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USING LIDAR DATA AND GEOGRAPHICAL INFORMATION SYSTEM (GIS) TECHNOLOGY TO ASSESS MUNICIPAL STREET TREE INVENTORIES

By

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Mississippi State, Mississippi

August 2011

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USING LIDAR DATA AND GEOGRAPHICAL INFORMATION SYSTEM (GIS) TECHNOLOGY TO ASSESS MUNICIPAL STREET TREE INVENTORIES

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Market and nonmarket urban forest resource values can be achieved through many cost reductions (e.g., improved air quality, fossil fuels for heating and cooling, stormwater runoff) and increases in tax bases for communities from improved property values. These benefits need to be measured quantitatively so decision makers can understand economic gains or losses provided by street trees. Resource inventories are often undertaken as part of the planning phase in a tree management program. It is a comprehensive assessment that requires an inventory of a community's tree resources and it acts as a fundamental starting point for most urban and community forestry programs. Whether an inventory is an estimate or a complete count, quantitative benefits and costs for urban forestry programs cannot accurately be represented without one.

This study provides a new approach to understanding a city’s street tree structure using data from a Light Detection And Ranging (LiDAR) sensor and other publicly available data (e.g., roads, city boundaries, aerial imagery). This was accomplished through feature (e.g., trees, buildings) extraction from LiDAR data to identify individual trees. Feature extraction procedures were used with basic geographic information system

(GIS) techniques and LiDAR Analyst to create street tree inventory maps to be used in determining a community's benefit/cost ratio (BCR) for its urban forest.

Only by explaining an urban forest's structure can dollar values be assigned to street trees. Research was performed with LiDAR data and a sample of ground control trees in Pass Christian, and Hattiesburg, Mississippi, located in the lower U.S. South where many communities have publicly available geospatial data warehouses (e.g., MARIS in Mississippi, ATLAS in Louisiana). Results from each city's estimated street trees revealed a BCR 3.23:1 and 6.91:1 for Pass Christian and Hattiesburg, respectively.

This study validated a regression model for predicting street tree occurrence in cities using LiDAR Analyst and a street sample. Results demonstrated that using LiDAR Analyst as a street tree inventory tool with publicly available LiDAR data and a sample adequately described 88% of a community's street trees which was used to calculate both market and nonmarket resource values.

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CHAPTER I

INTRODUCTION

A major land use issue faced by communities is expanding urbanization. The United States population roughly doubled between the late 1950s and 2000, and the population of the U.S. South has grown at an even faster rate (USSRS 2005). An ever increasing urban population, especially in the Sunbelt, has led to unchecked growth, with living and environmental conditions deteriorating at an alarming pace in many urban areas. The proportion of the U.S. population living in the South grew from 30.7% in 1990 to 32.5% in 2000. People tend to move to, and expand, urban/suburban areas. Urbanization has had, and will have, a substantial impact on the extent, condition, and health of a municipality's surrounding forests and other natural resources.

As urbanization, development, and building abandonments continue to degrade city environments, planners and managers must rely on professionals to effectively manage and reverse this process and its effects on the urban forest using a sustainable approach. Many urban planners in metropolitan areas have access to computer-aided programs allowing them to develop a comprehensive inventory of public and private trees as well as permitting documentation (i.e., inventory growth and yield) of their urban forest over time. As a result, urban forestry will continue to expand its importance and become more readily recognized as spatial modeling techniques and information technologies are developed and justified in their use for qualifying and quantifying forest inventories and benefits and costs of the urban forest.

An important aspect to urban forestry development is the Nation's 16 regional tree growth zones (e.g., Coastal Plain zone for Charleston, South Carolina; South zone for Charlotte, North Carolina) as identified by the Center for Urban Forest Research (CUFR) in Davis, California (McPherson 2005). Each growth zone has had an extensive analysis conducted by CUFR to establish relationships between the top 20 tree species found in each zone, by tree age, size, leaf area, and foliar biomass; all parameters used to apply dollar values for each species specific zone. Now that these growth zones are completed, more urban and community forestry programs will have enhanced capabilities for quantifying their resources with a higher level of confidence when analyzing benefits and costs for street tree management.

For a building to stand firm and endure through the years, a strong foundation is required to maintain structural integrity. This principal holds true when building a municipal Geographical Information System (GIS) program to identify items needed such as street tree inventories, fire hydrant inventories, and list of parcels within their respective zoning districts. The foundation for a street tree inventory is an accurate base map which will determine functionality of the municipality's GIS. There are many base maps readily available; however, choosing the appropriate base map depends on functionality and intended use. Base maps that can function in combination with utility infrastructure, emergency address locations, law enforcement, municipal land use, and urban planning applications provide strong foundations (Bloniarz 2003). As an example, customized layers of geographic and attribute data regarding land uses, are generally defined with color arrays. However, without an accurate base map to overlay or compare them to, these splashes of color will look more like an abstract painting on your computer screen than designations of residential, commercial, or agricultural properties.

Urban Forestry

The Cooperative Forestry Act of 1978 offered a statutory definition of urban and community forestry. "Urban Forestry is defined as the planning, establishment, protection, and management of trees and associated plants, individually, in small groups, or under forest conditions within cities, their suburbs, and towns" (Miller 1998). USDA Forest Service (USDA FS) guidance amplified this, defining urban forest management as the "planning for and management of a community's forest resources to enhance the quality of life. The process integrates economic, environmental, political, and social values of the community to develop a comprehensive management plan for the urban forest" (Miller 1998).

The USDA FS has adopted and funded a strategic initiative to coordinate the integration and dissemination of inventory software tools such as Mobile Community Tree Inventory (MCTI), Urban Forest Effects Model (UFORE), and Street Tree Resource Analysis Tool (STRATUM). STRATUM, an integrated software suite, can be used to generate a benefit/cost (B/C) analysis for the management of a community's urban street trees. Estimates of tree benefits produced by STRATUM depend, in part, on accurate estimates of tree age, dimensions, shape, leaf area, foliar biomass, and growth (i.e., regional growth curves). These parameters vary by species and location due to differences in growing conditions, management practices, climate, and soils. With all regional growth curves completed, this software suite will provide communities with a street tree inventory (estimated or completely counted) with the capabilities of assessing structure, function, and value of its urban forests and provide a stronger identity for the USDA FS and its stewards involved in urban and community forestry programs nationwide (McPherson 2003).

Critical to nationwide implementation of assessment tools like STRATUM, is biometric information on tree growth rates, dimensions, and leaf area for predominant species in each of the Nation's 16 regional tree growth zones (Figure 1). Accurate biometric data are essential to the modeling of annual benefits such as energy savings, rainfall interception, air pollutant uptake, and carbon dioxide (CO2) sequestration. All 16 growth rate zones have been completed by the CUFR and Davey Trees, a nationally recognized urban forestry management group, and have been incorporated into a new user friendly software suite i-Tree. Of note, growth zones may vary depending on where communities are located and local conditions may require a judgment on the part of the analyst on which growth zone to use. The i-Tree suite is an up to date, peer-reviewed tool of computer programs developed by the USDA Forest Service and others (i.e., Davey Tree Expert Company, National Arbor Day Foundation, Society of Municipal Arborists, and the International Society of Arboriculture) to provide urban and community forestry analysis and benefit assessment tools. The i-Tree software suite v 3.0 includes two flagship urban forest analysis tools and three utility programs [i.e., i-Tree Eco, i-Tree Streets, i-Tree Species Selector, i-Tree Storm, i-Tree Vue (Beta)]. The i-Tree software package Streets has now replaced STRATUM (Street Tree Resource Analysis Tool for Urban Forest Managers). The i-Tree suite v 3.0 of analysis tools is in the public domain and available by request through the i-Tree website (www.itreetools.org).

Figure 1 Sixteen regional tree growth zones in the United States as identified by the USDA Forest Service's Center for Urban Forest Research (CUFR) with 16 reference cities illustrated (http://cufr.ucdavis.edu). This map is used in i-Tree Streets to calculate specific zone benefits and generate management reports for urban trees.

With all zone specific regional growth curves established, techniques and guidelines reported can be used to infer BCRs for cities with inventory information on species makeup and diameter at breast height (DBH) measurements. Recent studies completed in Charleston, South Carolina and Charlotte, North Carolina have provided regional guidelines for benefit and cost assessments in this study (McPherson et al. 2005). These recent studies have the potential to be applied, in large measure, to regions in the Coastal Plain and South regions of the U.S. where few BCR studies have been undertaken.

Trees and forests within municipalities, regardless of community size or whether they are within a rural, urban, or suburban setting, all have the potential to provide residents with social, environmental, and economic benefits and other amenities associated with urban forestry (Groninger 1998). More and more studies are being performed in municipalities throughout many U.S. regions, with a primary component of these studies being an inventory of a municipality's street trees. Whether this inventory is an estimate or complete count, benefits and costs for urban and community forestry programs cannot accurately be represented without it.

Resource inventory is often undertaken during the planning phase in a tree care program. It is a comprehensive assessment or inventory of a community's tree resources and a fundamental starting point for most urban and community forestry programs. All inventories should provide basic data on tree and stand locations, numbers of trees, species classes and, to the extent possible, the condition or health of a community's trees. Initially, inventories often focus on trees on the public estate (i.e., parks, street trees, green spaces); but increasingly, availability of computer/remote sensing technologies are allowing communities to conduct comprehensive tree inventories on both public and private lands.

Remote sensing is a technique enabling cities and communities to analyze an urban forest's structure [e.g., height, stem size, canopy cover (CC), species]. Remotely sensed energy data (i.e., wavelength measures in the electromagnetic spectrum) from aircraft and satellites represent some of the fastest growing sources of data available. Data obtained with this technology is either passive or active. Passive relies on naturally reflected or emitted energy of surface images (i.e., similar to a photograph taken under sunlit conditions). Most remote sensing instruments fall into this category, by obtaining pictures of visible, near-infrared, and thermal infrared energy. Active means the sensor provides its own illumination and it measures what is reflected back in stages (i.e., 1st return, 2nd return, last return). Active data is used by remote sensing technologies [e.g., LiDAR (laser), radar] when recording information.

A tree inventory produced from medium- or large-scale aerial imagery that involves manual counting of individual trees can be time consuming. Tree density is estimated by combining estimates of crown closure and average crown coverage for the same area (Howard 1991). Howard's study, stressed that updating forest inventories is a continuous requirement which needs to have cost-effective strategies established for forest mapping. This study demonstrated how the use of time saving, automated methods to extract tree characteristics from remotely sensed data is increasingly recognized as an important way to quantify errors associated with spatial information.

The use of a GIS in combination with remotely sensed data to record these resources and their attributes can provide any city or town with a process to better understand monetary benefits provided and management costs derived from street trees (Goodwin 2005).

Objectives

This study's main objectives are to investigate two South Mississippi cities whose urban forests have existing LiDAR data and street trees located with a global positioning system (GPS). Currently, LiDAR technology has been used infrequently as a tool in urban and community forestry; however, this research can advance the body of knowledge in this emerging discipline. The street tree control points which have been located in Pass Christian and Hattiesburg will be investigated for a linear relationship with tree points identified with LiDAR Analyst using tree location, height, species, and point density as variables. The research objective is to integrate remote sensing information (i.e., LiDAR data) with ground control data to illustrate opportunities and constraints for the use of publicly available LiDAR data to create a street tree inventory. It was based on the premise that an adequate assessment of street tree metrics (i.e., height, CC, DBH) can be estimated through an integration of techniques and processes that uses reliable ArcGIS tools and the spatial statistical package R. Specific objectives are summarized:

1. Create a user friendly process for the development of a street tree inventory using ArcGIS software and accompanying tools with tested spatial statistical software.
2. Create a GIS map and database for each study city's street trees using remotely sensed data (i.e., LiDAR, county imagery) and sample ground control data.
3. Utilize case studies from urban forestry projects, (i.e., international, national, regional, local), to illustrate support for the study's methodology.
4. Utilize the estimated street tree inventory, growth zone, and estimated or real street tree management costs to estimate benefit/cost ratios (i.e., every dollar spent planting and managing street trees provides a certain amount of value in return) for each city.

CHAPTER II

LITERATURE REVIEW

Urbanization places a heavy burden on city planners and managers struggling to balance competing demands for residential, commercial, and industrial development with directives to minimize environmental degradation. City planners, managers, and government agencies increasingly rely on the use of information technologies and spatial modeling techniques to effectively manage this development process on a sustainable basis (Sugumaran 2005). Web-based decision support models are being developed using Internet Mapping Systems (IMS) for modeling urban growth. These Web-based models are being used to identify watershed sensitivity, as well as other environmental issues, with a variety of user-defined conditions for rapidly growing urban areas. By using multi-criteria evaluation tools, users are able to specify which criteria, and what weights, the model can use to generate a future scenario (e.g., urban sprawl affecting street tree CC or watershed quality). Being Web-based, these models can be used by any interested group or individuals (with basic computer navigational skills), in contrast to other similar tools (e.g., programs with software licensing) which are accessible only to those with the data, expertise, and computing power to use them (Sugumaran 2005). The growth in both software and hardware in the 21st century has improved user-friendliness, affordability, and ease in which spatial information can be managed (Merry et al. 2007).

Urban Forestry Historical Background

While efforts to nurture trees within communities can be traced back to the dawn of urbanism, the birth of urban forestry as a distinct scientific discipline is generally recognized as occurring in the United States during the 1970s (Miller 1988). In June 1967, the Citizens Committee on Recreation and Natural Beauty recommended to the President, in its landmark report *A Proposed Program for Urban and Community Forestry,* that an urban and community forestry program be created within the USDA FS to provide technical assistance, training, and research (Miller 1998). A 1968 federal Bureau of Outdoor Recreation proposal also supported the concept of federal assistance for urban forestry education and training to communities. It was not until 1971 when Florida congressman Sikes introduced the Urban Forestry Act to congress did this growing professional and public interest in urban tree resources culminate in the passage of federal legislation on May 5, 1972 (Miller 1998). The Urban Cooperative Forest Management Act of 1972 amended the Cooperative Forestry Assistance Act of 1950 to authorize the USDA FS to cooperate with the states in providing technical assistance for the "...establishment of trees and shrubs in urban areas, communities, and open spaces" (Johnson 1997).

In 1978, the initial interest in urban and community forestry was expanded by an appropriation of $3.5 million to fund a national urban and community forest program. Unfortunately, in the 1980s the federal commitment lagged as funding appropriated for urban forestry programs declined to a low of $1.5 million in 1984 (Maco 2002). However, the 1990 Farm Bill reestablished a federal commitment to urban forestry (Alvarez 2001). It expanded the USDA FS's authority to work with states on urban forestry and created a 15-member National Urban and Community Forestry Advisory

Council (NUCFAC) to assist in facilitating this action. NUCFAC is still in existence today. In 1993, funding for state programs increased to $25 million. In 1990, the America the Beautiful Act passed and was directed toward planting and improving trees in cities and towns (NASF 1990). State funding was provided to create an urban forestry coordinator and establish state urban forestry advisory councils (Johnson 1997).

Currently, many U.S. city inhabitants and elected officials, for the most part, appreciate the urban forest, not just because of aesthetics, but because of the environmental, economic, and social benefits it provides (Maco 2002). They can see the merit of funding tree plantings and maintaining these resources because of their inherent benefits. Stagnation of tree programs in the U.S. underscored the need to quantify the function urban trees provide to their communities (Tschantz and Sacamano 1994, Bernhardt and Swiecki 1999). Researchers have shown how benefits of urban forestry can be qualified and quantified for use by communities, urban planners, and developers (Anderson and Cordell 1985, McPherson 1991, Dwyer 1995, Xiao et al. 1998, Nowak et al. 2001, Maco 2002).

The Cooperative Forestry Act of 1978 offered a statutory definition of urban and community forestry. Urban forestry was defined as a process of planning, establishment, protection, and management of trees and associated plants, individually, in small groups, or under forest conditions within cities, towns, and their suburbs (Miller 1997). USDA FS guidance amplified this, defining management and planning of a community's urban forest as a tool and resource to enhance the quality of life. The process integrates the economic, environmental, and social values of the community to develop a comprehensive management plan for the urban forest (Miller 1997). In 2007, the USDA FS developed ideas to redesign state implemented State and Private Forestry (S&PF)

programs. These ideas revolved around improving program capacity to classify forest sustainability and achieving significant change in areas deemed high priority. This was accomplished by targeting financial resources to areas of greatest need as the most effective and efficient way to make a difference when resources were limited. Simply stated, for S&PF programs to be considered for funding they had to undertake a state-wide assessment and strategy for their forest resources. Assessments provided an analysis of forest conditions and trends across a state and mapped priority rural and urban forest landscapes. Resource strategies provided long-term plans for investing state, federal, and other resources where they can most effectively stimulate or leverage desired action and engage multiple partners. These bold initiatives became law with the passage of the Farm Bill in June 2008. This law, has promoted urban forestry as a discipline with three national themes of priority (i.e., conserve working forest landscapes, protect forests from harm, enhance public benefits from trees and forests).

Similarly, urban and community forestry can be distinguished as a discipline from conventional forestry, or silviculture, by its focus on areas where trees are typically a subordinate, as opposed to predominant landcover and timber production is not the ultimate objective. Traditional forest management often emphasizes economic values of marketed outputs of forest resources (e.g., lumber, pulp), while urban and community forestry is more interested in the environmental, social, aesthetic, and nonmarket economic values of trees. However, this distinction has lessened from a monetary viewpoint as urban forestry practitioners are documenting economic values of the urban forest as further justification for investment and protection measures (Jones and Grado 2005).

Urban Street Trees

On average, an urban street tree will have a life expectancy of approximately 10 years in an urban core and 30 years citywide (Godfrey 2005). During this period, the tree and its attributes (i.e., diameter, height, canopy spread) will grow, require maintenance (e.g., pruning, pest control, watering), and eventually removal as the tree will either die from natural causes, disease, pests, or other causes (e.g., vandalism, automobile incidents, development) related to its location. Making the appropriate selection of street tree species, in combination with timely inspections and maintenance, can increase a street tree population's average life expectancy, CC, and environmental benefits. However, these benefits are not realized without internal and external costs and infrastructure considerations requiring full support from a municipality's decision makers and the public, thereby allowing the community to achieve maximum return on investment.

Internally, decision makers (i.e., elected officials) oversee and fund agencies [e.g., public works, street departments, urban forestry departments (UFDs), parks and recreation departments, tree boards] that tend to street tree needs. There are also external considerations to be addressed when selecting a tree species to reduce maintenance costs (Godfrey 2005). These would include over-head wires (impacting expected tree height), distance to adjacent structures (impacting expected tree canopy radius as well as potential pruning cycles), and underground infrastructure (impacting root growth or tree pit design due to surface vents, manholes). Street trees will also be impacted by activities such as cyclical road reconstruction and maintenance and capital improvements such as infrastructure/utility work. Most urban infrastructure assets (e.g., water pipes, sewer pipes, gas lines, stormwater drainage structures) are located underneath streets and any excavation and work done to these facilities can potentially impact street tree health.

Trees and forests within municipalities, regardless of community size or whether they are within a rural, suburban, or urban setting, all have the potential to provide residents with environmental, economic, and social benefits and other amenities associated with urban and community forestry (Groninger 1998). Most B/C studies have been conducted in the Midwestern (i.e., Chicago, Illinois) and western United States (i.e., Modesto and Davis, California) (McPherson et al. 1994, Peper et al. 2001); however, recently studies which have potential to be applied to southern regions have been undertaken in Charlotte, North Carolina; Charleston, South Carolina; and Hattiesburg, Mississippi (Jones and Grado 2005). A primary component of these studies is a street tree inventory. Whether this inventory is an estimate or a complete count, benefits and costs for urban and community forestry programs cannot be accurately represented without it.

Urban Forestry Inventory

Many smaller cities and towns do not have tree inventory data which can reference numbers of street trees, forest health, or annual tree mortality. Those that have performed street inventories in the past have done so primarily using paper maps for small- to mid-sized cities (Jaenson et al. 1992, Maco 2002); however, with the development of technological advances in remote sensing and GIS these new methods have helped reduce the workload for inventory data collection and storage. Also as important in this new technology was the ability to use this inventory data to develop management plans with achievable goals.

Maintaining an urban street tree inventory has been a dynamic process involving citywide and individual tree needs. While most trees were included in an inventory as a result of validation through census, inspections, and construction/economic developments, there were also trees that have been added without notice due to unmonitored neighborhood or individual plantings. There also have been street trees located within a city's public space which were not the UFD's responsibility (Godfrey 2005). These were trees located in areas usually maintained by federal and state highway departments and were sometimes mistakenly referred to the UFD as a service request (e.g., pruning, removal). However, once the request was inspected by an UFD representative, it was forwarded to the appropriate agency (e.g., state or federal highway department). Also, while the inventory consisted of street trees as defined by an UFD within a public space, there were also trees that may be planted contiguous to public space on private property, whose growth habits (i.e., above- and below-ground) can impact public spaces. Above-ground tree growth can impact public spaces when limbs break, hang, or fall onto a sidewalk or street. Hardscaping features such as, sidewalks, streets, or buildings can experience damage from root growth due to improperly located trees. Conversely, a tree's roots may experience damage or mortality by improperly located hardscaping features. In most cases, if a tree fails it will become the UFD's responsibility (Godfrey 2005). All UFD internal and external operations involving service requests, work orders, jurisdiction, and planting location, can be managed through a GIS-based system.

The net impact of this lack of inventory data led to a misunderstanding of the status, condition, and trends affecting urban and community forests. Not only were communities unable to document monetary benefits and costs of their trees but, without good inventory data, communities were limited in undertaking systematic planning for tree resources and adequately documenting benefits trees provide to the community as a rational legal basis for protecting trees threatened by development. Also, there were budgetary implications for UFDs if they could not show accountability based on current or requested funding needs. This lack of knowledge about urban forests extends into the realm of the public utilization of technical information. Although there was a growing body of literature and educational materials available; there remained a need to deliver this information in a way that leads a broad public appreciation of the value and importance of urban forest resources and institutionalizes proper technical expertise in urban forestry, community development, and public infrastructure in regard to health requirements of urban trees.

Benefits of Urban and Community Forestry

Clark et al. (1997) stated that the vegetative resource was the engine that drove urban forests. Moreover, its structure, arrangement, scope, distribution, and physical condition all defined the effective benefits provided and costs accrued (Dwyer et al. 1992, Clark et al. 1997). Like any resource, caretaking and management of urban forest resources begins with a vegetative resource inventory (Miller 1997, Blionarz 2003).

The dollar value urban forests provide are tied to increased real-estate values; climate control and energy savings; air, soil, and water quality improvements; stormwater runoff mitigation; greenhouse gas reductions such as carbon dioxide (CO_2); wildlife habitat and corridor improvements; as well as aesthetics and community vitality and well-being (Dwyer and Miller 1999, Grado et al. 2008). Identifying and describing these benefits is considered an essential step to increasing public awareness and support for urban and community forestry programs. Furthermore, each analysis also demonstrated how street tree inventories and assessments led to better tree programs with fewer costs and more societal and environmental benefits (Maco 2002).

Recent studies in California facilitated by the USDA FS's CUFR have developed procedures for qualifying B/C analysis for urban forests (McPherson et al. 1999). This research described methods used to estimate environmental benefits provided by urban trees in Modesto, California. Twenty-two of Modesto's most abundant tree species were inventoried in a two-stratum random sample of young and old trees. Data collected on tree age, size, leaf area, and biomass were used to estimate species growth rates. The Modesto study included many tree species found in the U. S. Gulf Coast growth rate region of Louisiana and Mississippi; however, a recent study in the Gulf Coast growth rate region which used data from Charleston, South Carolina, was better suited to use as a baseline in this study.

Benefit Assessments

One benefit provided by street tree planting is an appreciation of real estate values. Anderson and Cordell (1988) found that a single large front-yard tree was associated with a $336 average increase in the sales price of single-family homes in Athens, Georgia. Not all trees are as effective as front-yard residential trees in increasing property values. For example, trees adjacent to multi-family housing units will not increase property values at the same rate as trees in front of a single-family home.

Changes in building energy use from tree shading have been assessed based on computer simulations outlined by McPherson and Simpson (1999). These models incorporated differences in building structure, climate, and effects of shading. Building characteristics were differentiated by age of construction (pre-1950, 1950-1980, and post-

1980) and took into account number of stories, floor area, window area, and insulation (McPherson and Simpson 1999).

Examining energy savings at the species level revealed the overall ability of a specific tree to provide energy savings throughout its life. Though limited by the age distribution found in Davis, California their study showed that an average small tree, such as a crape myrtle (*Lagerstroemia indica*), will save a homeowner on average, less than $5 per year, while larger trees [e.g., Chinese tallow (*Sapium sebiferum*) or hackberry (*Celtis laevigata*)], can average over four times those savings (Maco 2002).

Other ways to assess street tree benefits required an examination of their functionality in producing different benefits (Maco 2002). For example, large coniferous trees produced more energy savings than large deciduous trees, but were significantly less of a factor relative to property value increases. Another example was the differences between large and medium deciduous trees. If a tree manager was choosing between the two, their decision could be based on an evaluation of future benefits gained or lost. Choosing a medium-stature tree would give up little in terms of energy and CO_2 reductions, as well as property value, but air quality improvements would be decreased by approximately half (Maco 2002). In this fashion, tree managers can use this method to distribute trees in an equitable fashion and according to area needs, although site conditions and space availability also limit selection.

