported in Appendix 4.
Annual Benefits Analysis

Annual economic value summary

The economic value of New Haven’s street tree population based on the environmental benefits provided by street trees is presented in Table 3.

Table 3. Annual economic value of New Haven street tree population benefits.

<table>
<thead>
<tr>
<th>Environmental Benefits</th>
<th>Annual Economic Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy savings</td>
<td>$1,699,820</td>
</tr>
<tr>
<td>Aesthetic benefit</td>
<td>$1,556,403</td>
</tr>
<tr>
<td>Stormwater attenuation</td>
<td>$424,546</td>
</tr>
<tr>
<td>Air quality improvement</td>
<td>$309,995</td>
</tr>
<tr>
<td>Carbon dioxide sequestration</td>
<td>$46,031</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$4,036,796</strong></td>
</tr>
</tbody>
</table>

According to these results, the economic value of New Haven’s street tree population is most greatly attributed to its energy savings and aesthetic value. Carbon dioxide sequestration contributes the least economic value to the overall total benefit. The average New Haven street tree has an annual economic value of $152.74 (see Appendix 4).
ECONOMIC VALUE SUMMARY BY NEIGHBORHOOD

Across all categories, Westville’s street tree population had the highest economic value, totaling $426,000 annually. Long Wharf had the lowest economic value across all categories, totaling $24,904 annually.

After standardizing the data, Beaver Hills ranked at the top of the neighborhoods in terms of annual benefits per street foot at $4.26. Westville ranked fourth at $3.47 and Long Wharf remained at the bottom with the least value at $0.68 per foot (see Figure 2).

Figure 2. Annual economic street tree benefits standardized by street length

Roughly speaking, across the city the amount of trees per mile appeared to have some bearing on the amount of benefits per foot. However, there is much variation in this relationship. Newhallville, ranking third in terms of economic value per foot, has the largest number of trees per mile. Long Wharf has the fewest trees per mile, consistent with its lowest value ranking in terms of benefits per foot. Westville ranks eighth with Dwight in terms of trees per mile (see Figure 3).
Beaver Hills and Westville rank highest in terms of economic value per tree with the average street tree in each neighborhood valued annually at $179.34 and $178.17 respectively. Downtown trees have the lowest annual economic value at $119.30 per tree. The annual average tree value for each neighborhood is detailed in Appendix 4.

ECONOMIC VALUE SUMMARY BY SPECIES

The economic value per tree by species ranges between the highest valued species, American elm, at $278.36 and the lowest valued species, Apple, at $35.54. The Kwanzan cherry is valued just slightly higher than Apple at $35.70 per tree, whereas the American elm is valued much higher than the next most valuable species categories. These highest and lowest values for these species generally hold true across all benefits categories. Details on the economic value per street tree by species can be found in Appendix 4.
In total, the Norway maple sub-population contributes the largest economic value to New Haven’s total street tree population at $885,941 per year. The Apple sub-population contributes the lowest economic value at $9,490 per year. However, it is wise to keep in mind that Norway maple makes up the largest proportion of the street tree population at 21.9% whereas the Apple population makes up 0.2% of the total street tree population. Details regarding the economic value that species sub-populations contribute to the overall tree population can be found in Appendix 4.

*Analysis by STRATUM benefits categories*

**ENERGY**

In total, New Haven’s street tree population saves the city 2,667.4 Mwh of electricity, with an estimated value of $373,699, and 941,847 therms of natural gas, with an estimated value of $1,326,121.

Westville demonstrates the highest amount of annual energy savings ($180,367), whereas Long Wharf has the lowest amount of annual energy savings ($10,551). On a per tree basis, Beaver Hills has on average the most valuable trees in terms of annual energy savings ($77.69 per tree). Downtown had the least valued trees in terms of annual energy savings ($43.73 per tree).

The Norway maple sub-population provides the largest amount of annual energy savings ($364,093), whereas the Apple sub-population provides the least amount of annual energy savings ($3,789).

The American elm provides the highest energy savings per tree at $109.17. The next highest savings is from the Northern red oak at $88.94 per tree. The species with the
lowest value per tree in energy savings are Apple ($17.14 per tree) and Kwanzan cherry (18.78 per tree).

Street tree energy values by species and neighborhood are detailed in Appendix 4.