Guidelines developed by McPherson and Simpson (1999) can also be used for calculating CO_2 reductions attributed to urban forests. Net CO_2 reductions were calculated on the basis of avoided emissions as the product of energy use and what can be directly sequestered and released through tree growth, removal, and maintenance. These guidelines illustrated how to sum stored sequestered CO_2 in above- and below- ground biomass over the course of a year for representative species of nine tree classes.

Xiao et al. (1998) used numerical simulation to estimate annual rainfall interception and storage by urban trees. The model incorporated tree species, leaf area, crown density, and height, and used hourly meteorological and rainfall data specific to a municipality. The implied value of the intercepted rainfall ($\$/m^3$) was based on an annual expenditure for a municipality's stormwater quality program. This simulation can produce a total annual benefit of intercepted rainfall over 40 years, or whatever time is estimated to recoup the complete program reinvestment (Xiao et al. 1998).

Studies on CC show that a city with as little as 24% tree CC can still remove up to 89,000 tons of pollutants annually, valued at $419 million (Grado et al. 2008). Other studies suggested deciduous and evergreen trees can remove up to 9% and 13% of air particulates, respectively, and the estimated annual value of pollutant uptake by a typical medium-sized tree ranged between $12 and $20 (McPherson and Simpson 1999).

Canopy cover, or more precisely, the amount and distribution of leaf surface area, is the driving force behind an urban forest's ability to produce benefits for a community. As CC increases, so also do benefits afforded by increased leaf area. It is important to remember that street trees throughout the United States represent less than 10% of their respective urban forest (Moll and Kollin 1993). In other words, benefits city residents realize from all urban vegetation is far greater than values found in street trees alone. Unlike vegetation found on private lands, however, residents pay governmental entities to manage street trees for the benefit of the community. To realize the maximum return on this investment, government should strive to maintain present CC in a way that promotes annual increases in cover.

Environmental benefits of trees are associated with the amount of CC they provide (Maco 2002). Ideal CC is difficult to assess for a given community because of influencing factors (e.g., climate, land use, location). Though it was generally considered that more CC is better, a most favorable degree of CC can be assessed for a given city (Clark et al. 1997). In general, varying levels of CC depend on location and the municipality's objectives on that area for development and tree cover. Municipalities can perform a periodic CC analysis to determine whether their ordinances and management methods are adequate and effective in increasing CC (Bernhardt and Swiecki 1999).

McPherson et al. (1999) derived benefits associated with extending pavement longevity when 50% of street tree CC provided direct shade over street pavement. However, Maco determined a more accurate estimation can be made using simple trigonometry with data collected in a sample inventory based on planting location and average setback distance (Maco 2002). This method measured not only actual total CC, but the amount over pavement and sidewalks. This yielded results conducive to quantifying benefits as well as providing a measure of management success. An alternative proposed by Bernhardt and Swiecki (1999) used an index based on CC at the edge of pavement (CCEP). While useful for comparisons over time, CCEP is not a true measurement of CC and cannot be used to estimate benefits directly related to the CC area (Maco 2002).

Costs of Urban and Community Forestry

Large U.S. cities possess the resources to conduct urban forestry research; however, many small- to medium-sized cities or communities do not (Maco 2002). These communities, with limited fiscal budgets, usually do not have resources, whether monetary or technical, to conduct comprehensive municipal tree assessments. By evaluating methods which are affordable and reliable, these communities will be able to manage their city trees for long-term sustainability of their urban forests. A new understanding of street tree populations in small- and medium-sized communities will help managers mitigate urban heat islands, conserve water and reduce flooding, reduce air and water pollution, identify hazardous tree species, reduce sidewalk repair costs, preserve landmark trees, and protect critical wildlife habitat (Maco 2002). City managers and planners should be made to realize that benefits provided by investing in their trees can help make their communities more enjoyable places to live, as well as help attract new businesses and residents. As an example, if promoting tourism is a community objective; an attractive urban forest can help achieve this goal. However, success in achieving these goals can only be accomplished by providing urban and community leaders with appropriate assessment tools and information on the coinciding costs for use in evaluating and implementing urban and community forest programs.

Benefit/Cost Analysis

During the early 1980s B/C ratios were an unfamiliar concept in urban forestry, yet Bartenstein (1981) promoted B/C ratios as a planned precedence for assessing urban tree program cost-effectiveness. Hudson (1983) demonstrated that B/C analyses quantified benefits gained through city street trees, but demonstrated the need for caretakers and managers of urban forests to identify all program costs. This need was viewed as an important step in developing an economically feasible urban and community forestry program. As the process moved into the early 1990s, McPherson (1992) found that B/C analysis could be used as a planned method to acquire funding for urban forestry programs. This was accomplished by showing the rate of return from investments in an urban forestry program. With an understanding that B/C analyses were guides to be used, and were not constant, this provided caretakers and management with insights on how to direct their program needs. Freeman (1993) acknowledged the true utility of B/C analysis by stating if the management objective is to maximize net economic values associated with the use of environmental and natural resources, then B/C analysis becomes, in effect, a set of rules for optimum management and a set of defined procedures for measuring benefits and costs.

There has been extensive research and recommendations on what could be quantified in monetary terms in the caretaking and management of the urban forest (Dwyer 1991, Gobster 1991, Hull and Ulrich 1991, McPherson 1991, Schroeder and Lewis 1991, Dwyer et al. 1992, Macie 1994, McPherson et al. 2006), but actual quantification has been slow in coming. Fewer still are efforts aimed at putting quantified components into a full-scale B/C analysis (Maco 2002). This has been particularly true in the southern United States (Jones and Grado 2005).

B/C analyses have been performed in large and small U.S. cities such as Chicago, Illinois; Sacramento and Modesto, California; and Charleston, South Carolina (McPherson et al. 1994). Work has also been done in Hattiesburg, Mississippi (Jones and Grado 2005). By quantifying and qualifying the structure of their city trees, these communities were able to show, in dollars, the benefits over costs of their urban forest and associated programs.

Research has shown that street tree benefits outweigh program costs. Maco (2002) used a practical approach to assess structure, function, and value of street tree populations in small communities with Davis, California (population 55,000) as the study area. B/C analysis performed in Davis, California demonstrated returns of $3.78 in benefits for every $1 spent on tree care (Maco 2002) while in Charlotte, North Carolina it was demonstrated that there were returns of $3.25 in benefits for every $1 spent on tree care. In Charleston, South Carolina it was demonstrated that there were returns of $1.35 in benefits for every $1 spent on tree care (McPherson et al 2005). Several factors, such as lowered benefits, explain Charleston's low return. The environment's mild climate and abundance of clean air brought in by sea breezes is one explanation, and street tree composition another. As crape myrtles (*Lagerstroemia indica*) and sabal palms (*Sabal palmetto*) make up 40% of the street tree population, they have smaller leaf areas and return far fewer benefits on a per tree basis (McPherson et al. 2005).

A similar 2005 study performed in Hattiesburg, Mississippi demonstrated returns of $4 in benefits for every $1 spent on tree care (Jones and Grado 2005). This study examined benefits and costs of their street tree program using GPS and GIS mapping technologies. It also demonstrated a computerized approach for small- to mid-sized communities with limited funds to estimate their street tree population, structure, and health using a sample inventory of street trees (Jones and Grado 2005). Hattiesburg's study used methods, adaptations, and an inference similar to Maco's and concluded for every dollar spent $4.00 was returned to the community (i.e., BCR of 4:1).

Street Tree Structure

Explaining street tree structure is the first step in providing an understanding of tree program costs. This will enhance long-term management effectiveness and increase the ability of street trees to maintain community benefits. Species composition, age complexity, CC, condition, and plantable spaces are the structure's telltale indices of urban forest health, stature, management needs, and conflicts (Maco 2002). Only by explaining tree structure can dollar values be assigned to environmental functions street trees provide to enable tree caretakers to use this information to maximize those benefits while reducing costs.

Growth Modeling of Urban Trees

A study in Charleston, South Carolina demonstrated how using a stratified random sample of street trees, drawn from the municipality's tree database, helped establish relations between tree age, size, leaf area, and biomass (McPherson et al. 2006). Subsequently, estimates for determining the magnitude of annual benefits were derived in relation to predicted tree size. This sample was composed of the 19 most abundant tree species found in the city, and from these data growth rates of all street trees was inferred. The species were:

- Live oak (*Quercus virginiana*)
- Sabal palmetto (*Sabal palmetto*)
- Laurel oak (*Quercus laurifolia*)
- Loblolly pine (*Pinus taeda*)
- Red maple (*Acer rubrum*)
- Honeylocust (*Gleditsia triacanthos*)
- American holly (*Ilex opaca*)
- Hackberry (*Celtis laevigata*)
- Sycamore (*Platanus occidentalis*)
- Pecan (*Carya illinoinensis*)
- Crape myrtle (*Lagerstroemia indica*)
- Water oak (*Quercus nigra*)
- Flowering dogwood (*Cornus florida*)
- Jelly palm (*Butia capitata*)
- Southern magnolia (*Magnolia grandiflora*)
- Willow oak (*Quercus phellos*)
- Sweetgum (*Liquidambar styraciflua*)
- Southern red oak (*Quercus falcata*)
- Callery pear (*Pyrus calleryana*)

To obtain information spanning the life cycle of predominant tree species found in Charleston's urban forest inventory. Tree species needed to be stratified into nine DBH classes (McPherson et al. 2006):

- 0–3 in (0.00–7.62 cm)
- 3–6 in (7.62–15.24 cm)
- 6–12 in (15.24–30.48 cm)
- 12–18 in (30.48–45.72 cm)
- 18–24 in (45.72–60.96 cm)
- 24–30 in (60.96–76.20 cm)
- 30–36 in (76.2–91.44 cm)
- 36–42 in (91.44–106.68 cm)
- >42 in (>106.68 cm)

Each of the 19 most abundant species in Charleston, South Carolina had 30 to 70 trees selected to survey, along with an equal number of alternative trees. Measurements recorded for selected trees included DBH, tree crown and crown base, crown diameter in two directions, and tree condition and location. However, when one of the abundant species was not found during sampling a replacement tree, if any, from the original targeted population was sampled instead.

Street Tree Sampling Methods

Jaenson et al. (1992) established a methodology to estimate a city's street tree population and its structural characteristics. Maco (2002) further developed this methodology by establishing an order of equations used to estimate street tree structural characteristics in a manner which can be applied to estimating resource units to benefits. Jaenson et al. (1992) demonstrated, and Maco (2002) confirmed, that using 2,300 street trees as a sample will provide an accurate estimation of species diversity, population, and other variables. Jaenson's study in New York state concluded that an increasing sample size would increase precision; however, the improvement would not be substantial enough to warrant the extra time and cost for personnel and data analysis (Jaenson et al. 1992). Jaenson et al. (1992) found their statistical methodology for street tree sampling to be accurate within 10% of actual population totals. This error was determined through a comparison of the sampling method results coupled with known populations in four New York cities surveyed between fall 1989 and summer 1990. These sites were chosen because they represented areas ranging from 5.6 mi^2 (Ithaca) and 78.5 mi^2 (Brooklyn) and had complete or partial street tree inventories. Existing inventories allowed the sampling method to be validated for accuracy and was found to be within 10% of actual tree populations. The purpose of the sample inventory was to estimate tree populations based on planting space occupancy.

Inventory Methods and Technologies

Many technological advances and techniques are being developed to better facilitate inventory data collection and storage and reduce costs. Handheld GPS units as well as palm pilots are being used for collecting data, while GIS and remote sensing are providing new ways to store, manage, and analyze collected data. These new techniques and technological advances all aid in urban forest resource management and planning.

The creation of a tree inventory can employ highly elaborate methods, involving computers and aerial photography or satellite imagery, or rely on simpler techniques, such as a "windshield" survey of street trees (Maco 2002). Windshield surveys are simply two or three people riding slowly through parts of a city targeted for inventory recording as many tree types and sizes as possible to establish a rough estimate of tree species in each tree growth zone. Technological advances, along with their learning curves and costs need to be compared to simpler methods and their costs. Accuracy of inventory data acquired is also an important consideration for municipalities or urban forestry consultants.

GIS Use for Inventory in Urban Forestry

Most definitions of a GIS focus on two aspects of a system, its technology and/or problem solving capabilities (Malczewski 1999). As a technological perspective it is viewed as a system with a set of tools used for the input, storage, manipulation, and analysis, capable of producing spatial data connected to a specific geographic coordinate on the Earth's surface. The system's problem solving aspect can be viewed as a functionality which can play an important role in decision making. According to Foote and Lynch (1996), system functionality has three important aspects: (1) it can be thought of as a digital database connected with a common geo-spatial referencing system which becomes the common thread for storing and accessing information; (2) it has the ability to integrate a variety of geographical systems (e.g., remote sensing, GPS, AUTOCAD) which can be used for analysis and decision making; and (3) it is an important decision support system using integrated geo-spatially referenced data in a problem solving environment (Malczewski 1999).

A GIS database can be viewed as a representation or model of real world geographical systems consisting of data represented as entities and objects. A geographical entity may represent an element of the real world such as a city, street, and a county or parish boundary which is connected in geographical space. A feature (i.e., GIS stored feature attributes in a relational database) or an object (i.e., a GIS program storing the object with its attributes together and object's topology) is how a geographical entity is viewed in a GIS system. For example, a city could be a point, a street could be a line, and a county or parish could be a polygon. Malczewski stated that it is better to view a GIS as a process rather than software or hardware when being used to support decision making for spatial and attribute data.

With technological advances in GIS, tree inventories databases can be produced and contain appropriate arboreal attributes (e.g., species, diameter, height, canopy spread, location, pruning needs), which can be used with STRATUM to determine benefits and costs of a community's street tree inventory. Studies in Washington D.C. (Goodwin

1996), Davis, California (Maco 2002), and Charleston, South Carolina (McPherson 2005), were examples exhibiting how databases created and stored in a retrievable format can, with a GIS, improves an UFD's effectiveness and efficiency.

GIS technology has now advanced to a point where street tree (i.e., spatial data) inventory and database files (i.e., attribute data) created with a licensed computer program (e.g., ArcGIS, AGIS) can be supported in a GIS Internet Map Server (IMS) (Goodwin 1996, Ward and Johnson 2007). An IMS provides users access to other digital data (i.e., parcel maps, utility lines, topographic maps, watersheds, wetlands, market analysis, transportation routes), which can be used by interested individuals or groups and not require a program license or powerful computer equipment. Interested individuals or groups using an IMS could be a part of a city's workforce looking to improve management or, in the public domain, looking for developable land.

GIS Map Layers for Resource Inventory

Base maps are the primary data layers (e.g., aerial imagery, municipal boundaries, streets) used in GIS projects to provide a visual foundation of the area of interest (Bloniarz 2003). It is critical in any GIS project that spatial referencing systems are understood because this determines how spatial feature locations are measured using the correct projection and geographic coordinate system (GCS) (Chang 2004). A projection references spatial data using a planar grid to preserve a feature's measured shape, area, distance, and/or direction (Chang 2004). The type of planar projection (i.e., conformal for shape, equivalent for area, equidistant for distance, azimuth for direction) to use depends on what is most important to preserve (Figure 2).

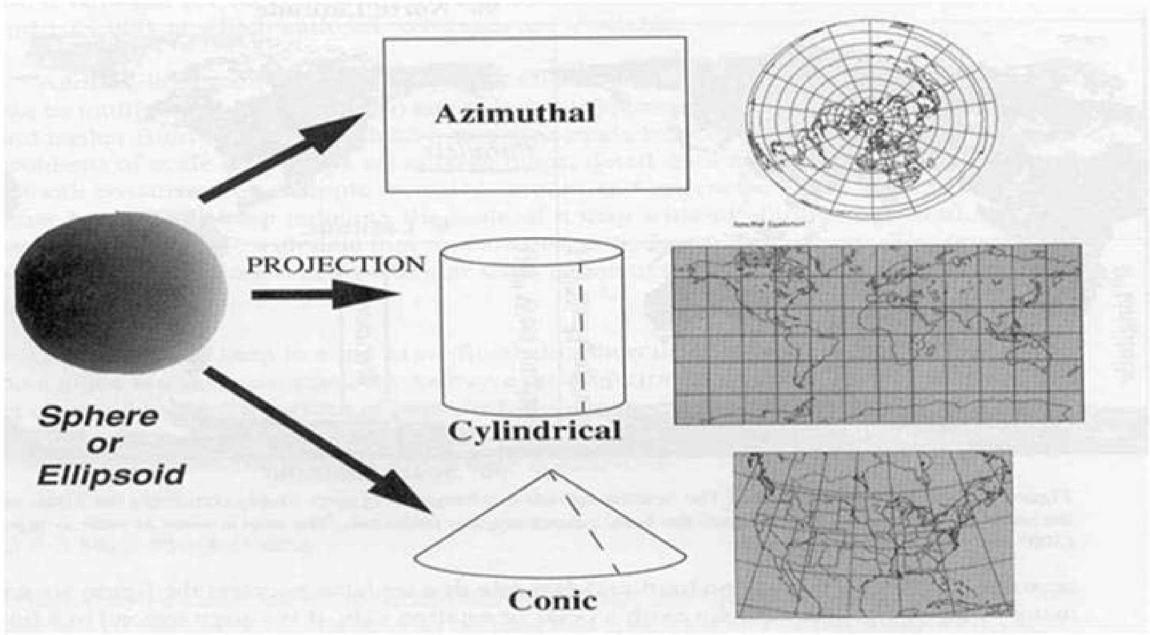

Figure 2 An illustration on how different planar projections (i.e., azimuthally, cylindrical, conical) appear when they are placed on the Earth's surface as a grid (Chang 2004).

A GCS uses a three-dimensional spherical surface to reference spatial data points on Earth. This GCS is sometime mistakenly referred to as a datum; however, a datum is only a part of the GCS equation. A GCS equation includes an angular unit of measure, a prime meridian, and a datum based on a specific spheroid. A spatial data point is referenced by its longitudinal and latitudinal values. Longitude and latitude are angles measured from the Earth's center to a point on the Earth's surface in spherical coordinates, not planar. Angles often are measured in degrees (or in grads). In the spherical system, 'horizontal lines', or east-west lines, are lines of equal latitude, or parallels (Chang 2004). 'Vertical lines', or north-south lines, are lines of equal longitude, or meridians. These lines encompass the globe and form a network grid called a graticule.

Maps with different datum will not have the same spatial referencing system so it is important to make sure it is understood what datum the map is based on. A located feature on different map layers using different datum can have different coordinates (i.e., latitude and longitude) which could display a difference in location up to several hundred meters. A datum is a reference ellipsoid together with an offset from the center of the Earth which is used in map making to represent the Earth's surface. Two datum used in the United States by USGS are North American Datum 27 (NAD27), and North American Datum 83 (NAD83) (Bolstad 2008). However, since no single reference ellipsoid will accurately represent the entire globe's surface perfectly some misrepresentation will exist. This is due to the Earth's shape which isn't perfectly spherical. The Earth's shape is flattened at the poles and bulges at the equator requiring a different reference ellipsoid for each global region. Feature misrepresentation is minimized when the ellipsoid mirrors the actual Earth surface. A GIS project's foundation is only as strong as its base map and other map layers which make up the project because one map layer, with the wrong spatial reference system, projection, and or datum, could jeopardize an entire project's accuracy.

Land Use Imagery in GIS

Photographs and other images of the Earth taken from the air and from space show a great deal about the planet's landforms, vegetation, and resources. Aerial and satellite images, known as remotely sensed images, permit accurate mapping of land cover and make landscape features understandable on regional, continental, and even global scales. Transient phenomena, such as seasonal vegetation vigor and contaminant discharges, can be studied by comparing images acquired at different times.

The USGS began using aerial photography for mapping terrain and other natural resources (e.g., watersheds) in the 1930s (Chang 2004). Upon which time photographs from its mapping projects and some satellite imagery from other federal agencies began to be archived. Satellites and aircraft operational to document landscape scenes use both visible and invisible parts of light waves from the electromagnetic spectrum. When scenes are processed the result is color infrared imagery. Remotely sensed imagery is categorized by pre-established mission parameters (i.e., altitude of the aircraft or spacecraft, sensor qualities, time of year) for a specific region or study area (Lillesand and Kiefer 2000).

Orthophotos are digital aerial photographs that have been orthorectified (Lillesand and Kiefer 2000). Rectification is a process that uses terrain elevation data to adjust any distortion or displacement in an image which could be produced by differences in terrain breaks and/or camera tilt. Rectification provides an orthophoto with the ability to be used as a base map (Lillesand and Kiefer 2000). With the ability of aerial photographs to illustrate ground texture in much greater detail than most paper maps, orthophotos also are useful as a study area base map, for updating maps, and for studying surface features not necessarily otherwise visible. The USGS and other geospatial data warehouses [e.g., Mississippi Automated Resource Information System (MARIS) http://www.maris.state.ms.us/; Atlas http://www.atlas.lsu.edu/] produce digital orthophotos for map revision and for computer analysis using GIS (Figure 3).

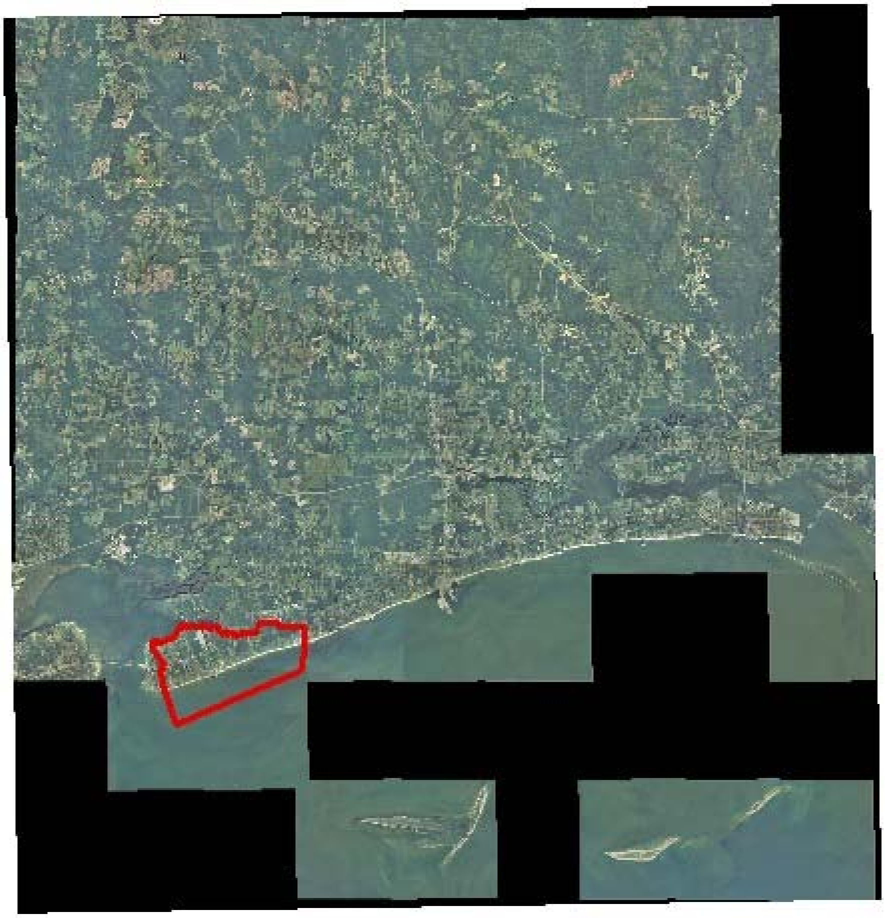

Figure 3 A publicly available digital orthophoto from the Mississippi Automated Resource Information System (MARIS) illustrates land uses in Harrison County, Mississippi during 2005, as different colored patterns. The red figure outlines Pass Christian, Mississippi's city limits.

GIS in Urban Forestry

The advantage of using a GIS over separate conventional paper maps or analytical spreadsheets is the ability to utilize software mapping capabilities and related data together in a quicker and more efficient manner. In a GIS environment, the base map remains constant in the ever-changing kaleidoscope of interactive data analysis. As an example, the comparison of land use changes can be made possible with GIS and remote sensing technology (Godfrey 2005). Comparing land use changes over time with paper maps would be laborious and time consuming; however, by using computer programs large regions could be investigated for land use changes by differences in areas of pixels with a few clicks of a mouse.

Many GIS initiatives are precipitated at the local municipal level as a desire to promote the community to residents and decision makers (Berado 2005). The impetus could all begin with a municipality's need to update a hand drawn street map. Upon completion, this street map can be made available to residents, visitors, and municipality departments (e.g., public safety, public works, code administration, police departments) whereas other resources (e.g., street signs, fire plugs, 911 addresses, water mains, shut off valves) can be inventoried to assess conditions and needs. When a street tree inventory database (either as a sample or a complete tally) is completed as part of a planned GIS implementation, it can become an integral part of the overall development of an urban forestry program (Berado 2005). Case studies (e.g., Brookline, Massachusetts; Grand Terrace, California; Washington, D.C.) involving municipal street tree management using a GIS to its full potential, have shown how management becomes more thorough and cost effective (Goodwin 1996).

In 1995, funding through a grant from the USDA FS's Northeastern Area Urban Forestry Research Center and private sources precipitated a partial street tree inventory in Springfield, Massachusetts (completed in the metropolitan center only) and a complete street tree inventory in Brookline, Massachusetts. These cities employed a GIS to record their street tree locations and attributes (Goodwin 1996). This study demonstrated how GIS software provided for more efficient street tree management. By using tree locations, attributes, and maintenance needs, which have been carefully inventoried and stored geographically, this software, provided managers with a functional ability to more cost effectively process data.

A case study in 2005 in Grand Terrace, California, demonstrated how, in spite of having a small staff beset with many diverging demands, the benefits of a GIS program aided in the city's development and increased management efficiency (Godfrey 2005). The study outlined some ambitious goals within the city's GIS program. Through grants available to many municipalities, software was acquired, and through cooperation with adjacent jurisdictions and regional agencies, Grand Terrace was able to initiate this program. Evolving goals were in line with the City Council's overall goal of improved communications with the community. The city recognized that, by providing widely available geographic and related information to its staff and citizens, it enabled its staff to do jobs more efficiently and effectively, as well as provide requested information to Grand Terrace citizens via the Internet (Godfrey 2005).

A case study in 2004 in Washington, D.C. demonstrated how using a GIS computer program to store and query inventory data in conjunction with a central relational database management system platform, provided a municipality's UFD with a dynamic tool for integrating functional requirements (Godfrey 2005). Primary functional requirements of any new system can include customer call intake, generation of service requests, tracking of inspections, generation and tracking of work orders, flexible reporting capabilities, cost tracking (i.e., for internal and external work), inventory, work history, maintenance, capability for field data collection and downloading (i.e., for real time and/or end of day), and distributed access and maintenance.Godfrey's (2005) study demonstrated how, when planning a GIS-supported tree information system, it should be flexible, have an open architecture, and maintain an intuitive manner of data entry for maintenance and editing. This was demonstrated, when determining data needs for a tree inventory system to determine process refinement of business and data flow modeling in a GIS environment. By defining a business process model (i.e., flow of business process activities) and a data flow model (i.e., timing and responsibilities for data input and output) a municipality can better understand input and output data requirements for their chosen information system. This study demonstrated, by distinguishing static data (i.e., addresses) from dynamic data (i.e., dates), that insights can be provided into how a business process model could be set up by using daily, weekly, monthly, and yearly reporting cycles and performance benchmarks (Godfrey 2005). This study's importance illustrated the process for determining functional requirements for a GIS and how it became important in defining the database model necessary for a tree inventory model.

Remote Sensing in Urban Forestry

Remote sensing is an art and science used with specific techniques to analyze an urban forest's structure (e.g., height, stem size, CC, species). Remotely sensed imagery from aircraft and satellites represent one of the fastest growing sources of data available for urban analysis (Chang 2004). Data obtained is either passive or active (Lillesand and Kiefer 2000). Passive data relies on naturally reflected or emitted energy of the surface features (i.e., similar to a photograph taken under sunlit conditions). Most remote sensing instruments fall into this category, which are capable of obtaining pictures of visible, near-infrared, and thermal infrared energy. Active data use sensors which provides its own illumination and measures that comes back in ranging stages or light pulse returns (i.e., first, intermediate, last). Remote sensing technologies using active sensors included LiDAR (laser) and radar (Lillesand and Kiefer 2000).

Remote sensing collects data by way of imaging while not in direct contact with the area, object, or phenomena under investigation (Lillesand and Kiefer 2000). This technology is enabling cities to analyze their urban forest CC. For example, the non-governmental organization American Forest's computer program 'City Green' uses the National Oceanic Atmospheric Administration's (NOAA) Landsat satellite imagery which is taken at different intervals in time (e.g., 1972, 1982, 2000) to show temporal changes in CC. This technology is expanding methods previously used to accomplish this task, as well as providing new ways to explore a city's natural and built resources, either separately or in combination.

Passive Data

In the use of multi-spectral imagery it is common practice to use the red, green, and near infrared spectral channels of the electromagnetic wavelength spectrum to differentiate (classify) between vegetation and human development. Part of the problem of classifying an image is in the identification of training samples based on some understanding of land use/cover in a particular area of an image. A 1999, Modesto, California study facilitated by the USDA FS's CUFR developed procedures for qualifying and quantifying tree species using NASA's Airborne Visible Infra Red Imaging Spectrometer (AVIRIS) data (Xiao 2003). AVIRIS is a world class instrument within the realm of remote sensing because of its unique optical sensor that delivers calibrated images of the upwelling spectral radiance in 224 contiguous spectral channels (also called bands) with wavelengths from 400 to 2,500 nanometers (nm).

Active Data

LiDAR data has been used to develop methods for forest inventory purposes directly suited for practical inventory at the stand level (Naesset et al. 2004). Mean tree height, stand volume, and basal area have been the most important forest mensuration parameters of interest to decision makers. Laser (LiDAR) data have been related to field training plot measurements using regression techniques, and these relationships have been used to predict corresponding properties in all forest stands in an area. Experiences from Finland, Norway, Sweden and the U.S. show that retrieval of stem volume and mean tree height on a stand level from laser scanner data performs as well as, or better than, photogrammetry and other remote sensing methods (Naesset et al. 2004). Laser scanning is, therefore, now beginning to be used operationally in large areas for forest inventory purposes. LiDAR technology can provide horizontal and vertical information at high spatial resolutions and vertical accuracies (Parker and Evans 2005). Forest attributes such as canopy height can be directly retrieved from LiDAR data. Direct retrieval of canopy height provides opportunities to model above-ground biomass and canopy volume. Access to the vertical nature of forest ecosystems offers decision makers new opportunities for enhanced forest monitoring, management, and planning.

Most importantly, airborne laser data with an appropriate point spacing has been used to inventory large forest areas provided that precisely georeferenced field sample plots were used initially as training data to develop empirical relationships between laser data and biophysical variables (e.g., mean tree height, stand volume); however, little research has been done using this data for urban forest inventories (i.e., street trees, green spaces, stormwater corridors). This study used this empirical relationship and the ArcGIS tool LiDAR Analyst to develop relationships between ground control tree points and LiDAR Analyst tree point's height and location for urban street trees. LIDAR Analyst is an extension that works with ArcGIS and enables GIS analysts using LIDAR data to generate high-quality, three-dimensional models of bare earth, buildings, individual trees, and forests (VLS 2007). This extension can completely automate the collection of 3D terrain and geospatial features from airborne LIDAR data. As an example, during the feature extraction process by LiDAR Analyst, attributes such as height, CC, and DBH were estimated and created. The speed and accuracy of its extraction capabilities was dependent upon the LiDAR data's point spacing density.

LiDAR Feature Extraction for Tree Inventory Development

The basic idea of single tree-based forest inventory was that the calculation of stand attributes for an individual stand was based on measurements of stem position, tree height, species, and crown area for individually detected trees (Brandtberg 1999). All other stand variables were derived from these basic characteristics in combination with field data. Tree position, height, and crown areas can be obtained from laser scanner data, whereas tree species is obtained from image data, laser data, or a combination of laser and image data (Brandtberg 1999).

It has been shown by Brandtberg (1999) and Hyyppa and Inkinen (1999) that single trees were measurable in high-density laser data. One promising method for the detecting and measuring single trees has been developed in Sweden. The method consists of three steps: (1) creating a digital canopy model (DCM) using an active surface algorithm; (2) smoothing the DCM with different scales; and (3) determining appropriate scale in different parts of the image by fitting a parabolic surface to the canopy model (Persson et al. 2002). When the method was validated at the Remningstorp, Sweden test site, over 70% of the trees, representing 91% of the stem volumes, were detected (Persson et al. 2002).

Hyyppa and Inkinen (1999) and Persson et al. (2002) used laser data to delineate and determine tree crowns, stem position, height, crown diameter, stem diameter, and timber volume for each tree. Stem position was set to the location of the local maximum of the DCM, and tree height was set to the maximum height value of the DCM. Crown diameter was calculated using the area of a segment, assuming segments have the shape of a circle. Stem diameter was predicted using linear regression with height and crown diameter as independent variables. Stem volume was calculated using volume equations for individual trees (Laasasenaho 1982), with tree height and stem diameter as explanatory variables. Persson et al. (2002) validated laser data-derived estimates of tree position, tree height, and crown diameter using field measurements of these variables obtained at the Remningstorp, Sweden test site. The two latter variables were estimated with an RMSE of 0.63 m (2.6%) and 0.61 m (12%), respectively.

Hyyppa and Inkinen (1999) also showed that the tree heights of 89 selected single trees in the upper canopy could be obtained with a standard error of less than 1 m (5.8%). Underestimation of tree heights was 0.14 m. Correspondingly, Maltamo et al. (2004b) found the standard error of height varied between 3% and 9% for different tree species, and height underestimation was about 1 m. Pyysalo and Hyyppa (2002) and Pyysalo (2000), considered the reconstruction of single-tree crowns from laser scanner data. Based on 50 ground-measured trees, it was found that dense laser scanner data described in more detail the upper forest canopy and, therefore, were suitable for extraction of tree height information. The lower crown was characterized in less detail and variables extracted for the lower canopy were less accurate. It should be noted, however, that the obtained canopy profile seemed to be indicative of the tree species [Scots pine (*Pinus sylvestris*) versus Norway spruce (*Picea abies*)] (Pyysalo and Hyyppa 2002).

LiDAR Tree Species Classification

In Hyyppa et al. (2001), forest canopy profiles were created using laser scanner data. It was visually concluded that profile information included valuable data about tree species (e.g., discrimination between pine/birch versus spruce). Tests have also been performed in Sweden using laser data for species classification of delineated tree crowns (Holmgren 2003, Holmgren and Persson 2004). All laser points within each segmented tree crown were grouped together to form the point cloud belonging to each tree. Laser points were divided into ground hits, within crown hits, or DCM surface hits according to their distances to the DCM or ground. To separate between Norway spruce and Scots pine, features were derived from laser data on a single-tree level capturing differences in crown shape and structure. These two species could then be discriminated from each other with an accuracy of 95% using laser data alone (Holmgren and Persson 2004).

Holmgren's 2003 study revealed that when individual trees were recognized from a laser image, major problems could potentially occur when a dominant tree layer was detected and suppressed other trees or the shortest dominant trees were not found. Also, trees occurring in closed groups were difficult to detect therefore, underestimated tree stocking. Holmgren's research concluded that one solution would be to combine tree counts detected by single-tree segmentation methods with the prediction of unseen small trees by using theoretical distribution functions (Holmgren 2003).

A study by Koukoulas and Blackburn (2002) revealed that an automated feature extraction, based on prototypes, was only partially successful when applied to remotely sensed imagery of natural scenes due to the complexity and unpredictability of the shape and geometry of natural features. Koukoulas and Blackburn (2005) provided a new method for extracting locations of treetops by applying GIS overlay techniques and morphological functions to high spatial resolution airborne imagery (Koukoulas and Blackburn 2005). Their method was based on the geometrical and spatial tree crown properties. First, a Digital Elevation Model (DEM) was generated from LIDAR data and then subtracted from the original LiDAR imagery to create a Canopy Height Model (CHM). Next, a set of procedures using image contouring and manipulation of resulting polygons were implemented to extract treetops from aerial photographs and the CHM. This allowed criteria to be developed and threshold values set using a supervised approach for the acceptance or rejection of features based on field knowledge. Finally, tree species were mapped by classifying ATM data and this data was co-registered with the treetop layer to provide individual deciduous tree locations. This study demonstrated that, for broadleaved deciduous plantations, the success of treetop extraction using aerial photographs was 91%, but was much lower using LiDAR data (Koukoulas and Blackburn 2005). However, this study demonstrated that for semi-natural forests, LiDAR produced better treetop extraction results than aerial photographs with a success rate of 80%, which was considered high, given the complexity of these uneven-aged stands.

All aforementioned research produced strong statistical results supporting the use of airborne laser data to inventory large forest areas provided that precisely georeferenced field sample plots were used initially as training data to develop empirical relationships between laser data and biophysical variables (e.g., mean tree height, stand volume). This empirical relationship can then be used to predict characteristics for all forest stands in an area of interest.

CHAPTER III

METHODS

Southern Coastal Plain and Mississippi Land Uses

Cities used as study sites were located in the Southern Coastal Plain (SCP). This is a region in the lower south covering 110,060 mi^2 in Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia (USDA 1992). Land-based resources located in the SCP are about 69% wooded, 17% cropland, and 11% pasture land (USDA 1992). About 3% of the area is used for rangeland, urban development, or other purposes. The woodland is 65 to 75% privately owned and 25 to 35% industrially owned. A small percentage, less than 10%, is federally owned.

Timber production is important, in Mississippi alone, total industry output related to forestry and forest products exceeded $17 billion and related value-added exceeded $7.12 billion (Munn and Henderson 2007). Cash crops include soybeans, corn, peanuts, and cotton (USDA 1992). Major vegetable crops, melons, tobacco, and pecans are important in some areas. Recently, livestock farming has increased. Pastures are used mostly for beef cattle but some dairy cattle and hogs are raised. Controlling soil erosion and improving drainage on low wetland areas are major issues facing management of these resources (USDA 1992).

Study Areas

The study objective entailed looking at urban forests in two cities; Pass Christian and Hattiesburg in South Mississippi. The former was chosen since it is typical of a smaller community, and the latter is more representative of a mid-size city. Both cities have publicly available LiDAR data collected in flight missions (i.e., in 2005, 2006) by Earth Data International, Inc. for the Mississippi Department of Environmental Quality. Also, each city has a representative sample of street tree points and attributes with locations recorded with a mobile GPS. Tree point data was obtained by this researcher for each city (i.e., Pass Christian in 2008, Hattiesburg 2004).

Pass Christian

Pass Christian, Mississippi's economy evolved from a bountiful seafood industry and as a resort destination. The area was first settled by French Canadians in 1699 that ceded their interest in 1763 to the English in what was then called West Florida. In 1780, the Spanish took over relinquishing their land use rights to the United States in 1810 when it became a territory (City of Pass Christian 2009). The city's name comes from the French explorer Nicholas Christian L'Adnier who found a deepwater pass to a natural harbor centrally located on Pass Christian's waterfront. In 1838, the city was chartered as a town and the first yacht club of the South (and second in the U.S.) was established in 1849 (City of Pass Christian 2009). The city is located at the western most boundary of Harrison County, bounded by water on three sides (i.e., Gulf of Mexico, Bay St Louis, Johnson Bayou) (Figure 4).

Pass Christian has a total area of 15.3 mi^2 of which 7.4 mi^2 is estimated to be buildable land and 7.9 mi^2 is water or wetlands. The population was 6,579 during the 2000 U.S. census. Since Hurricane Katrina's destruction on August 29, 2005 the population dwindled to 3,200; however, as of 2010 the population has climbed back over 5,000. Pass Christian, has a long history as a resort style village where cool Gulf of

Mexico breezes spread throughout the city, and where ancient moss-draped live oaks provide stability and protection. Live oaks spread their limbs casting shadows which afford their residents and visitors a place for rest and relaxation. Pass Christian has been struck by two of the strongest Hurricanes to ever hit the United States; Hurricane Camille in 1969 and Hurricane Katrina in 2005. The people are much like the ancient live oaks that have witnessed this city's passage of time because they are still there; rooted in the view of the Gulf, its gentle breezes, and the food it provides.

Figure 4 Mississippi state map locating the two study area cities in South Mississippi, Pass Christian and Hattiesburg.

Hattiesburg

Hattiesburg, Mississippi's economy evolved from the timber industry in the late 1800s and the city was incorporated in 1884 (Figure 4). Located at the fork of the Leaf and Bouie Rivers, Hattiesburg provides a unique blend of affordability and a high standard of living for 50,000 plus residents (City of Hattiesburg 2010). Hattiesburg's 50 mi^2 is a growing micropolitan area in part of Forrest and Lamar Counties designated a Metropolitan Statistical Area (MSA) in 1994. In 1994, it also ranked 68th among 313 MSAs in the United States for "economic strength," with a combined population of more than 100,000 residents (Fruth 1997).

Hattiesburg is known as the "Hub City" because U.S. Highways 49, 11, and 98 and Interstate 59, radiate from the community like spokes from the hub of a wheel. Hattiesburg's location, within 100 miles of Jackson and Natchez, Mississippi; Mobile, Alabama; and New Orleans, Louisiana provides easy access via modern highways. South Mississippi's weather ranges from the occasional below freezing temperatures in the winter to scorching hot summers. South Mississippi's near tropical temperatures rarely remain below freezing during daylight hours. Foresters, horticulturists, and landscapers take advantage of a longer growing season than most of the country and lawns are typically green year round. Key weather related variables for south Mississippi are shown in Table 1.

Table 1 2003 Average temperature, humidity, and precipitation in South Mississippi (City of Hattiesburg 2010).

Average temperature	January 48°F	June 80°F
Average high temperature	January 80°F	June 94°F
Average low temperature	January 18°F	June 80°F
Average annual humidity	74%	
Average annual rainfall	60 inches	

Ground Control Inventory

Control tree point data used for each city was a representative sample of tree species that occur within 30 ft of a street. Hattiesburg's control tree point data was collected during the summer of 2004, and Pass Christian's control tree point data was collected during the summer of 2008. Control tree point data collected during the inventory included the following attributes: species, land use (i.e., residential, commercial, public, unimproved), DBH, height, canopy cover, condition, pruning needs, conflicts, notes. Also, each tree's location was recorded using a global positioning acquisition system. Location, species growth category (i.e., hardwood, pine, magnolia, other), tree height, and CC were primary values used for determining if any linear or statistical relationship existed with LA tree point and control tree point attributes.

An inference from frequency of occurrence of growth categories was used to estimate Pass Christian and Hattiesburg's citywide total of municipal street trees and their structural characteristics. Methods used for estimating street tree populations were based on accepted and validated methods used to conduct random stratified samples of street tree populations. Using Jaenson's, stratified sampling technique (Jaenson et al. 1992); municipal street trees and any additional private street trees located in the public ROW were targeted for inventory (i.e., trees within 30 ft of a street) in Pass Christian during the summer of 2008 and were previously inventoried using the same technique in a 2005 study for Hattiesburg (Jones and Grado 2005). Statistical sampling has shown that a suitably selected random sample consisting of only a small fraction of the tree population can often be used to estimate characteristics of the entire population with an acceptable high level of accuracy which implied an acceptable, low degree of error (Cochran 1977).

Inventory Protocols

Each ground control tree's geographical location was recorded with a sub-meter accuracy Trimble GPS unit. Tree points created with LA used the ground control points to determine what if any relationship existed between the two tree point's position, tree height, DBH, and crown diameter. Arboreal attributes (e.g., height, DBH, CC) recorded during the sample inventory of control trees were used to compare with attributes and locations for LA created trees in each point tile. All trees found during sample within the city ROW of each street followed data collection protocols. If any additional comments were needed that did not fall into a data collection protocol they were noted on the back of the field inventory sheet (Appendix B). Two-person teams (a measurer and recorder) were used to record data using a field inventory sheet. Equipment used during the inventory included a Mobile GPS to record the position of a tree's x y coordinates for orientation and distance measurements. An Advantage CIL laser system was used to measure tree height, and an industry proven DBH-tape was used to measure tree DBH. Data were recorded for each inventoried street as follows:

- GPS coordinates (unique referenced point),
- street name,
- inventory date, and
- names of persons who conducted survey.

Recorded Tree Data

Data was recorded for each tree during the street survey inventory process. This included species code, tree ownership, location, and use. Species codes were the first two letters of a tree's genus followed by the first two letters of the species epithet. For example, a Chinese hackberry (*Celtis sinensis*) will be coded as CESI. VOID was entered for a vacant planting area within the ROW, whereas a linear measurement of 80 ft or more was a plantable space void of trees (Maco 2002). A species code reference list was assembled and attached (Appendix C).

Trees were considered city owned (Yes = 1) if they were within a 10 foot city ROW, or located in a median, or within the city ROW and not privately owned and cared for (Maco 2002). All other trees were considered private (No = 0). Determination of private trees was identified by evaluating the landscaped area for recurring species selection and groupings planted by the property owner. Likewise, out of place trees located within the ROW, and not deemed city trees, were considered privately owned trees. For example, if a street unit's city trees consisted of a relatively uniform distribution of Chinese tallow (*Sapium sebiferum*), and a single Windmill palm (*Trachycarpus fortunei*) was in the distribution, it was considered a private tree (e.g., a Windmill palm that matches other Windmill palms found in landscaping on property beyond the city ROW). If a street tree was planted by the community, a date was recorded; otherwise N/A was entered where information was not available. A number (1-4) was entered to correspond with the type of neighborhood or environment adjacent to the inventoried tree. These trees were coded as:

1 = single home residential,
2 = multi-home residential,
3 = commercial/industrial, and
4 = other (e.g., vacant, institutional, agricultural, park).

Using standard methods of forest mensuration, a DBH-tape was used to measure bole diameter (Avery and Burkhart 2002). DBH was then recorded to the nearest inch. Total tree height was determined using a laser and height was recorded to the nearest tenth of a foot (e.g., 37.2 ft). Crown diameter was measured by averaging the widest crown radius and narrowest crown radius measurement and multiplying by two. Measurement of crown diameter was recorded to the nearest foot.

The condition of each inventoried tree was recorded as a number (1-3) that corresponded with the following condition classes (Maco 2002):

1 = Good = Healthy vigorous tree. No signs of insect, disease, or mechanical injury. Little or no corrective work required. Form representative of species.
2 = Fair = Average condition and vigor for area. May need corrective pruning or repair. Lacks desirable form characteristic of species. Shows minor insect injury, disease, or physiological problem.
3 = Poor = General state of decline when it shows severe mechanical, insect, or disease damage; if death is imminent, remove (RMV) will be recorded under pruning.

The need for pruning was determined visually. Y = yes (i.e., pruning recommended) and the following codes were recorded for each type of pruning recommendation:

YLL = 1 = lower limbs need pruning,
YA = 2 = dead-wood present and needs crown cleaning,
YC = 3 = large limbs greater than 2 inches needing removal,
YUG = 4 = needs undergrowth removed,
YT = 5 = thin two or more stems or other undesirable tree stems, and
N = 0 = if the tree does not exhibit or require any of the above conditions.

The code Yes = 1 was recorded, where the following conflicts (e.g., damaged sidewalks, hazardous trees, improper spacing, poor visibility) were present or due to tree growth patterns. No = 0 was recorded where conflicts were not present. If a tree's root or roots were causing adjacent sidewalks to heave > 0.75" it was noted as either Yes = 1 or < 0.75" and No = 0.

Harris (1992) considered a tree to possess hazardous characteristics if it was structurally unsound and there was a possible target (i.e., structures, vehicles, people), significant weak structural growth was present (e.g., lack of dominant stem, poor limb attachment), if there was decay of the trunk or if there were branches, cankers, rot, and signs of root loss or decay. If these conditions existed it was noted as a Yes = 1 or No =

0. However, if target structures, humans, or vehicles were not present then no hazard existed (Harris 1992). These hazards were considered conflicts when clear views of street signs or intersections were obstructed by a tree or trees. Additionally, public street lamps or lighting that was obstructed by a tree constituted a conflict.

Conflicts were also considered as present if a tree or trees were spaced too closely to other public or private trees or structures or if the tree had reached its full potential size and it was determined that the form compromised or inhibited the tree's limited growing space (Maco 2002). If trees obstruct or interfere with overhead utility lines it was noted as either a Yes = 1 or No = 0.

Structural Analysis

Data collected during the street sample inventory facilitated assessment of structural components in Pass Christian and Hattiesburg's municipal forest. Determining species dominance and their DBH composition by point tile and citywide was determined from species frequency of occurrence found during the sample inventory of control trees in each tile. Species dominance and DBH composition were then transferred to LA trees created in each city's individual point tiles using each control tile's species frequency of occurrence to represent species and DBH in each LA tile. Species and DBH data summaries for each point tile were constructed using Microsoft Excel and Microsoft Access. Excel was used to transfer species and DBH information summarized from control trees to LA tree points. Also, Excel was used to increase each LA tree point tile by the number the model predicted as missing in each tile.

With estimates of each point tile's LA tree populations, inferences were then made by this study to estimate LA tree populations for species categories and DBH classes based on frequency of occurrence in each point tile. As an example, in point tile Hub_29, 288 trees composed of 27 different species were recorded during the control tree sample (i.e., 1 ALJU, 5 ACPA, 13 ACRU, 5 ACSA, 11 BENI, 1 CECA, 2 COFL, 1 MEAZ, 2 CAIL, 2 GIBI, 4 ILOP, 30 LAIN, 7 LIST, 1 LITU, 12 MAGR, 1 MGSP, 1 MAVI, 2 NYSY, 16 PYCA, 97 PITA, 4 QUFA, 3 QULA, 37 QUNI, 16 QUVI, 11 SASE, 2 TRWE, 1 ULAM) and used to report frequency of occurrence. This frequency of occurrence was calculated by dividing the total number of a particular species of tree found in a zone by the total number of trees found in a zone (e.g., PYCA - Flowering pear's frequency = 16 trees/288 trees = 0.05 or 5% of the zone.

Methodology for Extracting Urban Trees from LiDAR Data

As more and more LiDAR missions are flown and completed over state regions, an inventory methodology as proposed in this research could prove to be a valuable tool for creating a street tree inventory in cities that desire to engage in an urban and community forestry program. Publicly available data (i.e., LiDAR data and color aerial imagery for Harrison and Forrest County) collected post-Hurricane Katrina is available through MARIS and Mississippi Department of Environmental Quality (MDEQ) in a format compatible with ArcGIS and was used in this study with control trees inventoried for this research project in 2008 for Pass Christian and in 2004 for Hattiesburg to fulfill the study's objectives.