AIR QUALITY

In total, it is estimated that a net total of 59,951 lbs of air pollutants are taken from the atmosphere by New Haven street trees each year. Of this total, 31,863 lbs are deposited and 36,492 lbs are avoided. BVOC emissions are estimated to be 8,402 lbs. The annual total net economic value of air quality benefits is estimated to be $309,995.

Westville accounts for the largest amount of pollutants deposited and avoided at 6,595 lbs or $34,174 annually. Long Wharf accounts for the least amount of pollutants deposited and avoided at 351 lbs or $1,906 annually.

Street trees in Beaver Hills are estimated to have the highest amount of economic worth per tree at $14.77 annually followed by Westville at $14.29 annually and then followed by Amity at $14.22 annually. The neighborhoods with the lowest valued trees in terms of air quality benefits are Downtown at $7.80 per tree, Edgewood at $8.83 per tree and Dixwell at $9.42 per tree annually.

The Norway maple sub-population contributes the largest amount of benefits to air quality with 13,701 lbs deposited and avoided, equating to $67,231 annually. The next highest valued sub-population is Pin oak with 8,604 lbs deposited and avoided equated to $47,592 annually.

American elm has the highest annual value per tree in terms of air quality benefits at $22.63 per tree, followed by the Northern red oak at $16.44 per tree.
the lowest annual value are the Apple at $2.76 per tree and the Kwanzan cherry at $2.95 per tree. The average New Haven street tree has an annual economic value of $11.73 per tree in terms of air quality benefits.

Detail regarding annual air quality benefits can be found in Appendix 4.

CARBON

*Carbon sequestration and avoidance*

In total, New Haven’s street trees sequester 7,516,183 lbs of carbon dioxide annually, equating to $25,104. The total carbon released through decomposition is 1,443,061 lbs per year and through maintenance is 325,345 lbs per year. Total carbon released through decomposition and maintenance is valued at $5,906 per year.

Total carbon dioxide avoided annually is 8,034,091 lbs per year valued at $26,834 annually. The net total of pounds of carbon avoided and sequestered comes to 13,781,868 lbs, equating to an estimated net benefit of $46,031 annually.

In terms of carbon sequestered and avoided, Westville’s street trees have the highest aggregate annual value at $5,138. The lowest aggregate annual value comes from the Long Wharf neighborhood at $275.

In terms of average annual value per tree for carbon sequestration and avoidance, Beaver Hills has the highest annual economic value at $2.30 per tree followed by Westville at $2.15 per tree and then Annex at $2.12 per tree. The neighborhood with the lowest valued trees for this category is Downtown at $1.14 per tree. On average, New Haven’s street trees are worth an annual $1.74 per tree for this category.
The Norway maple sub-population has the highest economic value for carbon sequestration and avoidance at $12,014 per year. The Apple sub-population has the lowest economic value at $77 per year. Per tree, American elm has the highest average annual value at $3.15 per tree followed by Pin oak at $2.49 per tree and Northern red oak at $2.43 per tree. The species with the lowest average annual value is Apple at $0.29 per tree.

*Carbon Stored*

New Haven’s street tree population stores an estimated 168,755,600 lbs of carbon annually, with an estimated economic value of $563,644. The average New Haven street tree is worth $21.33 in terms of its carbon storage capabilities. Westville’s sub-population has the most carbon stored, worth $80,992. The Long Wharf sub-population has the least amount of carbon stored worth $3,470, followed by the West Rock sub-population at $4,739. Street trees in Beaver Hills have the highest annual economic worth on average at $34.35 per tree, followed by Westville at $33.87 per tree. The Downtown sub-population has the lowest annual economic value at $10.61 per tree, followed by the Wooster Square/Mill River sub-population at $12.33 per tree.

The Norway maple sub-population stores the most carbon, valued at $128,481 per year. The Apple sub-population stores the least amount of carbon valued at $707 per year. Per tree, American elms have the highest average annual storage capacity valued at $41.96 per tree, followed by Northern red oak at $40.83 per tree. Japanese zelkova has the least average economic value at $2.64 per tree, followed by Apple at $2.65 per tree.
and Callery pear at $3.00 per tree. The average annual economic value of a New Haven street tree in terms of carbon storage is $21.33 per tree.

Details regarding the amount and value of carbon sequestered, avoided and stored can be found in Appendix 4.

STORMWATER

New Haven’s street tree population intercepts a total of 53,064,590 gallons of rainfall annually, equating to an estimated value of $424,546. Thus, the average New Haven street tree is valued at $16.06 in terms of stormwater attenuation.