Data Processing

LiDAR contractors acquired data from March 21 to April 12, 2006 using its aircraft. Each county (i.e., Harrison for Pass Christian, Forest for Hattiesburg) was divided into a grid where each individual area was referred to as point tile. This reduced the large overall amount of LiDAR points for the entire county into smaller, more manageable units of data. Pass Christian's three point tiles varied in size (i.e., 3.6, 4.2, to 14.0 mi^2) conforming to the boundaries of the Gulf of Mexico to the south and Johnson Bayou to the north. Hattiesburg's four point tiles used in this study were uniform in size (i.e., 9.0 mi^2). Data was captured using an ALS50 LiDAR system, including an inertial measuring unit (IMU) and a dual frequency GPS receiver. An additional GPS receiver was in constant operation over a National Geodetic Survey published point at Hattiesburg-Bobby L. Chain Municipal Airport. During the data acquisition, receivers collected phase data at an epoch rate of 1 Hz. The contractor EarthData International, Inc. of Fredrick, Maryland, developed the following products for the City of Hattiesburg, USGS, and MDEQ and to comply with Federal Emergency Management Agency (FEMA) guidelines for flood mapping requirements.

1 Final LiDAR data georeferenced to MS State Plane East Zone, North American Datum (NAD) 83, North American Vertical Datum (NAVD) 88, US Survey foot,
2 Bare earth LiDAR data in ASCII (comma separated values) and LAS format,
3 Raw point cloud LiDAR data in LAS format,
4 LiDAR intensity data in TIF format,
5 Digital flight line index in ESRI-compatible format, and
6 Survey control report.
7 LiDAR processing report.

Airborne LiDAR data was acquired at an altitude of 8,000 ft (2,438 m) above mean terrain with a swath width of 5,823.57 ft (1,775.03 m), which yields an average post spacing of LiDAR points of no greater than 9.84 ft (3 m). The project was designed to achieve a vertical accuracy of the LiDAR points at 7.28 in (18.5 cm) root mean square error (RMSE). The horizontal datum was NAD 83 and vertical datum was NAVD 88. When compared to GPS survey grade points (i.e., control identification points in the field) in generally flat non-vegetated areas, at least 95% of the positions have an error less than or equal to 37 cm (equivalent to RMSE of 18.5 cm if errors were normally distributed). Point spacing was confirmed by ArcGIS to be no greater than 9.84 ft (3 m) apart for Hattiesburg's four point tiles.

Processing of LiDAR data and other shapefiles (i.e., roads, city boundaries, wards, tree points) in ArcGIS and LiDAR Analyst that was performed in this study followed the flow chart illustrated in Figure 5.

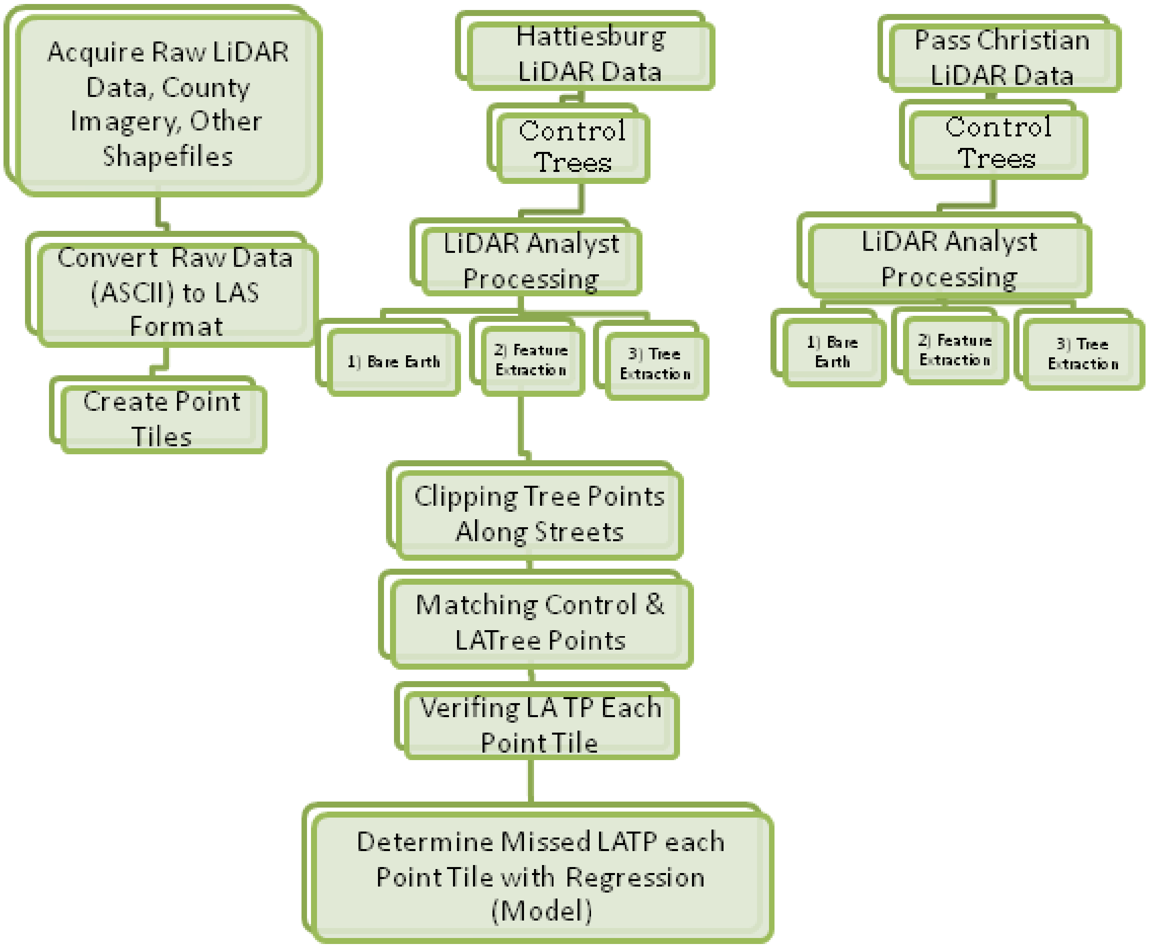

Figure 5 Flow chart for data acquisition and processing to determine missed tree points with a regression model. These were steps used in this study with LiDAR Analyst and ArcGIS for each city's control and LiDAR Analyst created tree points.

This study's process used tools within a GIS environment to create maps of tree point locations [i.e., LiDAR Analyst tree points (LATP), control tree points] in Pass Christian and Hattiesburg to estimate each city's overall street tree population. Several ArcGIS tools were used to separate LiDAR Analyst (LA) trees and control trees for each specific point tile. Toolbox functions of clip, buffer, and selection by location were used to create new shape files specific to each point tile. Clipping and buffering GIS functions were used to match (select) trees created with LA with a control tree counterpoint from the field inventory. This matching of LA trees and control trees was accomplished through the ArcGIS selection process based on a LATP not exceeding a distance of 30 ft from a control tree point. The distance of 30 ft was determined to be the best fit by visual observation of different buffering distances. Results from LiDAR identified trees were compared with control tree data to predict how many trees were missed by LA in each point tile.

A regression model $Y = \beta_0 + \beta_1 X + \xi$ was used in this study to predict trees missed by LA by comparing them with each point tile's control street trees collected during the on ground inventory. The regression model $Y = \beta_0 + \beta_1 X + \xi$, where: X= created LA tree points; Y= total LA tree points in each point tile (i.e., tree points created initially by LA plus the tree points missed by LA); β_0 and β_1 are the estimated intercept and slope; and ξ is the random error with a mean of zero and variance σ^2. It is important to note that other statistical models were used (e.g., log, polynomial) to estimate statistical significance between LiDAR Analyst tree points and control tree points; however, the results were not as significant in predicting missed LiDAR Analyst tree points as the simple regression model. The computer program R was used to determine the regression model's strengths and weaknesses with a statistical significance for each point tile's linear relationships. R is an integrated suite of software tools for data manipulation, statistical computation, and graphical display that is object-oriented, interactive, freeware supported by a large user network (Venables 2007).

The linear relationship (i.e., intercept, slope) determined by the regression model between the control trees and LATPs was used to predict the percentage of trees missed by LA for each point tile. Percentages of missed LATP determined for each tile using the regression model are then used in the regression model again to determine an overall intercept and slope percentage that can be used with each tile for estimating missed LA tree points. This was the percentage used to estimate categories of total street tree populations, structure (i.e., species composition, diversity, age distribution), tree function (i.e., magnitude of environmental benefits), and tree values (i.e., dollar values of benefits realized versus costs) for each point tile in a study area. Each point tile's trees were summed to infer each city's total tree population and individual categories of structure, function, and value. Each category was inferred using control tree inventory attributes found in each point tile in Pass Christian, and Hattiesburg, Mississippi. This process was directed toward planting location points (i.e., 30 ft from street edge) in the public right-of-way (ROW) of a city's streets. This process provided spatial locations (i.e., geographically located points) of street trees and inventory information (i.e., arboreal attributes) used to describe each city's overall street tree population.

ArcGIS, LiDAR Analyst, and R were used to create and analyze point patterns to complete this study. First, publicly available data (i.e., LiDAR, county imagery, city shape, wards, streets) was acquired from MARIS and MDEQ free of charge. The projection and datum used (i.e., Mississippi State Plane East Zone) throughout the project was determined by the most frequently occurring projection found in the many layers of publicly available data. Data processing required different tools (e.g., buffer, clip, select) and extensions (i.e., LiDAR Analyst, Georefrencing) that were used in ArcGIS for generating and analyzing each city's different LiDAR point tiles. A main project folder was created for all spatial files created through each individual GIS process performed with multiple folders and sub-folders with precise file paths to identify new files related to a specific task. Each new file created with a GIS tool or extension process (e.g., buffering, clip, adding x, y coordinates, selecting attributes, creating quadrats) were stored within the main project folder to maintain an orderly process and allow for easy retrieval and use in the overall methodology. LiDAR point tiles were created using ArcGIS toolbox 3-D Analyst to generate a point tile's attributes (i.e., geographical extent, total LiDAR points, point spacing). Each point tile's point density and areal extent was used to create specific areas of control tree points and LiDAR Analyst tree points for use in the regression model.

LiDAR Analyst was used to perform a step by step process to extract unique feature groups. Before the step by step process can be performed, LiDAR data has to be converted from an ASCII file into an LAS file format so it can perform individual feature extraction. The three step extraction process created a unique map layer for each feature grouping (i.e., 1. bare ground, 2. buildings, 3. individual trees and forest). Each step in the map layer creation process has to be followed to create the desired final feature layer of individual tree points. The step by step process was illustrated in (Appendix A). Each step required that a choice be made for certain attributes (e.g., minimum tree height, maximum forest size). Therefore, it was appropriate to accept most defaults; however, more desirable results may be obtained by changing default parameters (e. g., growth characteristics such as spacing and crown shape) to better fit a city's specific urban trees.

Tree points that were created with LiDAR Analyst were used to compare with control tree points to determine if a linear relationship exists in a regression model.

Benefit and Cost Analysis for Street Trees

Total benefits for a city were represented as the discounted sum of all resource values for each individual (DBH class) size of each specific tree species growth rate category (e.g., broadleaf deciduous large, broadleaf deciduous small, broadleaf evergreen large, broadleaf evergreen medium, conical evergreen large). For example, Pass Christian and Hattiesburg, Mississippi's overall resource value benefit and BCR was determined using defaults in i-Tree Streets. Each city's street tree inventory created by LA plus predicted trees LA missed as determined by the regression model were input into i-Tree Streets. This inventory was separated into species, growth categories, and DBH classes based on species frequency of occurrence determined from ground inventory. Resource values used for each regional growth rate category found in Pass Christian and Hattiesburg, Mississippi were the same as those used in i-Tree Streets defaults for the Coastal Plains and South regions. These two growth rate regions use estimates of data collected in each region for tree age, size, leaf area, and biomass to estimate each species specific crown volume and leaf surface area to determine an individual resource value for each tree species by growth rate category and DBH class. The i-Tree Streets program required that each species growth rate category was stratified into DBH classes in either inches or centimeters (e.g., inches: 0-3, 4-6, 7-12, 13-18, 19-24, 25-30, >30) or by individual tree measurements.

Each genus and species that was recorded during each city's sample inventory was placed in one of i-Tree Streets growth rate categories listed below to determine each city's total dollar value benefits. This was determined by multiplying each specific tree categories total estimated population by the appropriate resource values determined for each regional tree growth zone. The total street tree population stratified by species growth rate category and age (i.e., DBH) that was estimated with the regression model for each city is shown in Appendix F.

- Broadleaf deciduous
  - large (>15 m [50 ft]) (DL)
  - medium (8-15 m [25-50 ft]) (DM)
  - small (<8 m [25 ft]) (DS)
- Broadleaf evergreen
  - large (>15 m [50 ft]) (EL)
  - medium (8-15 m [25-50 ft]) (EM)
  - small (<8 m [25 ft]) (ES).
- Conical Evergreen
  - large (>15 m [50 ft]) (EL)
  - medium (8-15 m [25-50 ft]) (EM)
  - small (<8 m [25 ft]) (ES).

After all LA tree point tiles were updated in Excel to include any missed tree points determined by the model they were appended to an Access database sheet that was inserted into i-Tree Streets. The tree inventory with species codes separated by DBH was created as an Access database to enter into i-Tree (APPENDIX F). Creating a new project for each city in the computer program i-Tree Streets required entering the following information: median home prices, a city's annual budget, growth region, city size in square miles, street miles, regional benefit and costs (i.e., for electricity, natural gas use, air quality improvements, CO_2 mitigation, stored carbon, stormwater mitigation), and management costs. All of the aforementioned criteria were required for assessing and reporting benefits and costs on each city's tree structure, species composition, age distribution, importance values, environmental benefits, and BCR.

Property Values

Median home prices for Pass Christian and Hattiesburg were entered into i-Tree to determine what a single large front yard tree, regardless of species, increased the average home resale value. This price category was adjusted in this study using Charleston, South Carolina and Charlotte, North Carolina numbers to determine a present day dollar value, on a similar large tree in Pass Christian and Hattiesburg. In Charleston, a typical mature large tree [25-year-old live oak, average leaf surface area (LSA) 2,758 ft^2] was the basis for valuing the capacity of trees to increase property value (McPherson et al. 2006). For example, it was estimated that a single, street-side live oak (12-18" DBH) added about 212 ft^2 of LSA per year. This indicated that live oaks can add $72.21 per year to the value of an adjacent home, condominium, or business property. Using a price per ft^2 LSA, i-Tree Streets establishes a guideline to value different tree sizes in Pass Christian and Hattiesburg based on each city's median home price.

Energy and Natural Gas Savings

Changes in building energy use in Pass Christian, and Hattiesburg from tree shading were inferred based on previously derived computer simulation models (McPherson and Simpson 1999). These models incorporated differences in building structure, climate, and effects of shading. Building characteristics were differentiated by age of construction (i.e., pre-1950, 1950-1980, post-1980) taking into account number of stories, floor area, window area, and insulation. Shading effects for deciduous and evergreen large, medium, and small trees were calculated at four ages after planting (i.e., 5, 15, 25, 35 yrs), for three different tree-to-building distances at 3-6 m (10-20 ft), 6-12 m (20-40 ft), and 12-18 m (40-60 ft), and using eight different positions with selected azimuths (i.e., 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°).

From simulation results performed in Charleston, an algorithm was developed to predict energy savings for a tree at each possible location (i.e., distance and direction from building) with each leaf pattern and size. Using aerial photos and the distribution of street tree locations of Charleston's street trees, with respect to buildings, the algorithm determined an average energy savings per tree at each location. Average annual savings were summed over species and age for all trees to derive citywide totals. Dollar values of electrical energy savings and natural gas savings were based on market prices for Pass Christian and Hattiesburg in i-Tree Streets by using regional \$/kWh and \$/therm, respectively. It should be noted that energy costs recommended by i-Tree Streets defaults may not be a true representation for a specific city and should be verified by a local energy provider.

Atmospheric CO_2 Reductions

Net CO_2 reductions were calculated based on avoided emissions from energy use and that which was directly sequestered and released through tree growth, removal, and maintenance. As a byproduct of electricity generation, benefits from CO_2 reductions for Pass Christian and Hattiesburg were based on a local utility emission factor of \$/kg per kWh (lbs/kWh). Summing the storage of CO_2 in above- and below-ground biomass determined sequestration over the course of one season for a representative species of different tree type categories. Carbon dioxide released was based on estimation that 80% of tree carbon was released to the atmosphere the same year as mortality occurred through the process of chipping and the resultant decomposition of tree biomass such as mulch. Tree mortality was determined by i-Tree Streets using a predetermined regional percentage for each age class removed due to tree mortality in Pass Christian and

Hattiesburg using a three-year average. Released CO_2, as a result of tree maintenance, was estimated to be $/kg of CO_2/cm DBH based on an average annual consumption of gasoline and diesel fuels used by the city's UFD. A dollar value of CO_2 reductions was expressed in ($/metric tonne or $/short ton) based on default control costs recommended by i-Tree.

Air Quality Improvement

When building energy use was reduced by shading, power plant emissions of air pollutants, as well as CO_2 emissions, were reduced. Changes in volatile organic compounds (VOCs), nitrogen dioxide (NO_2), as well as particulate matter of <10 micron diameter (PM_{10}) were calculated as emission offsets. Calculations for offsets were performed using the same method for CO_2, as described above with utility-specific emission factors (Maco 2002).

I-Tree uses direct removal of pollutants from the atmosphere by expressing the products dry deposition velocity, a pollutant concentration C, a canopy projection area, and a time step (Maco 2002). Hourly deposition velocities for NO_2, ozone (O_3), and PM_{10} were calculated using methods described by Scott et al. (1998) to estimate resistances on an hourly basis throughout a "base year" (Maco 2002). This value was inferred from the Charleston and Charlotte studies for Pass Christian and Hattiesburg.

Dollar values for resource units were applied using the market value of pollution emission credits traded on the open market and are listed in APPENDIX G. The program i-Tree Streets used weighted averages of all transactions ($/metric or shot ton) during 2009 to determine the $/kg values of NO_2, PM_{10}, and VOCs in Pass Christian and Hattiesburg.

Stormwater Runoff Reductions

As described by Xiao et al. (1998), a numerical simulation was used by i-Tree to estimate annual rainfall interception and storage by urban trees for Pass Christian and Hattiesburg. The model incorporated tree species, leaf area, crown density, and height, and used hourly meteorological and rainfall data from each study region. Effective interception was the proportion of precipitation intercepted by a tree that would otherwise result in direct surface runoff, a factor that must be accounted for valuing effectiveness in reducing stormwater management costs (Maco 2002). The implied value of intercepted rainfall ($\$/m^3$) was based on annual expenditures for urban stormwater quality programs and produced a total annual benefit of intercepted rainfall over 40 years, or the time estimated to recoup complete reinvestment in a stormwater quality program (Xiao et al. 1998).

An essential component in understanding stormwater runoff is the evaluation of each type of land use area and its effectiveness in producing runoff. Pass Christian and Hattiesburg, lacked complete data for annual expenditures on stormwater management estimations comparable to Charleston and Charlotte were used to estimate each city's total stormwater runoff benefit.

Assessing Total Benefits and Costs

Annual benefits were summed for each street tree in i-Tree Streets, for all LiDAR point tiles in each city, and were summed using prices determined for each city's specific growth region. However, the BCR reported is specific to the year entered into the i-Tree program (e.g., 2005, 2010, 2011). Citywide resource values (i.e., annual average energy savings (kBtu/tree); annual average electricity savings (kWh/tree); annual average natural gas savings (kBtu/tree); H_2O interception m^3/tree) are estimated using each species growth category for its specific DBH class or individual DBH measurement to calculate Pass Christian and Hattiesburg's overall dollar value benefit (Appendix G).

Street Tree Management Cost for Pass Christian and Hattiesburg

Management costs for each city were determined by what city department was responsible for street tree maintenance. However, the cost to perform an inventory (i.e., complete or sample) was not included in the annual costs as it would skew the BCR since inventory methods and costs are continually changing and would be specific to each community. Public and private street trees in Pass Christian that are greater than 18 inches in circumference are protected (pine is excluded) by a city ordinance. Permission to remove protected trees has to come from the city's tree board. At present there is not an UFD in Pass Christian to initiate planting, pruning, and other maintenance needs. However, the city's public works department does provide weekly debris removal from public streets. Street trees in Hattiesburg are managed through the city's UFD. Total costs associated with Pass Christian and Hattiesburg's street tree management was estimated through guidance provided by Pass Christian's chief operating officer Malcolm Jones and Hattiesburg's Urban Forester Andy Parker. Costs used for each city were presented in Appendix D. Also, each city's total street tree annual net benefits and their associated BCR were calculated and reported individually using i-Tree Streets (Appendix G).

CHAPTER IV

RESULTS

GIS Outputs of LiDAR Data and Tree Points

The first objective to create a user friendly process and a regression model for the development of a street tree inventory using reliable ArcGIS tools and R a tested spatial statistical package was successful as the process can be replicated by users with a limited knowledge of ArcGIS by following cookbook steps presented in Appendix A. The model exhibited a statistical significance (i.e., R^2 of 0.88) in predicting trees that were missed by LiDAR Analyst. Indicating cities with existing LiDAR data (e.g., coarse point spacing data used by FEMA for contour mapping) could explain 88% of the estimated variation in their street tree population.

It is important to note that the model only predicts 88% of a city's street tree inventory because of coarse point spacing in the LiDAR data. The model used tree points created with LA and ground control tree points in 7 point tiles (i.e., 3 from Pass Christian, 4 from Hattiesburg) to statistically predict how many trees were missed by LA. The model for all 7 point tiles used a simple regression formula: $Y = \beta_0 + \beta_1 X + \xi$, where the intercept $\beta_0 = 41.03$; slope $\beta_1 = 1.15$; X = created LA tree points; ξ is the random error with a mean of zero and variance σ^2; and $>$ = total LA tree points (i.e., tree points created plus those missed). As an example: the point tile Hub_29 had 3,690 LA tree points created and when used with the models slope and intercept (i.e., 1.15 x 3690 + 41.03) it estimated that LA missed 595 trees and the point tile actually has 4,284 total trees. The 7 point tiles plotted along its prediction line was illustrated in Figure 6.

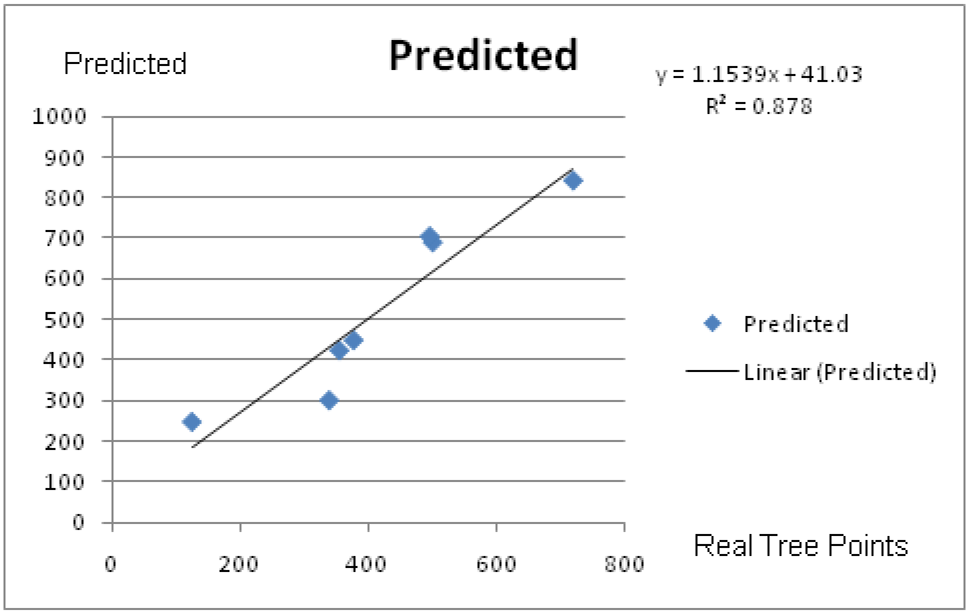

Figure 6 The regression model graph illustrates the strength and direction of relationship between the independent (i.e., control tree points) and dependent (i.e., LiDAR Analyst created tree points) variables for the 7 point tiles (i.e. 3 for Pass Christian and 4 for Hattiesburg). An R^2 of 0.878 represents the percentage of variation in y (i.e., trees missed by LiDAR Analyst) that is explained by the regression line.

Objective two was only partially met because the database of arboreal attributes created by LA for each city's street trees was not representative of true height, canopy spread, or DBH. Tree height from LA tree points and corresponding control tree points were investigated with regression to explore any correlation; however, the R^2 was low for each point tile revealing little correlation to LA and control tree point attributes. This was attributed to the LiDAR data's coarse point spacing which did not allow LA to correctly identify the highest points on all trees. Therefore, LA also incorrectly interpolated canopy spread and DBH measurements for most trees as it used height to infer these metrics. However, LA was successful in producing an acceptable map of tree points which could be used to identify areas with potential stocking problems (i.e., overstocked possibly needs thinning, understocked possibly needs planting). Also, the map provided each city with a visual baseline of trees points that could be used to estimate arboreal attributes through sampling. A sample of tree height variation (i.e., how well the control tree point's height matched with its corresponding LiDAR Analyst created tree point) and R^2 values for corresponding control and LATP in each point tile is listed in Table 2.