Westville intercepts the largest amount of stormwater (6,303,233 gallons) and Long Wharf intercepts the least amount of stormwater (356,372 gallons) annually. On a per tree basis, Beaver Hills and Westville are most highly valued in terms of rainwater interception at $21.44 and $21.09 per year respectively. Downtown and Edgewood tree have the least amount of value at $10.45 and $11.72 respectively.

The Norway maple sub-population provides the most value for stormwater attenuation, intercepting 9,998,143 gallons of rainwater annually. The Apple sub-population intercepts 91,898 gallons which is the least amount of stormwater intercepted by a species sub-population annually.

In terms of average economic value per tree for stormwater, American elm has the highest annual value at $31.55 per tree followed by the Northern red oak ($24.52 per tree) and Pin oak ($21.58 per tree). The species with the least annual economic value are Kwanzan cherry ($2.69 per tree) and Apple ($2.75).

Details regarding stormwater savings can be found in Appendix 4.
AESTHETICS

It is estimated that New Haven’s street tree population has an annual aesthetic value worth $1,556,403 with the average street tree worth $58.89 per year.

Westville has the highest valued sub-population worth $155,890 per year, followed by Fair Haven at $152,179 per year. The Long Wharf sub-population has the lowest aesthetic value at $9,321 per year.

Per tree, the neighborhood with the most highly valued trees is Westville at $65.20 per tree per year. The lowest aesthetically valued trees are in Quinnipiac Meadows where on average, the street trees are worth $48.15 per tree per year. The spread in economic worth for aesthetic value is relatively small compared to the other benefits categories across neighborhoods.

The Norway maple sub-population contributes the most aesthetic economic value at $362,612 per year. The Apple sub-population contributes the least worth at $3,363 per year.

On average, the American elm is most highly valued in terms of aesthetic value at $111.85 per tree per year, followed by Elm species at $90.54 per tree per year. The least valued species on average is the Kwanzan cherry at $10.55 per tree per year, followed by the Apple at $12.60 per year.

Details on aesthetic value can be found in Appendix 4.
Social Science Research Results

Results from social research data gathering include household income and poverty statistics by neighborhood are included in Appendix 5. During the site visit, typical streets in specific neighborhoods were identified and photodocumented (see Section V).

V. DISCUSSION: NEIGHBORHOOD CASE STUDIES

To provide an in-depth examination of the potential interconnectedness between the social and biophysical forces at play affecting the results of this study, four neighborhoods were chosen to focus the discussion. The Westville, West Rock, Beaver Hills and Newhallville neighborhoods were selected based on the somewhat unexpected and perplexing results for these neighborhoods and the interesting stories that result. If time allowed, numerous additional stories could be told about the other New Haven neighborhoods as well.

Westville

In all categories of benefits examined, as a neighborhood, Westville’s street tree population contributes the highest value of environmental services to New Haven’s street tree population. This is not all that surprising when considering that Westville is one of New Haven’s wealthiest neighborhoods with respect to household income and a relatively low level of poverty (see Appendix V).

The likely reason for this result is that Westville’s street tree population accounts for 9% of New Haven’s total street tree population, second only to Fair Haven which
accounts for 9.4% of the city’s total street tree population. Also, Westville has the highest proportion (72.8%) of trees in Good condition relative to the rest of the neighborhoods.

However, it is interesting to note that when looking at the benefits data standardized by street length, Westville ranks fourth behind Newhallville, a neighborhood generally thought to be lacking in resources. In fact, Westville has an average of $0.42 fewer benefits than Newhallville in terms of economic value per foot. When looking at this data across neighborhoods, this is a clear break between the highest valued tier of neighborhoods and the second out of four value tiers (see Figure 2).

Perhaps even more interesting, but telling, is that Westville has relatively few trees per street mile compared to the neighborhoods in the upper value tier, as well as neighborhoods with fewer economic benefits per foot than Westville. Westville has only 103 trees per mile, equal to Dwight, which ranks tenth in terms of benefits per foot. Newhallville, on the other hand, has 146 trees per mile, the most trees per mile of any neighborhood.

Even though Westville’s street tree population is contributing greatly to the overall New Haven population in both quantity and quality (it is second only to Beaver Hills in terms of average tree value), when examining this data in respect to street length, it appears that Westville has a great opportunity to plant even more street trees to contribute to the overall tree canopy. This is further confirmed in looking at the density of available planting sites in Westville (refer to Appendix 1).