Table 2 Control tree points that matched with LiDAR Analyst tree points with corresponding tree heights for each city's point tiles (i.e., Pass Christian B_8, C_7, C_8 and Hattiesburg H_29, H_30, H_40, H_41). Each set of point tiles were explored for a relationship between known height and predicted tree height the probability of predicting height is listed for each set of point tiles as an R^2 value.

B_8 C* Hts	B_8 LATP Hts	C_7 C* Hts	C_7 LATP Hts	C_8 C* Hts	C_8 LATP Hts	H_29 C* Hts	H_29 LATP Hts	H_30 C* Hts	H_30 LATP Hts	H_40 C* Hts	H_40 LATP Hts	H_41 C* Hts	H_41 LATP Hts
42	39.3	24	22.6	40	30.8	46	43.8	24	22.6	52	39.2	50	27.5
39	46.1	36	24.3	35	35.3	55	44.7	36	24.3	52	30.8	62	38.9
47	33.8	71	36.0	37	27.1	65	23.6	71	36.0	47	41.5	62	41.2
57	43.3	39	34.6	35	26.0	38	32.6	39	34.6	46	42.0	41	27.4
57	47.7	52	33.8	37	27.6	55	46.7	52	33.8	51	36.4	64	52.0
34	24.7	58	29.5	35	25.8	61	35.0	58	29.5	49	37.6	59	55.6
37	39.0	67	32.3	35	35.0	65	34.2	67	32.3	61	31.3	59	41.6
43	32.7	32	24.1	53	28.2	66	49.8	32	24.1	49	39.3	58	55.1
37	32.9	70	33.5	36	25.1	46	43.8	70	33.5	67	34.3	36	28.4
33	23.8	38	33.4	43	39.8	55	44.7	38	33.4	64	42.5	35	27.2
R^2	0.27		0.35		0.13		0.25		0.35		0.33		0.26
C* - Control Tree Points													
LATP – LiDAR Analyst created tree points													
Hts – Tree heights													

Objective three, which was to utilize case studies from other urban forestry projects, (i.e., international, national, regional, local), to illustrate support for this study's methodology proved to be ineffective because there were no studies using LA with coarse point spacing LiDAR data in the literature. However, there were many case studies to support the use of sampling to describe street tree populations, species distribution, frequency of occurrence, age distribution, annual benefits provided by street trees, and the use of GIS over paper maps. Many studies were performed in cities across the United States for specific growth regions (See map page 8) by The CUFR in Berkley, California. Pass Christian was referenced to a study completed in Charleston, South Carolina because they both occurred in the coastal plain growth region and Hattiesburg was referenced to a study completed in Charlotte, North Carolina because they both occurred in the south growth region. The advantage of using a GIS over separate conventional paper maps or analytical spreadsheets provided an ability to utilize mapping capabilities and related data together in a quicker and more efficient manner. Case studies in Washington D.C. (Goodwin 1996), Davis, California (Maco 2002), and Charleston, South Carolina (McPherson 2005), were examples exhibiting how databases created and stored in a retrievable format can increase effectiveness and efficiency in an UFD.

Objective 4 utilized the estimated street tree inventory and each study area's growth zone with their estimated or real street tree management costs did estimate benefit/cost ratios (i.e., every dollar spent planting and managing street trees provides a certain amount of value) for each city.

LiDAR Data Outputs

Each city's LiDAR data required processing to determine trees occurring 30 ft from a street edge. Spatial data [tree points (TP)] was created with LA from each study area's LiDAR data point tiles which were illustrated in Figures 7 and 8.

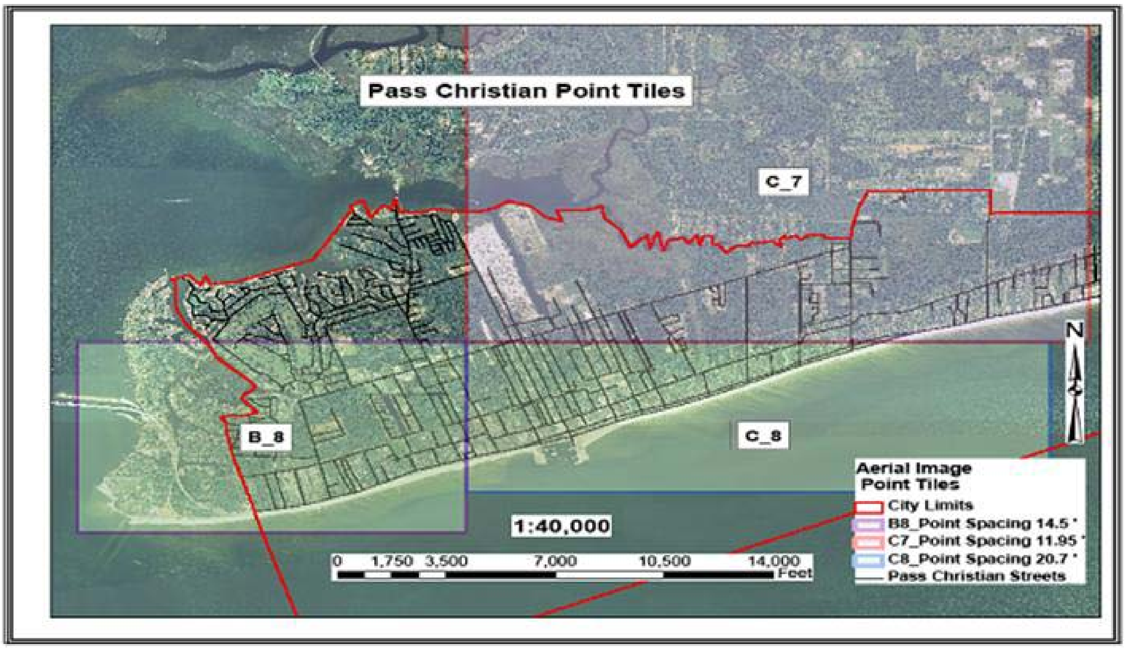

Figure 7 Pass Christian, Mississippi’s three LiDAR point tiles B8, C7, and C8 with an average point spacing of 14.5’, 11.9’, and 20.7’ apart, respectively, were used with LiDAR Analyst (LA) to generate tree points.

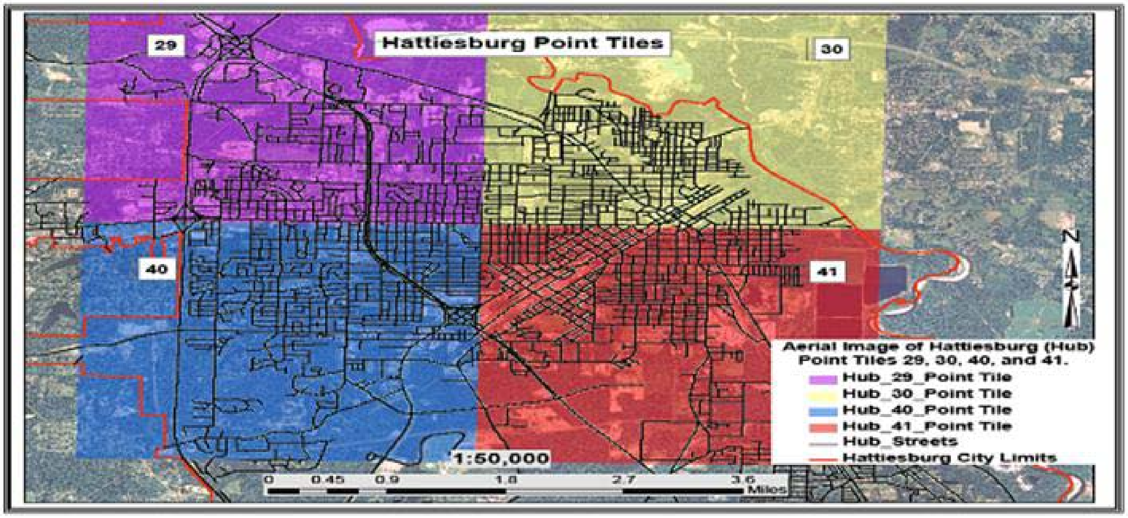

Figure 8 Hattiesburg, Mississippi’s four LiDAR point tiles 29, 30, 40, and 41 with an average point spacing of 6.2’, 6.6’, 5.9’ and 6.3’ apart, respectively, were used with LiDAR Analyst (LA) to generate tree points.

Pass Christian and Hattiesburg's total LiDAR point count with average point spacing in feet apart, tree points created with LA, and control trees recorded during inventory for all point tiles were listed in Table 3.

Table 3 Individual point tile data for Pass Christian and Hattiesburg, Mississippi with LiDAR point spacing in feet, total LiDAR points, LATP* created 30 feet from street edges, and control trees recorded during 2008 and 2004 inventories.

Point Tiles	Average Point Spacing	Total LiDAR Points/Tile	LATP Created 30' from Street Edge	Control Trees Inventory	Total LATP From Model
B_8	14.52	488,389	598	127	729
C_7	11.95	2,799,622	427	377	532
C_8	20.71	284,364	407	500	509
City Total			1,432		1,770
Hub_29	6.18	6,689,522	2,553	495	2,977
Hub_30	6.64	5,798,641	1,906	355	2,233
Hub_40	5.96	7,183,951	4,032	718	4,678
Hub_41	6.34	6,362,598	3,045	339	3,543
City Total			11,946		13,431
*LATP - LiDAR Analyst created Tree Points					

LiDAR Analyst used point data from each tile to create each study area's LA tree points. Total number of tree points created over Pass Christian's 7 mi^2 was 19,680 (i.e., B_8- 5,660TP; C_7- 10,724TP; C_8- 3,296TP) (Figure 9). Total number of tree points created over Hattiesburg's 50 mi^2 was 183,274 (i.e., Hub_29- 47,763TP; Hub_30- 30,273TP; Hub_40- 62,380TP; Hub_41- 42,858TP). It was important to note here that a zoomed in visual inspection of each city's total tree points revealed that many single dwelling homes had been classified as tree points indicating that it would be incorrect to use each city's total number of tree points created by LA. This incorrect classification of small homes and small buildings as tree points was attributed to the coarse point spacing in LiDAR data. However, zoomed in visual inspection of tree points that were selected occurring 30 ft from street edges did not reveal misclassified homes as tree points as most of the single dwelling homes were found to occur further than 30 ft from a street edge.

Pass Christian's 3 point tiles B_8, C_7, and C_8 consisted of 61 linear miles of streets with 1,432 LATP (i.e., B_8- 598TP, C_7- 427TP, C_8- 407TP) occurring 30 ft from a street edge (Figure 10). LATPs found in each tile were used in the model with each tile's control tree points used to estimate missing LATPs.

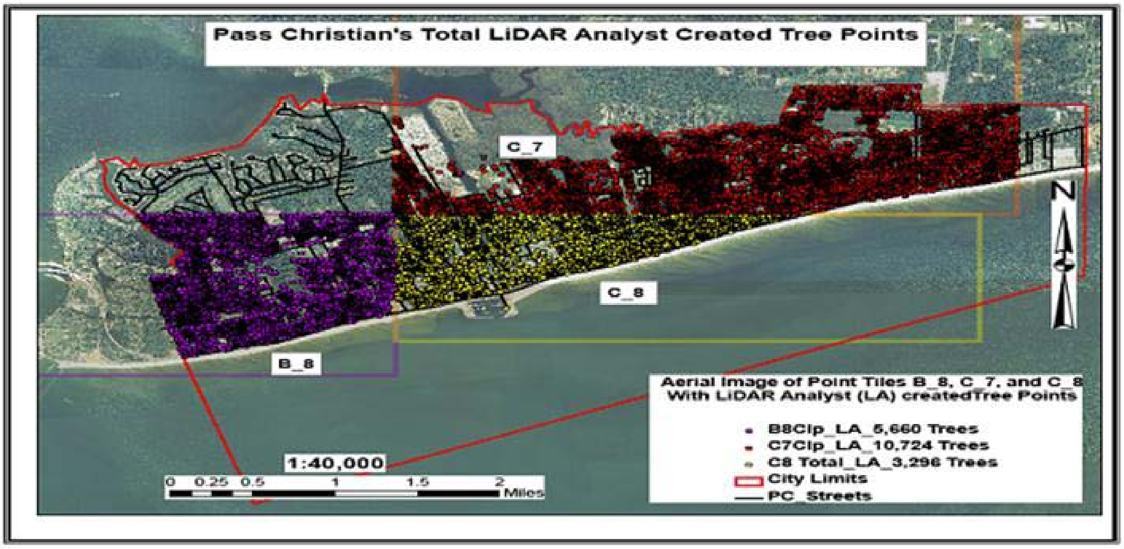

Figure 9 The aerial image above illustrates tree points created by LiDAR Analyst (LA) for each of the point tiles (i.e., B_8, C_7, C_8) in Pass Christian, Mississippi.

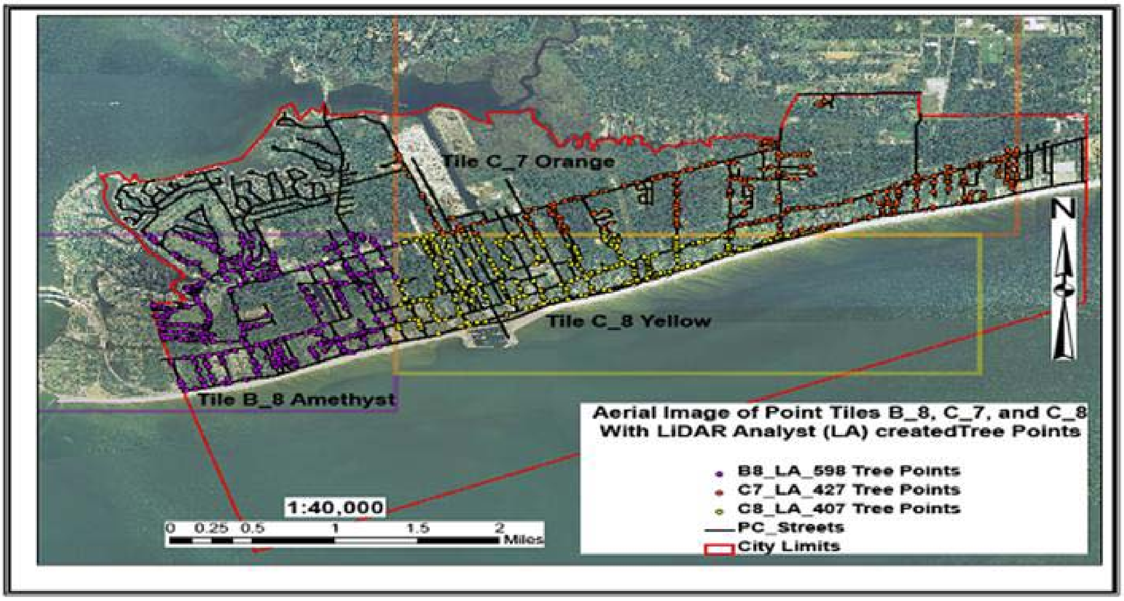

Figure 10 An aerial image of Pass Christian, Mississippi which illustrates tree points that occur 30 feet from a street edge as created by LiDAR Analyst (LA) for each point tile.

Hattiesburg's 4 point tiles consist of 366 linear miles of streets with 11,536 LATP (i.e., Hub_29-2,553TP, Hub_30-1,906TP, Hub_40- 4,032TP, Hub_41- 3,045TP) that occurred 30 ft from a street edge. LATPs found in each tile (Figure 11). The regression model used LATPs with each tile's control tree points to estimate those missed by LA.

The model used an 11.2 mi sample of 1,003 control trees occurring 30 ft from street edges in Pass Christian. Control trees inventoried used for comparison occurred along streets for 2 miles in B_8 (127TP), 3.5 miles in C_7 (377TP), and 5.6 miles in C_8 (500TP) (Figure 12). Control tree data was collected during the summer of 2008 and was used as the basis for Pass Christian's structural analysis of its street trees.

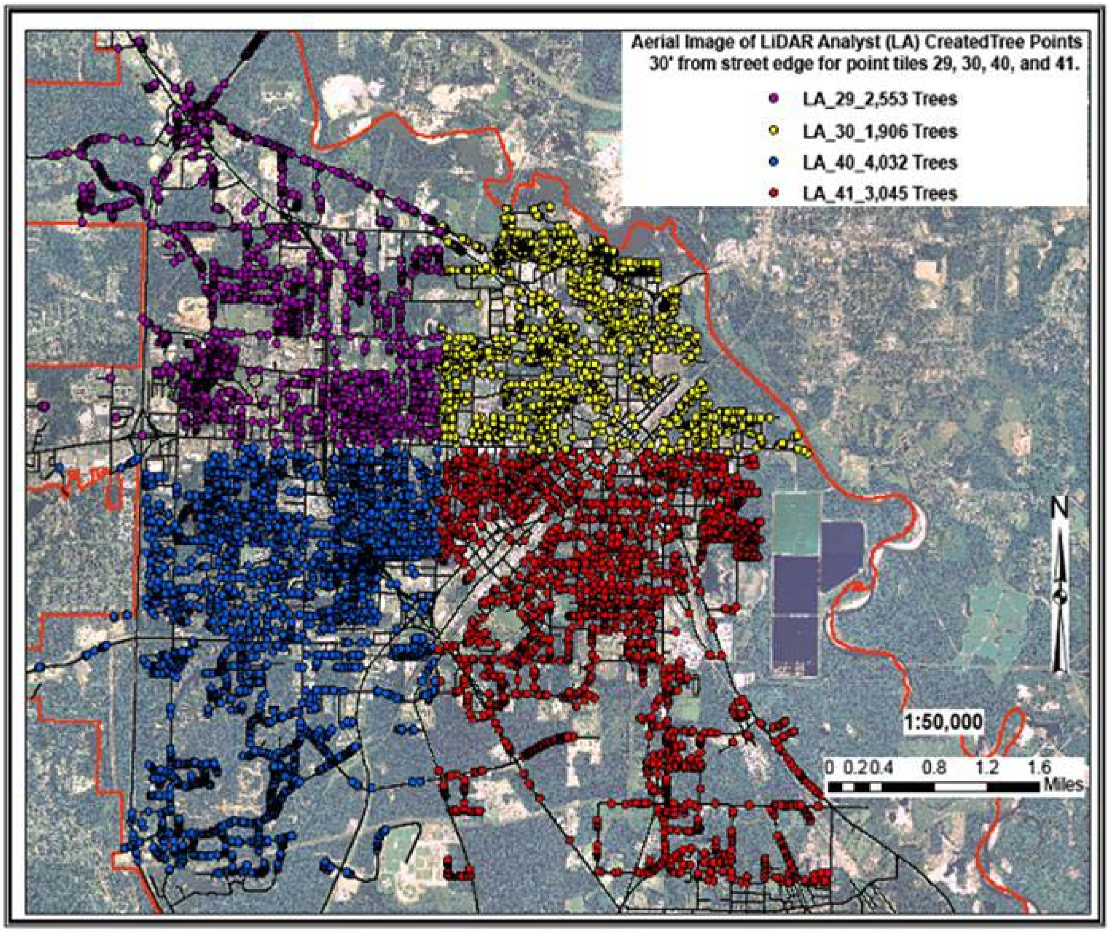

Figure 11 An aerial image of Hattiesburg, Mississippi which illustrates tree points created by LiDAR Analyst (LA) for each point tile that occurs 30 ft from a street edge. Point tile 29 illustrates 3,690 tree points created by LA and occurs 30 ft from a street edge.

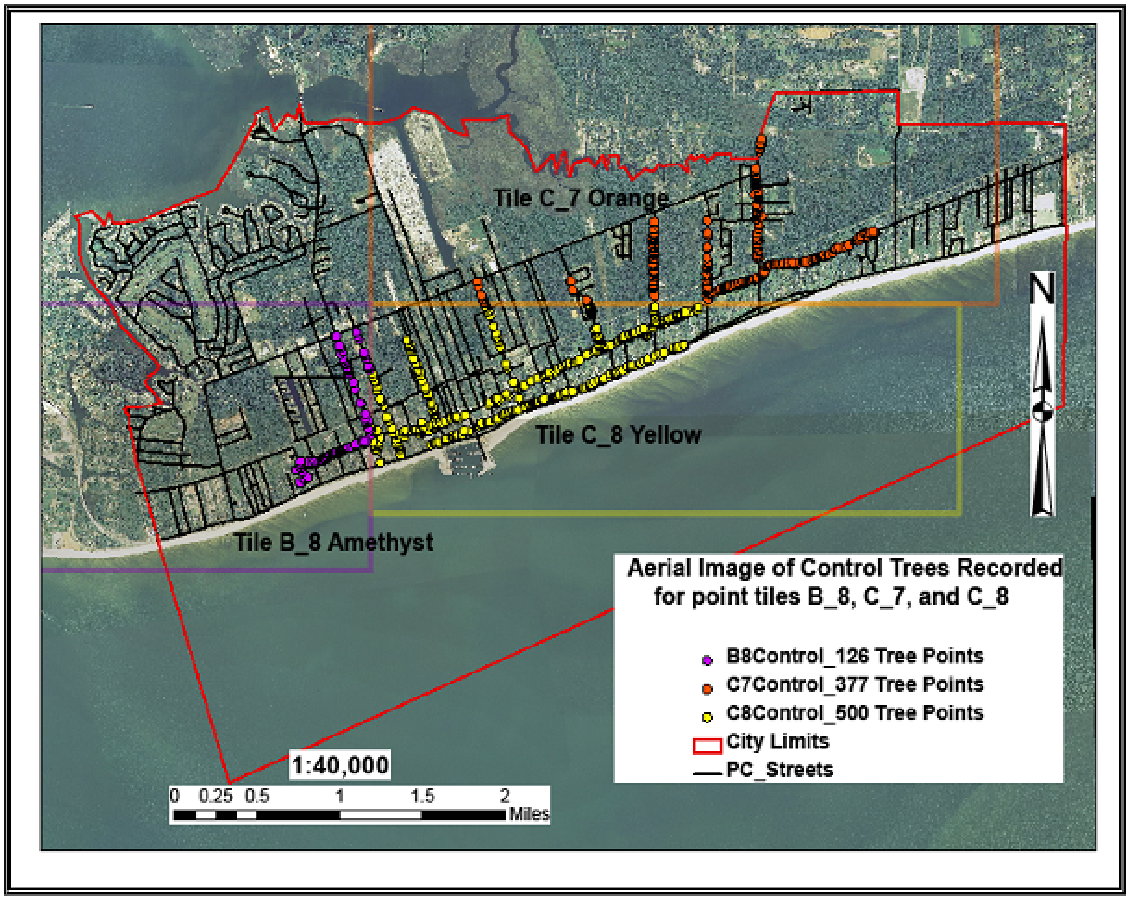

Figure 12 An aerial image of the control tree points inventoried and collected with a sub-meter accuracy Trimble global positioning system (GPS) for each point tile in Pass Christian, Mississippi during 2008.

The model used a 44 mi sample of 1,907 control trees occurring 30 ft from a street edge in Hattiesburg. Control trees inventoried used for comparison occurred along streets for 12 mi in Hub_29 (495TP), 10 miles in Hub_30 (355TP), 13.5 mi in Hub_40 (718TP), and 8.5 mi in Hub_41 (339TP) (Figure 13).

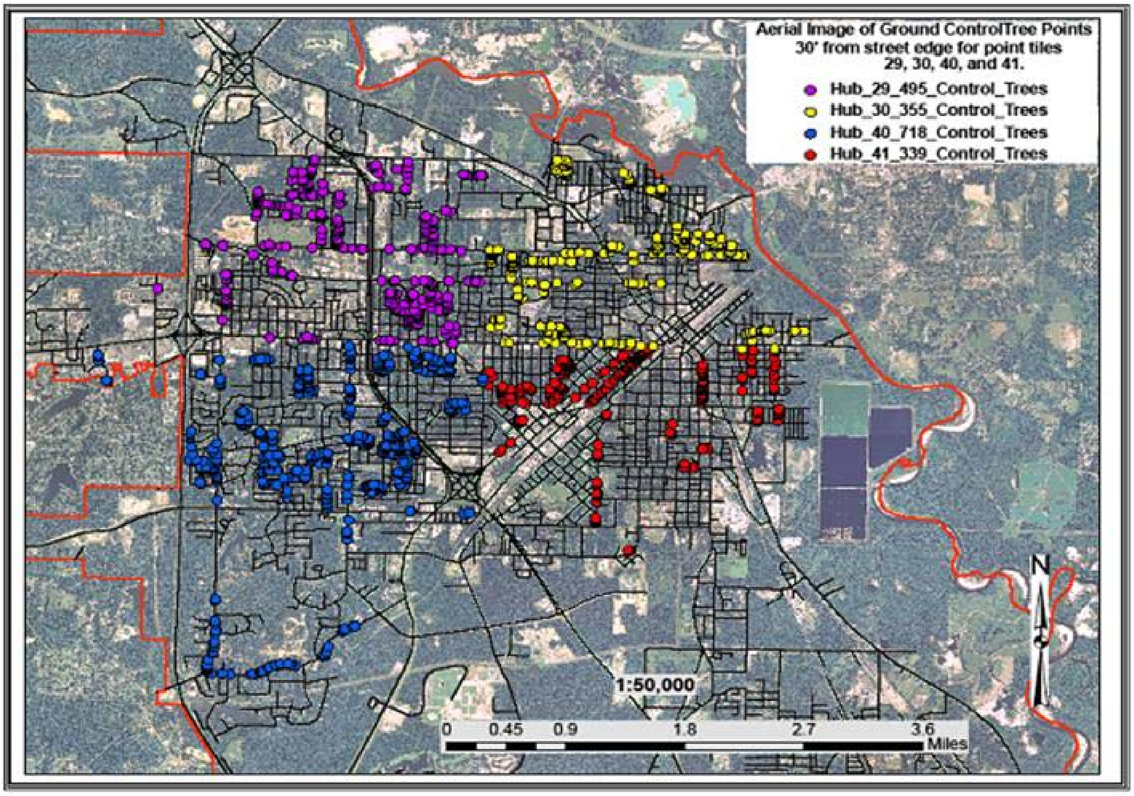

Figure 13 An aerial image of the control tree points inventoried and collected with a sub-meter accuracy Trimble global positioning system (GPS) for each point tile in Hattiesburg, Mississippi during 2004.

Pass Christian and Hattiesburg's Street Tree Structural Analysis

Data collected during the sample inventory facilitated an assessment of structural components (e.g., species distributions, age distributions, height dispersions, CC, importance values), environmental benefits, the increased property tax base from increased property values, and the overall BCR for the city's street tree management. Pass Christian and Hattiesburg's species distribution (Figure 14 and 15).

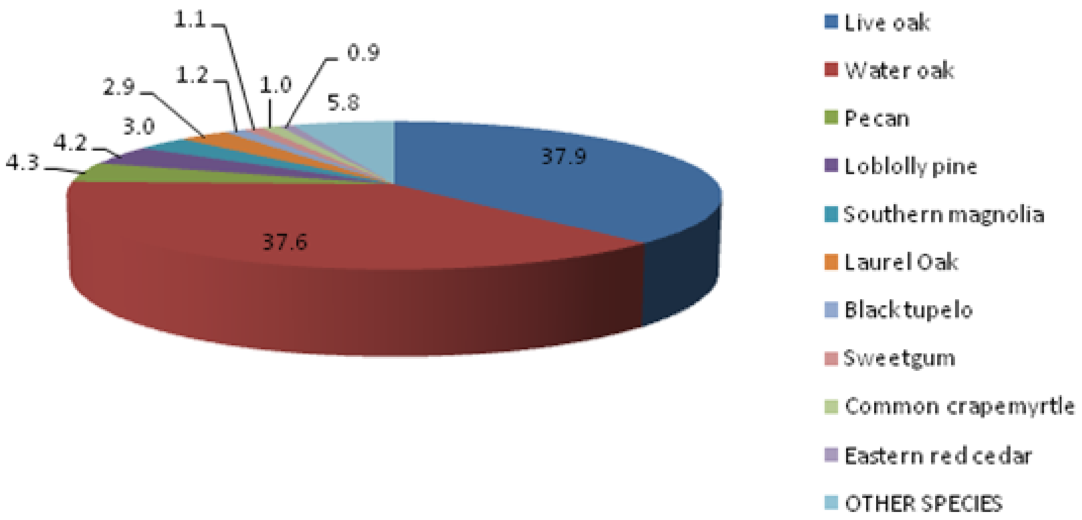

Figure 14 Pass Christian, Mississippi's street tree distribution by species for the entire city as it was recorded during the sample inventory in 2008.

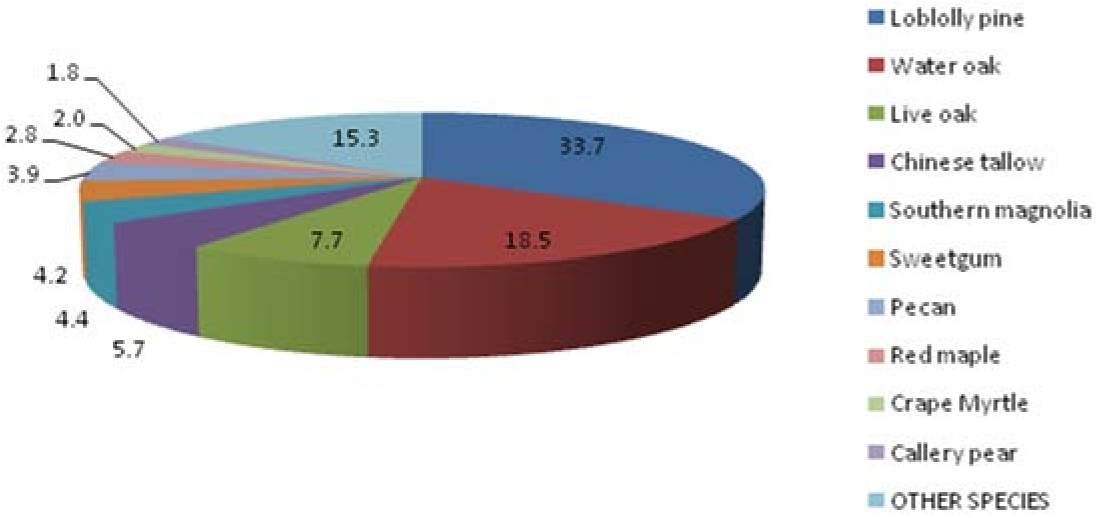

Figure 15 Hattiesburg, Mississippi's street tree distribution by species for the entire city as it was recorded during the sample inventory in 2008.

Frequency of occurrence and growth category for each tree species found in each point tile was determined from data recorded during the inventory taken for Pass Christian and Hattiesburg's street trees. Frequency of species occurrence and their growth categories were used to determine dominance among street trees. Species were stratified by DBH classes and individual measurements to provide a representation of age distribution based on a species frequency of occurrence throughout each city. This age distribution of species can allow management to concentrate planting in any uneven-aged populations to sustain canopy cover, and height classes for each growth category. DBH classes were illustrated in Figure 16 for Pass Christian and Figure 17 for Hattiesburg.

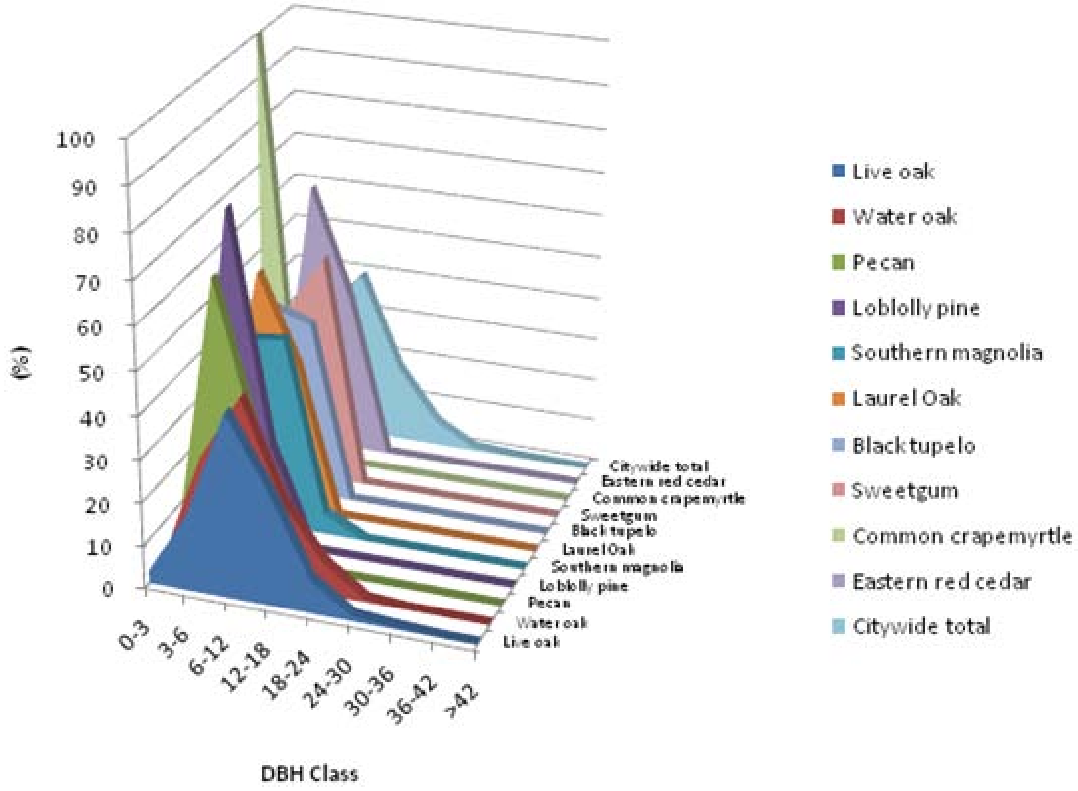

Figure 16 Age distribution of Pass Christian, Mississippi's predominant trees by diameter at breast height (DBH) class and percentage of occurrence recorded during the sample inventory in 2008.

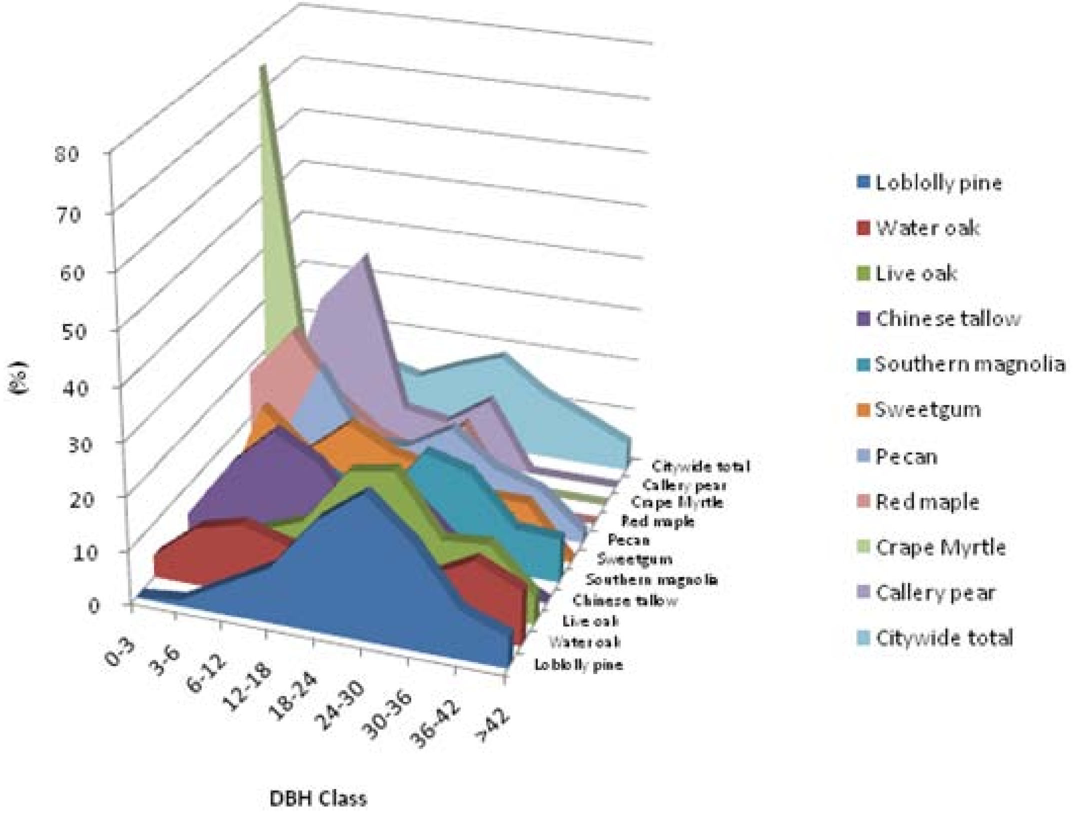

Figure 17 Age distribution of Hattiesburg's predominant trees by diameter at breast height (DBH) class and percentage of occurrence recorded during the sample inventory in 2004.

Targeting Pass Christian's and Hattiesburg's most abundant species during the inventory was challenging since most tree species found along each city street occurred in only two genus. *Pinus* (Pine) at 5% and *Quercus* (Oak) at 76% dominated the tree population in Pass Christian while the genus *Pinus* (Pine) at 26% and *Quercus* (Oak) at 30% made up the majority of Hattiesburg's tree population. The 19 most abundant species that used in Charleston, South Carolina and Charlotte, North Carolina to establish resource values for growth categories were also found during Pass Christian and Hattiesburg's street inventory just not in great abundance. Street tree species that were found to occur over 1% of the time during both city inventories (Tables 4 and 5).

Table 4 Pass Christian, Mississippi's common tree names, species code, total trees, and frequency of occurrence recorded during 2008 inventory.

	Common Name	**Species* Code**	**Species Total Count**	**Frequency %**
1	Pecan	CAIL	46	5
2	Date Palm	Date Palm	6	1
3	Hackberry	CELA	9	1
4	Cedar	JUVI	7	1
5	Crape Myrtle	LAIN	13	1
6	Sweet Gum	LIST	10	1
7	Magnolia	MAGR	34	3
8	Tupelo Gum	NYSY	11	1
9	Pine	PITA	49	5
10	Laurel Oak	QULA	39	4
11	Water Oak	QUNI	168	17
12	Live Oak	QUVI	548	55
13	Tallow	SASE	10	1
	Other Trees		53	4
Total			1,003	100%

*Species codes are defined in Appendix C.

Table 5 Hattiesburg, Mississippi's common tree names, species code, number of total trees, and frequency of occurrence recorded during 2004 inventory.

	Common Name	**Species* Code**	**Species Total Count**	**Frequency %**
1	Red Maple	ACRU	46	2
2	River Birch	BENI	12	1
3	Catalpa	CABI	18	1
4	Pecan	CAIL	63	3
5	Red Bud	CECA	24	1
6	Camphor	CICA	16	1
7	Cedar	JUVI	30	2
8	Crape Myrtle	LAIN	36	2
9	Sweet Gum	LIST	80	4
10	Magnolia	MAGR	83	4
11	Tupelo Gum	NYSY	13	1
12	Pine	PIPA	597	31
13	Sycamore	PLOC	14	1
14	Flowering Pear	PYCA	30	2
15	Red Oak	QUFA	16	1
16	Laurel Oak	QULA	23	1
17	Water Oak	QUNI	413	22
18	Willow Oak	QUPH	22	1
19	Shumard Oak	QUSH	10	1
20	Live Oak	QUVI	142	7
21	Chinese Tallow	SASE	101	5
22	Bald Cypress	TADI	17	1
	Other Trees		89	5
	Total		1,897	100%

*Species codes are defined in Appendix C.

There were 27 different tree species recorded in Pass Christian, however, only 13 species had an occurrence greater than 1% and 2 oak species accounted for 72% of all tree species. From all *Quercus* species recorded live oak (*Quercus virginiana*) an evergreen, had the greatest frequency of occurrence at 55%, water oak (*Quercus nigra*) was next with 17%. Other significant species were pecan (*Carya illinoinensis*), and loblolly pine (*Pinus taeda*), with each found to occur 5% of the time in Pass Christian. Other trees occurring along Pass Christian's streets that were recorded less than 1% of the time during inventory were red maple (*Acer rubrum*), camphor (*Cinnamomum camphora*), green ash (*Fraxinus pennsylvanica*), bamboo (*Bambusa glaucescens*), sweet bay magnolia (*Magnolia virginiana*), mulberry (*Morus alba*), pear (*Pyrus communis*), persimmon (*Diospyros virginiana*), pignut hickory (*Carya glabra*), cherry laurel (*Prunus caroliniana*), cypress (*Taxodium distichum*), willow (*Salix nigra*), and yew (*Podocarpus macrophylla*).

There were 38 different tree species recorded in Hattiesburg, however, only 2 species had an occurrence greater than 1%. Other trees occurring along Hattiesburg's streets recorded less than 1% of the time during inventory were Japanese maple (*Acer palmatum*), silver maple (*Acer saccharinum*), mimosa (*Albizia julibrissin*), dogwood (*Cornus florida*), persimmon (*Diospyros virginiana*), Japanese Plum (*Eriobotrya japonica*), green ash (*Fraxinus pennsylvanica*), honey locust (*Gleditsia triacanthos*), American holly (*Ilex opaca*), tulip poplar (*Liriodendron tulipfera*), sweetbay magnolia (*Magnolia virginiana*), cherry laurel (*Prunus caroliniana*), wild cherry (*Prunus serotina*), willow (*Salix nigra)*, windmill palm (Trachycarpus H. Wendl), and elm (*Ulmus Americana)*.

Management Costs for Pass Christian and Hattiesburg's Street Trees

Management costs for each city were provided by the city department which was responsible for street tree maintenance. The public works chief operating officer for Pass Christian (City Attorney Malcolm Jones) estimated annual personnel and equipment costs to perform annual maintenance as $50,000. This cost was separated into categories found in i-Tree Streets cost worksheet as $33,600 for tree and debris removal, $2,000 for watering young trees donated and planted by volunteers, and $14,400 for administration expenses. The city attorney agreed with the itemized cost estimates. In fiscal year 2009, the Hattiesburg's UFD budget was $250,440 or less than 1% of the city's overall budget of $115,000,000. The actual breakdown of this total dollar amount which was collected from Hattiesburg's urban forester Andy Parker is shown in APPENDIX E.

Benefit and Cost Dollar Values

Citywide resource values (i.e., annual average energy savings (kBtu/tree); annual average electricity savings (kWh/tree); annual average natural gas savings (kBtu/tree); H_2O interception m^3/tree) were estimated using each species growth category for its specific DBH class or individual DBH measurement to calculate Pass Christian and Hattiesburg's overall dollar value benefit (Appendix G). Individual categories generated by i-Tree Streets for citywide resource values, management costs, and overall BCRs for each city are illustrated in Table 6.

Table 6 Street tree annual benefits and costs categories used to calculate benefit/cost ratios and itemized by total dollars, dollars per tree, and dollars per capita that were saved and spent for each city.

Benefits	**Pass Christian**				**Hattiesburg**		
	Total($)	$/tree	$/capita		Total($)	$/tree	$/capita
Energy	27,540	9.79	4.59		207,770	17.41	3.78
CO2	6,285	2.24	1.05		56,922	4.77	1.03
Air Quality	1,322	0.47	0.22		-162,509	-13.62	-2.95
Stormwater	33,261	11.83	5.54		829,408	69.52	15.08
Aesthetic/Other	93,000	33.07	15.50		798,287	66.91	14.51
Total	161,408	57.40	26.90		1,729,878	144.99	31.45
Costs							
Planting	0	0	0		7,948	0.67	0.14
Contract Pruning	0	0	0		56,123	4.70	1.02
Pest Management	0	0	0		0	0.00	0.00
Irrigation	2,000	0.71	0.33		0	0.00	0.00
Removal	33,600	11.95	5.60		128,870	10.80	2.34
Administration	14,400	5.12	2.40		57,499	4.82	1.05
Inspection/Service	0	0	0		0	0.00	0.00
Infrastructure Repairs	0	0	0		0	0.00	0.00
Litter Clean-up	0	0	0		0	0.00	0.00
Liability/Claims	0	0	0		0	0.00	0.00
Other Costs	0	0	0		0	0.00	0.00
Total Costs	50,000	17.78	8.33		250,440	20.99	4.55
Net Benefits	111,408	39.62	18.57		1,479,438	124.00	26.90

Pass Christian's BCR is for every dollar spent there is a benefit value of $3.23 returned (2010 dollars). Hattiesburg's BCR is for every dollar spent there is a benefit value of $6.91 returned (2010 dollars). This was accomplished for each study area using total street tree species separated by growth rate category and DBH with each city's tree care cost in i-Tree Streets to calculate a BCR.

CHAPTER V

DISCUSSION

All ecosystems provide essential economic, social, and environmental importance needed to sustain humankind thus making them subjects for concentrated monitoring and study. Global land surface consists of 40% forest tree coverage forming one of our most important ecosystems (Westoby 1989). An on the ground inventory of species makeup and physical measurements of trees is still the most reliable method of describing attributes used to explain a forest's economic, social, and environmental importance. Yet, data collection in this way is labor intensive and costly making it a less desirable method of gathering required information needed to describe a forest's benefits. As computer technology advances it is providing a less labor intensive process of reporting tree numbers which are used to describe associated benefits. This is being accomplished through the examination of remotely sensed data (e.g., LiDAR, aerial imagery) which is only limited by the data's resolution. These computerized inventory techniques, when integrated with a GIS, can also provide the potential for developing urban forest management plans for sustaining forests and their benefits. However, high resolution data is still expensive to acquire and requires some on the ground collection to verify computerized inventory results, at least at the start of the process. This is why a methodology as proposed in this research has the potential to provide cities and towns with FEMA quality LiDAR data as a low cost inventory method for reporting on street tree numbers and subsequently the benefits they provide.

A GIS system can provide a unique process for establishing data collection, analysis, planning, and management programs related to a community's urban forest. GIS programs can be compelling through the use of robust tools when considering whether to look at the overall urban forest, or manage individual trees growing along streets or in parks. Whether the intention is to look at the urban forest from a broader scale, or examine individual tree species more closely, GIS can provide a strong backbone for justifying management to any city's UFD. The ability to geo-reference, display, print, and archive map information with attributes tied to a database makes a GIS an invaluable tool for urban forest management.

The creation of a complete or partial street tree inventory using a GIS mapping program with a database of arboreal attributes which can be retrieved and displayed in digital form has the potential to provide a municipality with a much faster capability to map tree locations and related data simultaneously versus the time consuming, labor intensive task of trying to manage street trees with conventional paper maps that use analytical spreadsheets as references. This digital mapping ability is available now and can assist city urban forest management and planning activities; however, managing living resources is in an ever changing dynamic environment requiring frequent updating.

LiDAR analysis is a developing remote sensing technology which can determine the shape of the ground surface (i.e., elevation), its natural features such as trees and shrubs, as well as human features such as buildings when the data has adequate point spacing. The LIDAR airborne instrument is a complex system consisting of an airborne/ground-based GPS, an inertial measurement unit (IMU), and an active laser sensor which is the source that measures light pulse distances (range) and angles that are returned to the system. These returns are measured by their density or point spacing on the ground which can range in density from 1-2 m (fine) to 3-6 m (coarse). Ground surface (i.e., elevation) was calculated by measuring the time required for the laser light pulses to travel to the surface and back to the sensor. This raw data set of light pulses offered an accurate, expedient, and cost-effective way to analyze wide-area elevation information for producing detailed DEMs. However, raw LiDAR data sets which consist of large amounts of elevation information on buildings, trees, power lines, and many other visible features cannot be represented in a GIS format without an extraction method or the use of an add-on tool such as LiDAR Analyst. As previously mentioned, many approaches and methods have been tried and developed with varying degrees of success. The LIDAR Analyst tool developed by Visual Learning Systems (VLS), Inc., P.O. Box 5012, Missoula, Montana 59806, USA shows future promise and an increasing ease of operation for extracting features (e.g., trees, buildings). This tool operates with the Environmental Systems Research Institute (ESRI) computer program ArcGIS 9.0 to generate complex geomorphic-structure mapping products, building renderings, advanced three dimensional modeling, and many more high quality mapping products (VLS 2007).

LIDAR Analyst uses two primary results derived from raw LiDAR data which were a first-return file and/or a last return data file. The combination of all data classes which were considered first-returns [i.e., those containing elevation data from the first surface (i.e., tree, ground, or building) struck by the laser pulse] made up the first-return file. The last return file was made up of a combination of all elevation data classes sensed from the last return of each laser pulse that was the last surface struck. However, in the case of larger surfaces such as buildings and parking lots the laser pulse was reflected only once and resulted in only one single return. Yet in areas where surfaces have holes, such as trees, the pulse was reflected at multiple levels, which resulted in first and last returns and sometimes more intermediate returns. LiDAR Analyst generated data can also be analyzed in a GIS environment with other data sets, such as orthoquads, multispectral, hyperspectral, and panchromatic imagery to show changes in landcover, classifications of tree types (i.e., deciduous, evergreen), and delineation of watersheds (Lillesand and Kiefer 2000).

LA did not perform well in extracting heights, CC, and DBH of corresponding control trees in the field. LATP height measurements varied (i.e., some were very close while many others were 10, 20, and sometimes as much as 30 ft less than actual height) when compared to corresponding control TP. This variation in heights was due to the coarse point spacing of the data which resulted in some tree tops being identified correctly while others were not. Also, since LA uses height to interpolate DBH and CC spread, comparison measurements between control trees in the field and corresponding LATP were also found to be unreliable. Each point tile matched trees were analyzed with a regression model to investigate any correlation between height differences. The relationship was determined to be weak with low R^2 values. However, this did not affect benefits calculated for each city because i-Tree Streets requires only species and DBH measurements for each city's street trees to determine overall resource benefits making height inconsistencies for matched control and LATP a non-factor when calculating benefits.

As LiDAR technology matures, more applications are being explored by USGS scientists and others throughout the U.S., both in collaboration with other federal agencies and alone, in support of USGS natural-hazards research (Crane et al. 2004). As the technology continues to improve and evolve, USGS scientists and others are developing new and unique methods to use and represent high-resolution LiDAR data, and new ways to make these data, and derived information, publicly available (Queija et al. 2005). This type of data will become more readily available as the USGS updates digital elevation models and as the FEMA investigates coastal regions for floodplain reevaluation and map modernization programs designed to update the Flood Insurance Rate Maps (FIRM) (Cunningham 2004).