The field visit confirmed the findings for this neighborhood. Westville has many streets lined with grandiose shade trees, but also has areas lacking street trees altogether.
In fact, when comparing a photo of a street in Westville to one in West Rock, a neighborhood with one of the lowest valued street tree resources, it is not easy to tell one from the other (Figure 4).

![Image of Westville (left) compared to image of West Rock (right).](image)

**Figure 4. Image of Westville (left) compared to image of West Rock (right).**

*West Rock*

This study suggests that West Rock has the lowest valued street tree population out of all New Haven neighborhoods, with the exception of Long Wharf. This may not be all that surprising when considering that the West Rock neighborhood is one of New Haven’s poorest. According to the 2000 U.S. Census, over 50% of West Rock’s residents live below the poverty line. This is the highest proportion of poverty out of any New Haven neighborhood. For comparison, approximately 24% of all of New Haven’s residents live below the poverty level (DataHaven, 2007).

In looking at West Rock’s street tree resource, West Rock’s street tree value by street length is second only to the Long Wharf neighborhood in terms of having the lowest value. West Rock is also second only to Long Wharf in terms of the fewest
number of street trees per street length. It should be noted here, though, that no New Haven residents live in the Long Wharf area.

Ironically, the West Rock neighborhood contains one of New Haven’s largest contiguous forested urban parcels, West Rock Park. Thus, even though West Rock’s street tree population may be contributing relatively few environmental benefits to the neighborhood, the area is most likely reaping many of these benefits from the adjacent West Rock Park not taken into account in this study. Furthermore, although the West Rock neighborhood has relatively few street trees, much of the neighborhood is still quite green and shaded by trees. On my site visit, I noticed many front yard trees close to the street that should essentially provide the same services to the community as street trees. The neighborhood’s tree canopy along the street is patchy throughout the neighborhood, mostly lacking along the public housing project area. However, the neighborhood as a whole does certainly does not feel barren as could be led to believe by the data.

The streets along the public housing development generally feel less shaded than the rest of the neighborhood (Figure 4). However, several young street trees are present along stretches of these roads, which will likely benefit the community by increasing scales in years to come.

Figure 5. Vegetated image in West Rock neighborhood.
Beaver Hills

Beaver Hills is quiet, with well-maintained single-family homes, beautiful yards and abundant mature and healthy shade trees lining the streets. According to the results of this study, Beaver Hills has the most valuable street tree resource per street length (Figure 2). In most of the environmental service categories, these trees provide the most environmental services on a per tree basis. Beaver Hills has a consistent pattern of large healthy-looking trees lining its streets with few places to plant additional trees.

My expectation from visiting Beaver Hills was that this neighborhood would be classified primarily as an upper-middle class neighborhood, making it consistent with the assumption that neighborhoods with more socioeconomic resources should have a more valuable street tree resource. However, the U.S. Census data is not so clear in this assumption. In looking at yearly household income, the largest percentage of Beaver Hills households, 20.2%, is between $50,000 and $75,000 per year, suggesting its upper to middle class status. However, the percentage of its residents living below the poverty line, also 20.2%, is larger then expected. For comparison, Westville, a relatively affluent neighborhood, has 6.9% of its population living below the poverty line according to the 2000 U.S. Census. However, areas of Westville look less affluent than most of Beaver Hills. Furthermore, Beaver Hills has a slightly higher percentage of people living under the poverty line than Newhallville, a neighborhood thought to have many socioeconomic challenges. Thus, in the case of Beaver Hills, it seems that the quality and quantity of
street trees is not necessarily a result of present affluence in the neighborhood, but may in fact contribute to a greater sense of affluence than what actually exists.

![Figure 6. Tree-lined streets in Beaver Hills neighborhood.](image)

Newhallville is a neighborhood perceived by many New Haven residents to have a large assortment of serious socioeconomic challenges, among them racial tensions, gang violence and random shootings.

Thus, I was surprised to see Newhallville competing with Beaver Hills and Wooster Square for the neighborhood with the most valuable tree resource, and surpassing Westville. When looking at the U.S. Census data, I am also surprised to see that the percentage of Newhallville’s population living under the poverty line is actually slightly lower (19.9%) than that of Beaver Hills. Although nearly 20% of Newhallville’s households have an income of less than $10,000 annually, a larger proportion (20.2%) bring in between $35,000 and $50,000 annually, and 16.2% brings in between $50,000 and $75,000. When compared to Beaver Hills and West Rock, Newhallville can hardly be considered “poor.” This is further confirmed by the pictures from my visit. When looking for a good picture opportunity to portray my feelings of Newhallville as a socioeconomically challenged neighborhood, I was hard pressed to find one.
The relatively high value of Newhallville’s street tree resource probably largely lies in the fact that Newhallville has more trees per mile than any other neighborhood in New Haven (Figure 3).