The LiDAR system used for Mississippi cities to update their elevation maps are accurate to 15-30 cm RMSE, depending upon land cover, and will support contours of 1'-2' vertical map accuracy standards. This level of accuracy meets FEMA standards. As FEMA completes updates for Flood Insurance Rate Maps (FIRM) throughout the U.S. Southern Coastal Plain (SCP) an inventory methodology as proposed in this research could prove to be valuable as a tool for street tree management in any city with LiDAR data desiring to engage in an urban and community forestry program. LiDAR Analyst has the potential to be used as an inventory tool that could perform the task of counting street trees faster and less expensive than a ground survey of street trees.

A BCR of 6.91:1 speaks very well for Hattiesburg's urban forestry program, and also says that city government in Hattiesburg has invested wisely. Pass Christian's BCR of 3.23:1 informs its decision-makers that their street trees are a valuable resource that should be protected and managed. It is the intent that this study's information be used as a guide to demonstrate benefits versus costs of urban forestry initiatives for growth regions in the Coastal Plain and South. This information can then be used to educate decision-makers in other regions of the country to promote the undertaking of urban and community forestry inventory projects. As important, this information can be used to support funding requests to provide money for projects (e.g., citywide, neighborhood, individual street) many communities would otherwise not be able to afford.

Importance Values (IV) are principally applicable to management as they indicate a community's dependence on the useful capacity of a specific tree type. Thus IV refers to the relative contribution of a particular species to the entire community (Barbour et al. 1987). While this holds true in an urban forest setting, as well as in natural communities, it may also be stated that an IV provides a meaningful interpretation with respect to the degree a city might depend on particular street trees, insofar as their environmental benefits are concerned (Maco 2002).

While importance values can be used to indicate trees well-suited to a city's conditions, it is important to remember that some species with low values may have represented species populations with an even-aged species distribution that were senescing (growing old) as a population. As an example, Maco's Davis, California study was compared with the Hattiesburg's study. To compare trees of similar growth and age, Modesto, California ash and Mississippi water oaks were examined. Though most of these trees were functionally deficient, they have served both cities well throughout their longevity. Not replanting these species based on their current senescing condition would be shortsighted. On the other hand, the fact that some tree species currently being heavily planted in Hattiesburg have low IVs suggested that Hattiesburg may be putting faith into species unlikely to provide stability or cost effective functionality. Flowering pear and crape myrtle were exhibiting relatively poor conditions at young ages, suggesting they were not trees that will age problem free without high pruning demands.

In Pass Christian and Hattiesburg, Mississippi and many other cities the urban forest found across the lower U.S. South present constraints and opportunities for tree managers, as well as each city's decision-makers. As development and expansion continue in and around cities, naturally occurring tree numbers will be reduced. This reduction will come primarily from developments; however, many will fall to chainsaw wielding tree services hired by property owners. Many uninformed property owners will remove trees, thinking the public or developers would rather purchase cleared lots. Informing municipalities, the public, and developers as to the worth of trees in dollar values may help impede some of these practices. A truly effective way for cities to protect their clean air and water resources is with their trees, and land use ordinances. With an effective land use ordinance, cities will be able protect and manage environmental capital. Cities without land use ordinances will lose many large trees to hasty development without any replacement plans. Ordinances can be structured to require replacement trees which will provide municipalities the opportunity to reduce hasty tree removal; however, without ordinances effectiveness will be constrained.

Management Implications

Information generated from iTree tools can be used by management to demonstrate the magnitude of benefits versus costs for urban forestry initiatives. This information, when applied using a GIS format to map locations of street trees, can provide a visual aid as to where management could concentrate its efforts (e.g., stocking, pruning, protection). Also, when information is presented visually in a map format it performs as an important aid for educating community leaders on the importance of maintaining street tree stocking to provide valuable benefits.

Methods utilized in this study established a new repeatable street tree inventory technique that uses ArcGIS and the add-on tool LiDAR Analyst with publicly available (free) LiDAR data. A sound inventory number provided the cities under study with the capability to report resource dollar value benefits per capita for street trees. Also, this inventory number provides decision-makers on how dollars spent by a public works department or an UFD returns a BCR on a per capita basis for dollars invested in street tree management.

Future research could further verify results of this research by using LiDAR Analyst in a community that has FEMA quality LiDAR data and a complete inventory of street trees. Also, this research could be advanced with future studies using Feature Analyst (i.e., a GIS extension used to better identify buildings and impervious surfaces than LiDAR Analyst) in conjunction with LiDAR Analyst and an appropriate tree sample to estimate a community's entire tree population. This could give urban foresters and planners the ability to better manage future growth of urban forests.

CHAPTER VI

CONCLUSIONS

This research has indicated the importance of urban forests as a resource benefit and the necessity for understanding its structure. Also, it has shown how GIS can be used as a tool to identify a community's inventory of street trees with LiDAR Analyst, a sample of the street trees under investigation, and a regression model. This inventory once identified can then be used to calculate a community's benefit cost ratio for managing this important resource. The information derived in this research can assist in promoting urban and community forestry projects and/or supporting funding requests to provide money for projects many of these communities could not otherwise afford. Using a GIS to manage street trees is an underutilized concept that is becoming a reality for many municipalities. As many municipalities realize street trees as assets they will also understand that they need to be managed much the same as city streets and water lines. Measured progress towards meeting the goals of an urban forest vision will require states, cities, and communities to devise a new way of thinking about their tree resources. Using dollar values as guidelines, tree resources may be seen less as a limitless, expendable commodity that can be ignored, and more as a renewable resource that must be properly managed to preserve and provide resource benefits.

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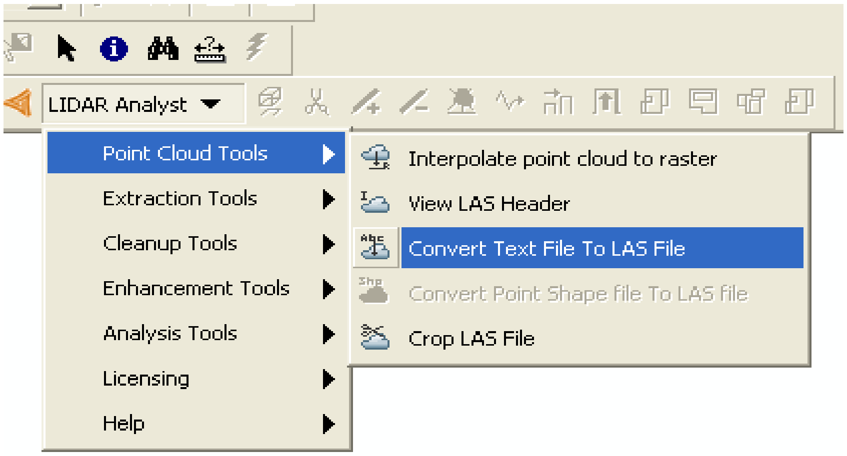
APPENDIX A

LiDAR ANALYST WORKFLOW PROCESS

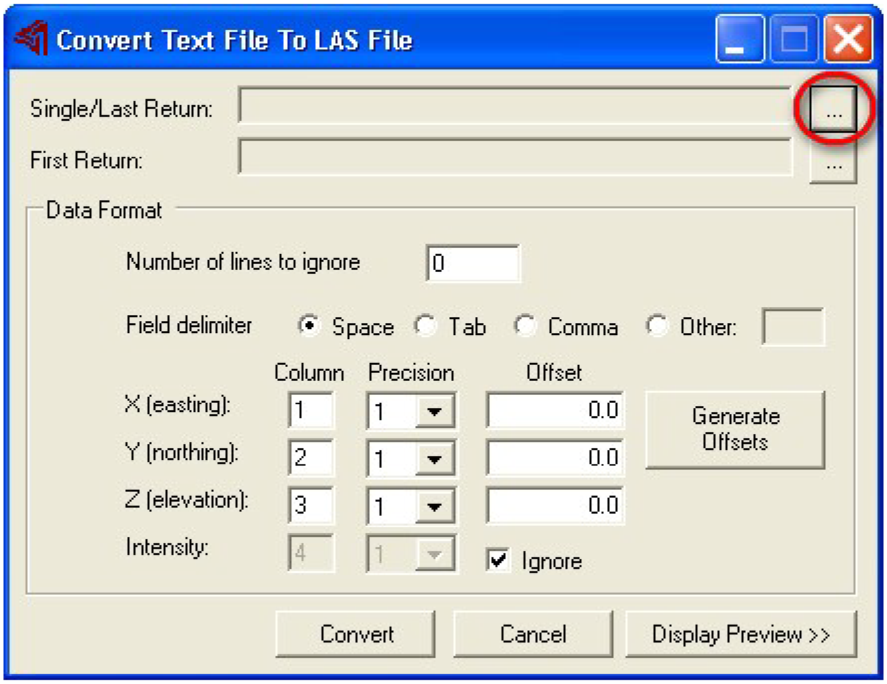
According to Visual Learning Systems (VLS), when it comes to LIDAR data processing, the synergy between the ArcGIS extensions LIDAR Analyst® and Feature Analyst® offers countless advantages (VLS 2007). Using a combination of both software programs can be a most effective method of unearthing information from LIDAR data. Within a matter of hours three-dimensional visualization can be achieved with LIDAR Analyst for a study area's bare earth surface, its buildings, and trees. Then, additional features of interest, such as roads and shorelines, can be classified with Feature Analyst for inclusion in a 3D model which can be visualized in ArcScene.

Below is a combined workflow for using LIDAR Analyst to perform basic extractions from LIDAR data to acquire LiDAR tree points:

1) Convert the LiDAR data text file into a .las file. First go to the LA menu and select "convert text file to LAS file"



Click the ellipses button and navigate to text file:


Convert Text File To LAS File

Single/Last Return:

First Return:

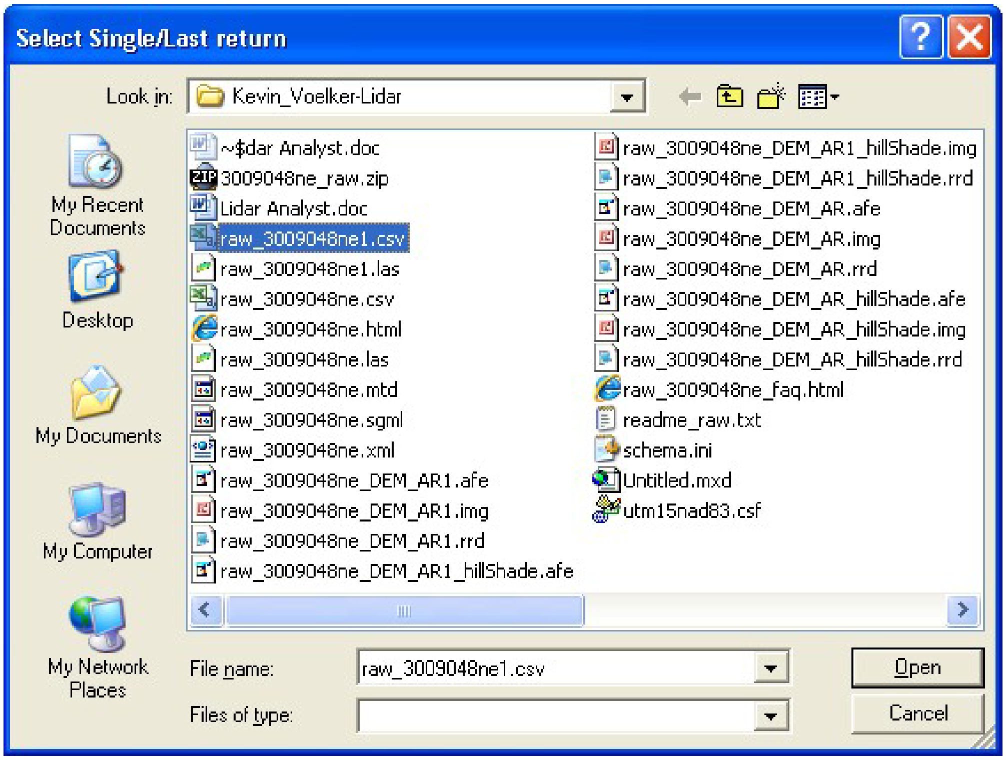
Data Format

Number of lines to ignore: 0

Field delimiter: ● Space ○ Tab ○ Comma ○ Other:

	Column	Precision	Offset
X (easting):	1	1	0.0
Y (northing):	2	1	0.0
Z (elevation):	3	1	0.0
Intensity:	4	1	☑ Ignore

Select the csv file and click “open”:


Select Single/Last return

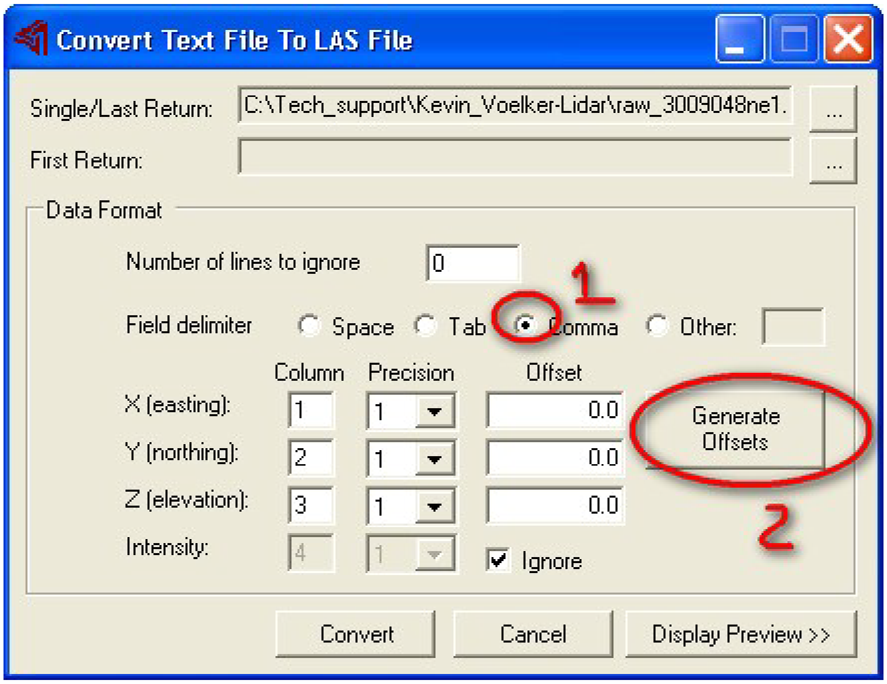
Look in: Kevin_Voelker-Lidar

~$dar Analyst.doc
3009048ne_raw.zip
Lidar Analyst.doc
raw_3009048ne1.csv
raw_3009048ne1.las
raw_3009048ne.csv
raw_3009048ne.html
raw_3009048ne.las
raw_3009048ne.mtd
raw_3009048ne.sgml
raw_3009048ne.xml
raw_3009048ne_DEM_AR1.afe
raw_3009048ne_DEM_AR1.img
raw_3009048ne_DEM_AR1.rrd
raw_3009048ne_DEM_AR1_hillShade.afe
raw_3009048ne_DEM_AR1_hillShade.img
raw_3009048ne_DEM_AR1_hillShade.rrd
raw_3009048ne_DEM_AR.afe
raw_3009048ne_DEM_AR.img
raw_3009048ne_DEM_AR.rrd
raw_3009048ne_DEM_AR_hillShade.afe
raw_3009048ne_DEM_AR_hillShade.img
raw_3009048ne_DEM_AR_hillShade.rrd
raw_3009048ne_faq.html
readme_raw.txt
schema.ini
Untitled.mxd
utm15nad83.csf

File name: raw_3009048ne1.csv

Files of type:

Click “comma” and then click “generate offsets”:



Convert Text File To LAS File

Single/Last Return: C:\Tech_support\Kevin_Voelker-Lidar\raw_3009048ne1.

First Return:

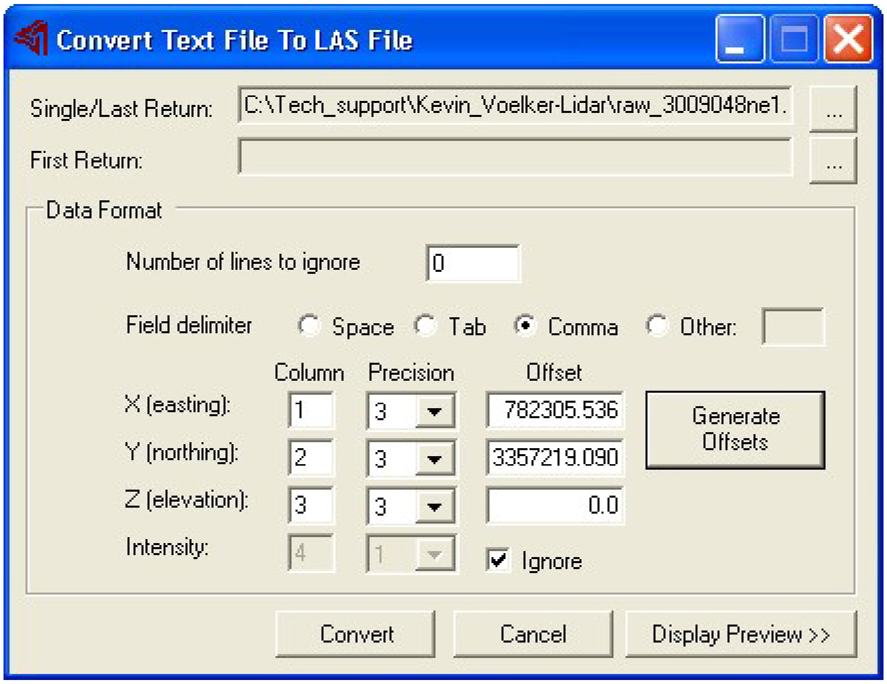
Data Format

Number of lines to ignore: 0

Field delimiter: ○ Space ○ Tab ● Comma ○ Other:

	Column	Precision	Offset
X (easting):	1	1	0.0
Y (northing):	2	1	0.0
Z (elevation):	3	1	0.0
Intensity:	4	1	☑ Ignore

After offsets are generated, the screen below will appear:



Convert Text File To LAS File

Single/Last Return: C:\Tech_support\Kevin_Voelker-Lidar\raw_3009048ne1.

First Return:

Data Format

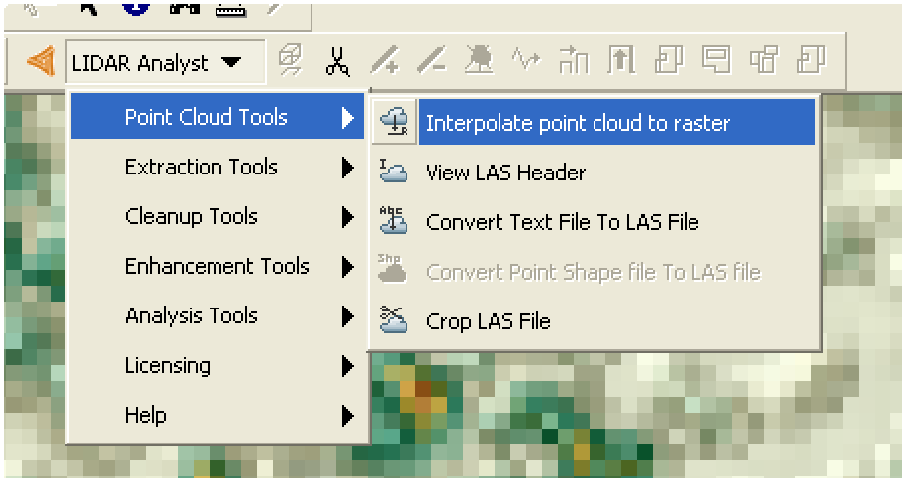
Number of lines to ignore: 0

Field delimiter: ○ Space ○ Tab ● Comma ○ Other:

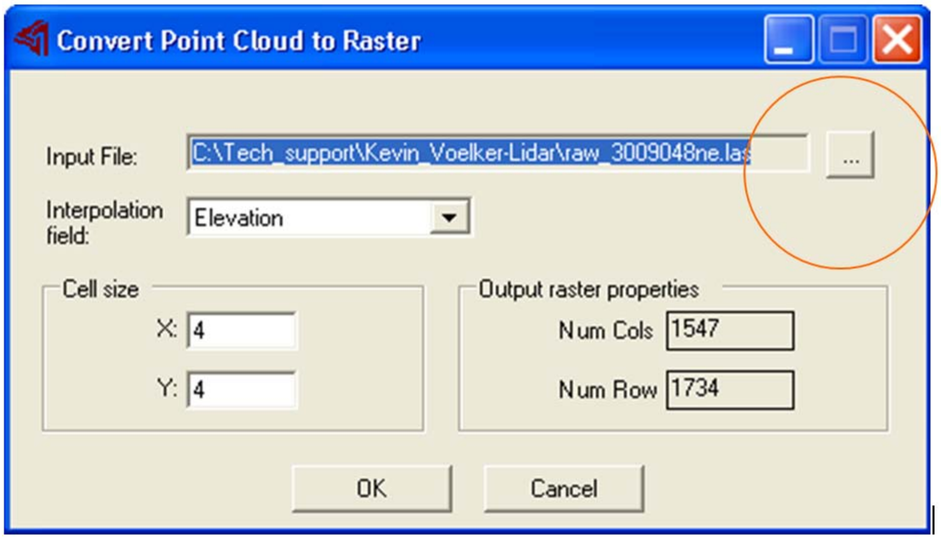
	Column	Precision	Offset
X (easting):	1	3	782305.536
Y (northing):	2	3	3357219.090
Z (elevation):	3	3	0.0
Intensity:	4	1	☑ Ignore

Click “Convert” to create an las file.

2) Next select the “Interpolate point cloud to raster” option on the LA toolbar.



Click on the ellipses button on the “Convert Point Cloud to Raster” window.


Convert Point Cloud to Raster

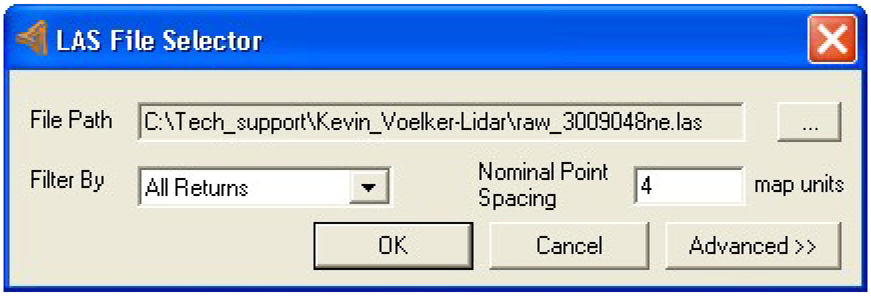
Input File: C:\Tech_support\Kevin_Voelker-Lidar\raw_3009048ne.las

Interpolation field: Elevation

Cell size
X: 4
Y: 4

Output raster properties
Num Cols 1547
Num Row 1734

Set the parameters in the “LAS file selector window to all returns and set the nominal point spacing to whatever is required by the data.



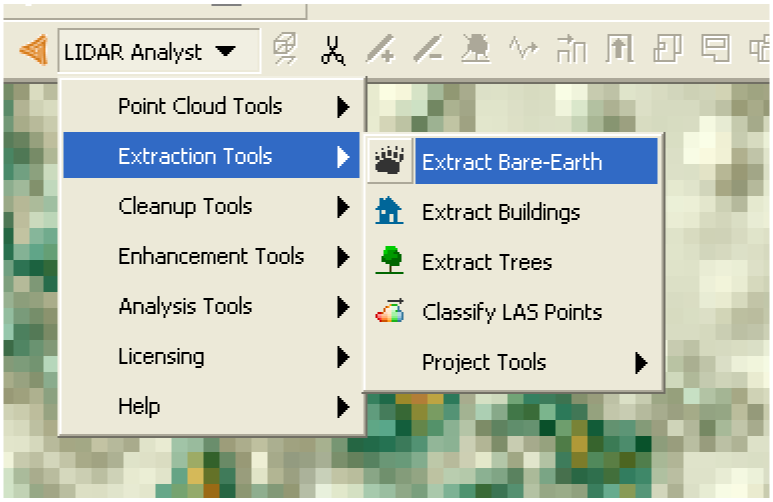
File Path C:\Tech_support\Kevin_Voelker-Lidar\raw_3009048ne.las

Filter By All Returns

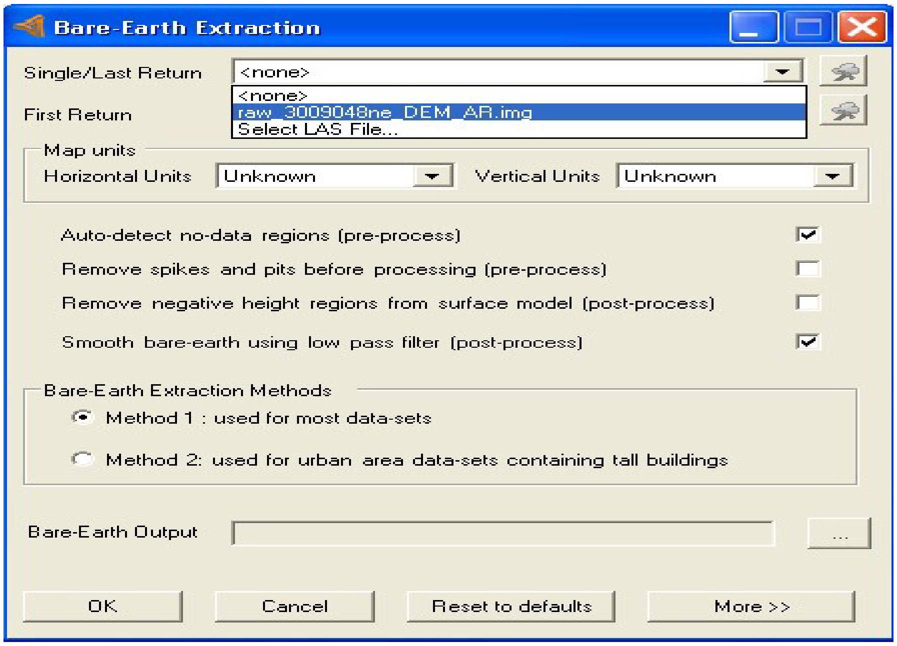
Nominal Point Spacing 4 map units

Click "OK" to create the all returns raster.