When looking at the couple of pictures I took of Newhallville on my visit, the neighborhood does not stand out to me as in dire need of a vigorous tree planting effort. In fact, on past visits, I noticed that some of the residents take great pride in maintaining their streets and improving them through plantings. This is evidenced in the many well-maintained planting beds around the street trees containing perennials that are carefully protected with small fencing.

VI: STUDY LIMITATIONS

Like all models, STRATUM is limited in its capability to portray reality. Models do not produce empirical results based on strict scientific experiments. Instead, models make calculated assumptions to paint a picture of a best guess on reality. Since models
are developed by people, the assumptions and inner workings of models are inherently biased.

However, conducting a laboratory experiment on something as large and dynamic as measuring the ecosystem service benefits of street trees would be nearly impossible. Thus, a model such as STRATUM is a very valuable tool for at least getting an idea of the value of street tree resources. However, it is important for resource managers relying on the results of such models to be reminded that these results are best estimates that may be refined through ground-truthing the results for their particular situation.

A model is also only as useful as the data that is put into it. The data used in this study was collected in 2000, which is the most recent (and perhaps only) complete dataset for New Haven’s street tree population, and deficiencies in that data were apparent. In the past seven years, trees have certainly grown, some have likely declined in health, and trees have been planted and removed. Thus, even though the results of this study portray a picture of New Haven’s street tree population for 2000, they are no means 100% accurate. Luckily, although the urban environment is dynamic, trees themselves do not tend to change dramatically in the course of a few years. Thus, the results of this model are likely a reasonable portrayal of reality, but should not be heavily relied upon as accurate and empirical measurements.

Although this study does not account for the costs of maintaining New Haven’s street tree population, STRATUM does have the ability to conduct a cost-benefit analysis to determine the net economic value of street tree populations. This sort of an analysis would require more detailed municipal budget information than I was able to find. However, including the costs in a future analysis is required for a balanced estimate of
the worth of the street tree population. The costs should not only include the maintenance required to keep the tree population healthy, but also the costs incurred by the city in terms of sidewalk repairs, storm damage costs to private property by falling trees and limbs, etc.

In order to fulfill the objective of analyzing street tree ecosystem services across neighborhoods, it was necessary for the tree data entered into STRATUM to be associated with the appropriate neighborhoods. As mentioned earlier, the original inventory data did not include neighborhoods. Connecting the data of each tree to a specific neighborhood was accomplished by integrating GPS coordinates with the inventory data in ArcGIS. However, once this exercise was completed, it was apparent that the GPS data for the “Downtown” neighborhood was incomplete. Thus, the STRATUM data for Downtown is also incomplete and should not be heavily relied upon. Also, the total benefits for New Haven are likely less than what they would be if the Downtown data was complete. In total, the STRATUM results reflect approximately 950 entries missing from the inventory, the majority most likely missing from Downtown.

VII. CONCLUSION

This study demonstrates that New Haven’s street tree population provides benefits to the City above and beyond its aesthetic value. By taking into account the positive environmental externalities provided by the street tree population, we begin to understand a more accurate accounting of the value of urban trees.
Quantifying the environmental services provided by street trees provides helpful information for driving management decisions regarding many urban environmental problems such as poor air and water quality, and extreme urban climate effects. The information presented in this study demonstrates a method for generating quantifiable data to help develop street tree management plans tailored to these concerns. However, before moving forward in developing management plans, it is recommended that the inventory be updated and run through STRATUM again to produce data that is more reflective of the present conditions of New Haven’s street tree population.

ACKNOWLEDGEMENTS

I thank Colleen Murphy-Dunning at URI, and Dr. Bill Burch for their abundant guidance and support of this project.

I thank Jeff Ward with the Department of Forestry and Horticulture at the Connecticut Agricultural Station for providing me with the New Haven street tree inventory.

I thank Scott Maco with the Dave Tree Expert Company for issuing me an advanced version of STRATUM and for his technical support.

I especially thank Steve Quarterman with Straughn Environmental Services for his time and technical support on the mapping component of this project.
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