3) Create a bare earth using the All Returns layer. First go to the LA pull down menu and select "Extraction Tools>>Extract Bare Earth."



Select your all returns image as the "Single/Last Return."



Bare-Earth Extraction

Single/Last Return: <none>
- <none>
- raw_3009048ne_DEM_AR.img
- Select LAS File...

First Return

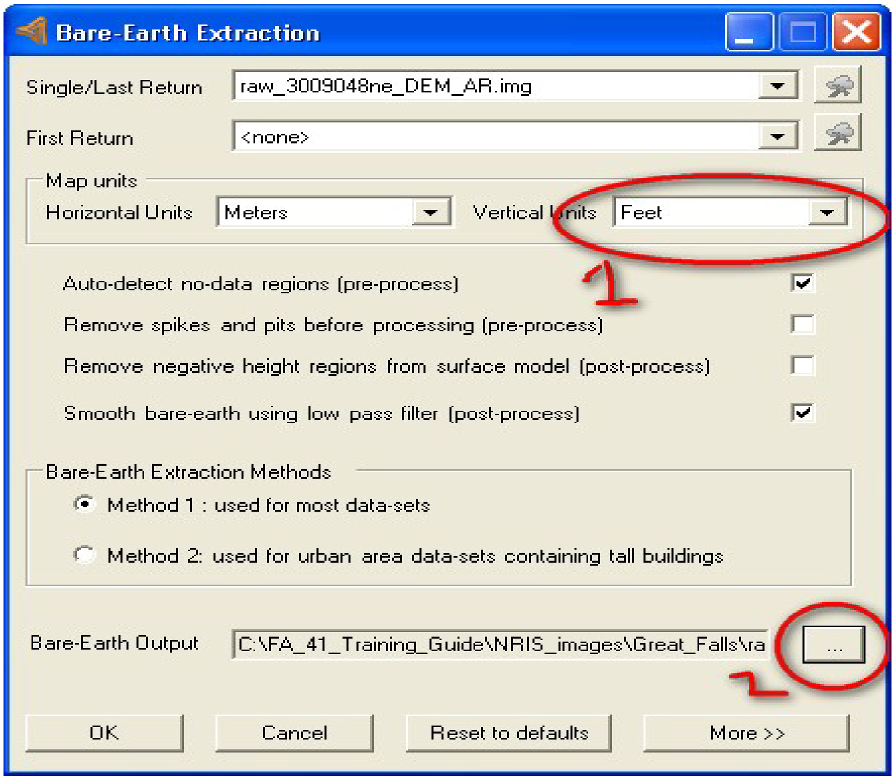
Map units
Horizontal Units: Unknown
Vertical Units: Unknown

Auto-detect no-data regions (pre-process) ☑
Remove spikes and pits before processing (pre-process) ☐
Remove negative height regions from surface model (post-process) ☐
Smooth bare-earth using low pass filter (post-process) ☑

Bare-Earth Extraction Methods
● Method 1 : used for most data-sets
○ Method 2: used for urban area data-sets containing tall buildings

Bare-Earth Output:

Set the vertical units to feet:



Bare-Earth Extraction

Single/Last Return: raw_3009048ne_DEM_AR.img
First Return: <none>

Map units
Horizontal Units: Meters
Vertical Units: Feet

Auto-detect no-data regions (pre-process) ☑
Remove spikes and pits before processing (pre-process) ☐
Remove negative height regions from surface model (post-process) ☐
Smooth bare-earth using low pass filter (post-process) ☑

Bare-Earth Extraction Methods
● Method 1 : used for most data-sets
○ Method 2: used for urban area data-sets containing tall buildings

Bare-Earth Output: C:\FA_41_Training_Guide\NRIS_images\Great_Falls\ra

Then hit OK to create the bare earth layer.

From this point, the bare earth with the all returns layer are used in LiDAR Analyst to extract trees and buildings. However, if the data's point spacing density pattern was spread out coarsely, instead of in a tight fine density, results will reflect this in the extraction process by misclassifying and missing features such as buildings and trees.

APPENDIX B

INVENTORY PROTOCOLS

Inventory Data to be Recorded

PSP Location
Zone #
Date
Beginning Address
Recorder's name
Ending Address

Tree #	Species Code	Year Planted or N/A	Land Use (1-4)	Tree Location (1-5)	Orientation of House or N/A	Setback From Street	DBH (in)	Tree Height (1-6)	Crown Diameter (ft)

Land Use:

1 = Single home residential
2 = Multi-home residential
3 = Commercial/industrial
4 = Other (e.g., vacant, institutional, agricultural, park)

Tree Location:

1 = Front yard
2 = Planting strip
3 = Cutout
4 = Median
5 = Other (e.g., planter, island)

House Orientation:

N = North
NE = Northeast
E = East
SE = Southeast
S = South
SW = Southwest
W = West
NW = Northwest

Inventory Protocols

Condition (1-3)	Pruning needs	Conflicts Present ?: Yes = 1, 0 = No						
		Sidewalk Heave	Hazardous Tree	Intersection	Spacing	Overhead Lines	Car Shaded	Other Requirements

Conditions:

- 1 = Good = Healthy vigorous tree. No signs of insect, disease, or mechanical injury. Little or no corrective work required. Form representative of species.
- 2 = Fair = Average condition and vigor for area. May need corrective pruning or repair. Lacks desirable form characteristic of species. Shows minor insect injury, disease, or physiological problem.
- 3 = Poor = General state of decline when it shows severe mechanical, insect, or disease damage; if death is imminent remove (RMV) will be recorded in pruning needs column.

Pruning Codes: YLL = 1 = Lower limbs need pruning.

YA = 2 = Dead-wood present and needs crown cleaning.

YC = 3 = Large limbs greater than 2 inches needing removal.

YUG = 4 = Needs undergrowth removed.

YT = 5 = Two or more stems or other undesirable tree stems that need thinning.

N = 0 = Entered if the tree does not exhibit or require any of the above conditions

APPENDIX C

CITY TREE CODES

Pass Christian tree codes, common names, Latin names, and growth categories.

Codes	Common Name	Latin name	BDS	BDM	BDL	BES	BEM	BEL	CES	CEM	CEL
ACRU	Red maple	Acer rubra		X							
BAGL	Hedge Bamboo	Bambusa glaucescens				X					
CAGL	Pignut Hickory	Carya glabra			X						
CAIL	Pecan	Carya illinoinensis			X						
CICA	Camphor	Cinnamomum camphora					X				
CELA	Hackberry	Celtis laevigata			X						
DIVI	Native Persimmon	Diospyros virginiana		X							
FRPE	Green Ash	Fraxinus pennsylvanica		X							
JUVI	Eastern Red Cedar	Juniperus virginiana								X	
LAIN	Crepe Myrtle	Lagerstroemia indica	X								
LIST	Sweetgum	Liquidambar styraciflua			X						
DIVI	Common Persimmon	Diospyros virginiana		X							
MAGR	Southern Magnolia	Magnolia grandiflora						X			
MAPO	Osage Orange	Maclura pomifera		X							
MAVI	Sweet Bay Magnolia	Magnolia virginiana					X				
MOAL	Mulberry	Morus alba		X							
NYSY	Tupelo Blackgum	Nyssa sylvatica		X							
PITA	Loblolly Pine	Pinus taeda									X
PLOC	American Sycamore	Plantanus occidentalis			X						
PRCA	Cherry Laurel	Prunus caroliniana				X					
PRSE	Wild Black Cherry	Prunus serotina		X							
POMA	Japanese Yew	Podocarpus macrophylla							X		
PYCO	Common Pear	Pyrus communis		X							
PYCOC	Pyracantha	Pyracantha coccinea				X					
QUFA	Southern Red Oak	Quercus falcata			X						
QULA	Laurel Oak	Quercus laurifolia						X			
QUNI	Water Oak	Quercus nigra			X						
QUVI	Live Oak	Quercus virginiana						X			
SANI	Common Willow	Salix nigra		X							
SAPA	Cabbage Palm	Sabal palmetto					X				
SASE	Chinese Tallow	Sapium sebiferum		X							
TADI	Bald Cypress	Taxodium distichum			X						
ULPA	Lacebark Elm	Ulmus parvifolia		X							

Hattiesburg tree codes, common names, Latin names, and growth categories.

Codes	Common Name	Latin name	BDS	BDM	BDL	BES	BEM	BEL
ALJU	Mimosa	Albizia julibrissin		X				
ACPA	Japanese Maple	Acer palmatum	X					
ACRU	Red maple	Acer rubra		X				
ACSA	Silver Maple	Acer saccharinum		X				
BENI	River Birch	Betula nigra		X				
CABI	Southern Catalpa	Catalpa bignonioides		X				
CAIL	Pecan	Carya illinoinensis			X			
CECA	Eastern Redbud	Cercis candensis	X					
CELA	Hackberry	Celtis laevigata			X			
CICA	Camphor	Cinnamomum camphora		X				
COFL	Flowering Dogwood	Cornus florida	X					
DIVI	Common Persimmon	Diospyros virginiana		X				
FRPE	Green Ash	Fraxinus pennsylvanica		X				
GIBI	Ginkgo	Ginkgo biloba		X				
GLTR	Locust	Gleditsia triancanthos		X				
HAVI	Witch Hazel	Hamamelis virginiana		X				
ILOP	American Holly	Ilex opaca	X					
JUVI	Eastern Red Cedar	Juniperus virginiana		X			X	
LAIN	Crepe Myrtle	Lagerstroemia indica	X					
LIST	Sweetgum	Liquidambar styraciflua			X			
LITU	Tulip Poplar	Liriodendron tulipifera			X			
MAGR	Southern Magnolia	Magnolia grandiflora						X
MASP	Crabapple	Malus spp.	X					
MEAZ	Chinaberry	Melia azedarach		X				
MAVI	Sweet Bay Magnolia	Magnolia virginiana					X	
MYCE	Wax Myrtle	Myrica cerifera				X		
NYSY	Tupelo Blackgum	Nyssa sylvatica		X				
PLOC	American Sycamore	Plantanus occidentalis			X			
PRCE	Purple Leaf Plum	Prunus cerasifera	X					
PRSE	Wild Black Cherry	Prunus serotina		X				
PIPA	Long Leaf Pine	Pinus paulustris						X
PITA	Short Leaf Pine	Pinus taeda						X
PYCA	Bradford Pear	Pyrus calleryana		X				
QUFA	Southern Red Oak	Quercus falcata			X			
QULA	Laurel Oak	Quercus laurifolia			X			
QUMI	Sawtooth Oak	Quercus michauxii			X			
QUNI	Water Oak	Quercus nigra						
QUPH	Willow Oak	Quercus phellos			X			
QUST	Post Oak	Quercus stellata						
QUVI	Live Oak	Quercus virgininana						X
SAAL	Sassafras	Sassafras albidium				X		
SASE	Chinese Tallow	Sapium sebiferum		X				
TRWE	Windmill Palm	Trachycarpus H. Wendl.	X					
ULAM	American Elm	Ulmus americana			X			

APPENDIX D

SAMPLE MUNICIPAL STREET TREE COST

Estimated or Actual Municipal Street Tree Costs

ANNUAL COSTS PER YEAR	Year 1	Year 2	Year 3
Tree Removal	___________	___________	___________
Tree Pruning			
Newly Planted	___________	___________	___________
Existing	___________	___________	___________
Irrigation			
Newly Planted	___________	___________	___________
Existing	___________	___________	___________
Pest and Disease Control			
Newly Planted	___________	___________	___________
Existing	___________	___________	___________
Tree Planting			
Purchase Price	___________	___________	___________
Planting (e.g., stakes, wrap, mulch)	___________	___________	___________
City Funded	___________	___________	___________
Grant Funded	___________	___________	___________
Infrastructure Repair			
Sidewalks	___________	___________	___________
Curbs	___________	___________	___________
Paving	___________	___________	___________
Sewer Lines	___________	___________	___________
Other-Specify (e.g., storms, vehicular, roots):			
________________	___________	___________	___________
________________	___________	___________	___________
________________	___________	___________	___________
________________	___________	___________	___________
Root Pruning	___________	___________	___________
Leaf Litter Clean-up	___________	___________	___________
Urban Forester/Urban Landscaper Compensation			
Supervisor	___________	___________	___________
Foreman	___________	___________	___________
Technicians or laborers	___________	___________	___________
Clerical	___________	___________	___________
Other-Specify (e.g., specialist, consultant, director):			
________________	___________	___________	___________
________________	___________	___________	___________
________________	___________	___________	___________
________________	___________	___________	___________
Social Security (match)	___________	___________	___________
Insurance (health)	___________	___________	___________
Workers compensation	___________	___________	___________
Retirement	___________	___________	___________
Equipment			
Vehicles (Annual costs should be based on rental, lease, purchase, mileage as replacement or mileage non-replacement)			
Cars	___________	___________	___________
Trucks	___________	___________	___________
Bucket Truck	___________	___________	___________
Dump Truck	___________	___________	___________

Estimated or Actual Municipal Street Tree Costs

Other-Specify:

________________ ___________ ___________ ___________
________________ ___________ ___________ ___________

Related Tools
Specify (e.g., power, hand, hoses, phones, safety markers):

________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________

Uniforms ___________ ___________ ___________
Repairs and Maintenance
Specify:

________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________

Litigation/Liability (e.g., trip and fall):
Specify:

________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________
________________ ___________ ___________ ___________

Administration ___________ ___________ ___________

For additional comments or other costs, please use space below or back of questionnaire.

APPENDIX E

MUNICIPAL URBAN FORESTRY COSTS FOR HATTIESBURG

Community: ___Hattiesburg, Mississippi____ Year: 2009

Number of trees planted __160_

Number of trees pruned _3,677_

Number of trees removed __104_

MUNICIPAL COMMUNITY FORESTRY EXPENDITURES

Tree Planting and Initial Care

Include cost of tree purchases, labor and equipment for planting, planting materials, stakes, wrapping, watering, mulching, competition control, etc. $ ___7,948___

Tree Maintenance

Include pruning, insect and disease management, fertilization, watering, etc. $ ___56,123___

Tree Removals

Include cost of equipment, supplies, labor, etc. $ __128,870___

Management

Include public education, professional training, memberships, salaries, street and park tree inventory. $ ___57,499___

Other

Include any other expenses not already mentioned.

Briefly describe.____ $ ____0_______

TOTAL MUNICIPAL EXPENDITURES $ __250,440___

COMMUNITY POPULATION ___50,000___

To qualify for Tree City USA total expenditures must be at least twice population. Transfer these two numbers to Standard 3 on application and attach this sheet to application.

OTHER COMMUNITY FORESTRY EXPENDITURES

Utility Line Clearance

Utility trimming expenses are allowed only if the city's tree program and has implemented a tree planting program and proper pruning methods as recommended in the Tree Line USA program. $ _____0___

Volunteer Time

Value of volunteer labor and other contributions from civic organizations. $ _____0___

APPENDIX F

POPULATION SUMMARY OF ALL TREES FOR BOTH CITIES

Population Summary of All Trees in Pass Christian

	DBH Class (in)								
Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Broadleaf Deciduous Large (BDL)										
Water Oak	23	290	450	209	79	7	0	0	0	1,058
Pecan	6	78	35	2	0	0	0	0	0	121
Laurel Oak	8	45	28	0	0	0	0	0	0	81
Tupelo Gum	5	15	14	0	0	0	0	0	0	34
Sweetgum	2	12	16	0	0	0	0	0	0	30
Others	0	26	21	0	0	0	0	0	0	47
Total	**44**	**466**	**564**	**211**	**79**	**7**	**0**	**0**	**0**	**1,371**
Broadleaf Deciduous Medium (BDM)										
BDM Other	26	19	15	0	0	0	0	0	0	60
Total	**26**	**19**	**15**	**0**	**0**	**0**	**0**	**0**	**0**	**60**
Broadleaf Deciduous Small (BDS)										
Crapemyrtle	29	0	0	0	0	0	0	0	0	29
BDS Other	0	0	0	0	0	0	0	0	0	0
Total	**29**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**29**
Broadleaf Evergreen Large (BDE)										
Live Oak	32	189	457	286	85	13	5	0	0	1,067
BDE Other	0	0	0	0	0	0	0	0	0	0
Total	**32**	**189**	**457**	**286**	**85**	**13**	**5**	**0**	**0**	**1,067**
Broadleaf Evergreen Medium (BDM)										
Magnolia	6	37	38	4	0	0	0	0	0	85
BEM Others	12	20	0	0	0	0	0	0	0	32
Total	**18**	**57**	**38**	**0**	**0**	**0**	**0**	**0**	**0**	**117**
Broadleaf Evergreen Small (BES)										
BES Other	2	0	0	0	0	0	0	0	0	2
Total	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**
Conifer Evergreen Large (CEL)										
Loblolly Pine	0	91	28	0	0	0	0	0	0	119
CEL Other	1	10	0	0	0	0	0	0	0	11
Total	**1**	**101**	**28**	**0**	**0**	**0**	**0**	**0**	**0**	**130**
Conifer Evergreen Medium (CEM)										
CEM Other	0	15	9	0	0	0	0	0	0	24
Total	**0**	**15**	**9**	**0**	**0**	**0**	**0**	**0**	**0**	**24**
Conifer Evergreen Small (CES)										
CES Other	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Palm Evergreen Medium (PEM)										
PEM Other	0	7	4	0	1	0	0	0	0	12
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**12**
Grand Total	**152**	**854**	**1,115**	**501**	**165**	**20**	**5**	**0**	**0**	**2,812**

Population Summary of All Trees in Hattiesburg

	DBH Class (in)									
Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Broadleaf Deciduous Large (BDL)										
Water Oak	91	242	291	234	302	292	217	315	223	2,207
Sweetgum	0	100	64	98	76	67	50	50	0	505
Pecan	0	42	120	59	61	84	54	42	9	471
BDL Others	9	100	105	93	104	107	40	60	48	666
Total	**100**	**484**	**580**	**484**	**543**	**550**	**361**	**467**	**280**	**3,849**
Broadleaf Deciduous Medium (BDM)										
Tallow	33	108	161	129	62	109	56	27	0	685
Red Maple	62	93	56	35	26	50	8	0	0	330
BDM Others	11	81	155	89	52	17	9	10	0	424
Total	**106**	**282**	**372**	**253**	**140**	**176**	**73**	**37**	**0**	**1,439**
Broadleaf Deciduous Small (BDS)										
Crapemyrtle	173	34	16	0	10	0	0	0	0	233
Flw. Pear	9	61	81	19	16	28	0	0	0	214
BDS Other	0	7	46	7	1	0	1	1	1	64
Total	**182**	**102**	**143**	**26**	**27**	**28**	**1**	**1**	**1**	**511**
Broadleaf Evergreen Large (BDE)										
Live Oak	0	23	77	106	206	220	116	123	48	919
BDE Other	0	0	0	0	0	0	0	0	0	0
Total	**0**	**23**	**77**	**106**	**206**	**220**	**116**	**123**	**48**	**919**
Broadleaf Evergreen Medium (BDM)										
Magnolia	0	36	85	66	49	106	94	46	43	525
BEM Others	0	27	29	15	21	23	0	14	0	129
Total	**0**	**63**	**114**	**81**	**70**	**129**	**94**	**60**	**43**	**654**
Broadleaf Evergreen Small (BES)										
BES Other	0	17	79	17	0	15	38	0	0	166
Total	**0**	**17**	**79**	**17**	**0**	**15**	**38**	**0**	**0**	**166**
Conifer Evergreen Large (CEL)										
Loblolly Pine	7	45	234	424	835	1,086	794	361	231	4,017
CEL Other	0	35	40	13	24	12	35	18	16	193
Total	**7**	**80**	**274**	**437**	**859**	**1,098**	**829**	**379**	**247**	**4,210**
Conifer Evergreen Medium (CEM)										
Red Cedar	0	0	66	40	25	14	11	13	14	183
CEM Other	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**66**	**40**	**25**	**14**	**11**	**13**	**14**	**183**
Conifer Evergreen Small (CES)										
CES Other	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Grand Total	**395**	**1,051**	**1,705**	**1,444**	**1,870**	**2,230**	**1,523**	**1,080**	**633**	**11,931**

APPENDIX G

TOTAL ANNUAL BENEFITS, NET BENEFITS, AND COSTS FOR ALL TREES IN BOTH STUDY AREAS

Pass Christian

Benefits	**Total ($)**	**$/tree**	**$/capita**
Energy	27,540	9.79	4.59
CO2	6,285	2.24	1.05
Air Quality	1,322	0.47	0.22
Stormwater	33,261	11.83	5.54
Aesthetic/Other	93,000	33.07	15.50
Total Benefits	161,408	57.40	26.90

Costs			
Planting	0	0.00	0.00
Contract Planting	0	0.00	0.00
Pest Management	0	0.00	0.00
Irrigation	2,000	0.71	0.33
Removal	33,600	11.95	5.60
Administration	14,400	5.12	2.40
Inspection/Service	0	0.00	0.00
Infrastructure Repairs	0	0.00	0.00
Litter Clean-up	0	0.00	0.00
Liability/Claims	0	0.00	0.00
Other Costs	0	0.00	0.00
Total Costs	50,000	17.78	8.33
Net Benefits	111,408	39.62	18.57
Benefit/Cost Ratio	3.23		

Annual Benefits of All Trees by Species ($/tree)						
Species	**Energy**	**C0$_2$**	**Air Quality**	**Stormwater**	**Aesthetic**	**Total ($)**
Live Oak	11.84	3.07	15.69	15.69	41.35	72.23
Water Oak	11.83	2.39	13.40	13.40	35.15	63.45
Pecan	4.25	0.87	3.94	3.94	23.76	33.46
Loblolly Pine	2.96	0.59	2.20	2.20	10.24	16.38
Magnolia	3.51	0.63	5.43	5.43	14.24	23.96
Laurel Oak	4.19	0.86	3.88	3.88	23.61	33.17
Tupelo Gum	4.49	0.92	4.21	4.21	24.31	34.61
Sweetgum	4.29	0.82	3.34	3.34	21.01	29.75
Crapemyrtle	0.47	0.05	0.38	0.38	2.87	3.83
Other Trees	3.16	0.63	3.09	3.09	15.61	22.90

Hattiesburg

Benefits	Total ($)	$/tree	$/capita
Energy	207,770	17.41	3.78
CO2	56,922	4.77	1.03
Air Quality	-162,509	-13.62	-2.95
Stormwater	829,408	69.52	15.08
Aesthetic/Other	798,287	66.91	14.51
Total Benefits	1,729,878	144.99	31.45

Costs			
Planting	7,948	0.67	0.14
Contract Planting	56,123	4.70	1.02
Pest Management	0	0.00	0.00
Irrigation	0	0.00	0.00
Removal	128,870	10.80	2.34
Administration	57,499	4.82	1.05
Inspection/Service	0	0.00	0.00
Infrastructure Repairs	0	0.00	0.00
Litter Clean-up	0	0.00	0.00
Liability/Claims	0	0.00	0.00
Other Costs	0	0.00	0.00
Total Costs	250,440	20.99	4.55
Net Benefits	1,479,438	124.00	26.90
Benefit/Cost Ratio	6.91		

Annual Benefits of All Trees by Species ($/tree)

Species	Energy	C0$_2$	Air Quality	Stormwater	Aesthetic	Total ($)
Loblolly Pine	19.16	4.63	-27.79	87.60	167.16	83.56
Water Oak	21.25	6.48	-12.56	85.74	176.33	75.42
Live Oak	23.56	7.27	-13.68	93.66	90.13	200.94
Chinese Tallow	12.06	5.11	4.76	33.74	51.25	106.91
Magnolia	19.59	3.67	6.60	61.69	19.87	111.41
Sweetgum	14.55	3.55	-15.97	51.23	72.85	126.21
Pecan	16.70	4.88	-13.78	64.97	71.59	144.35
Red Maple	8.91	2.97	2.30	28.81	48.73	91.71
Crape myrtle	1.89	0.38	0.75	2.52	3.87	9.42
Flowering Pear	6.52	1.34	2.94	12.80	19.49	43.08
Red Cedar	10.30	1.91	6.82	21.29	6.72	47.04
Other Trees	13.29	3.73	-3.38	44.78	45.63	104.05