Tree Inventories and GIS in Urban Forestry

by

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(ABSTRACT)

Planning and managing vegetation in urban areas is complex and can benefit from using computerized tree inventories and Geographic Information Systems. This paper outlines how tree inventories can be use to effectively manage trees in urban areas, to avoid project budget cutbacks, improve the efficiency of an existing program, and to educate and provide information to the public.

Urban foresters need to work with other disciplines within a municipality to effectively manage our urban resource. Urban planners, engineers, landscape architects and urban foresters should combine their efforts to maintain, protect, and regenerate the urban forests.

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I. STUDY OBJECTIVES

The specific objectives of this study are the following:

1. To review current literature on tree inventories and Geographic Information System (GIS) applications in urban forestry.

2. To explain the importance and values of tree inventories and the use of GIS applications in urban forestry.

3. To develop a rationale for implementing GIS to better manage urban forests.

II. INTRODUCTION

The forests in the United States have been changing and becoming more and more fragmented as society constantly grows. The need to manage trees in the urban setting has become an essential part of forestry. Computer tree inventories and geographic information systems (GIS) are presently being used to help urban foresters better manage this valuable resource. This paper explains the different types of tree inventories that are currently being employed in urban forestry as well as the type of information that can be collected to ensure practical management and benefits of this vital resource. Tree inventories can also be easily incorporated into a GIS to achieve a more thorough analysis. Methods of entering trees into a GIS with their associated attributes are also discussed. Finally, the importance of using GIS technology in municipalities to manage urban forests will be developed is discussed.

A. Forestry in an Urbanizing Society

The Census Bureau currently identifies 319 metropolitan areas in the United States, cities or urbanized areas of greater than 50,000 inhabitants (Schoeneman and Ries 1997). The total US population is at 248,710,000 and is expected to reach 267,462,000 by the year 2000.(Census Bureau 1992) The management of urban forests is becoming more essential and politically accepted with the increasing growth of urban and suburban population. Trees along with other plants can make living in our cities much more enjoyable. Trees help in absorbing noise, reduce air pollution and help reduce human stress. Urban trees also help in conserving household energy, aid in stormwater management, and affect carbon storage and sequestration.

The use of computers in urban forestry has only become common in the last decade. A 1973 survey of 172 U.S. cities found only 30 % conducted tree inventories and less than 3% handled these data by computer (Gerhold et al. 1987). Fourteen cities were known to be using computers for processing tree data by 1979, and six computerized inventory systems were available for general usage. In a 1980 survey of 2,861 U.S. cities with 1,534 respondents, 767 (50%) had systematic tree care programs: and 511 cities provided further information, indicating that 43% kept records on trees and 10 % had computerized records stored (Gerhold et al. 1987).

Trees growing in urban and surrounding areas are subject to considerable environmental stress. Soil profiles have often been drastically altered or disturbed, and often there is an increase in air pollution. Soil is a critical factor in an urban forest. Topsoil is often removed or replaced with subsoil during construction. Compaction occurs on building sites due to the heavy weight of the construction machinery. Soils that are compacted have poor aeration, and gaseous exchange between soil air and the atmosphere is restricted which results in poor tree root growth (Grey and Deneke 1978). Also, trees are often planted in cities where there was once a gravel road or some other impervious surface which prevents water from penetrating down through the rest of the soil layers and to tree roots. These factors result in trees becoming weakened making them more susceptible to secondary pests such as diseases and insects. Managing urban forests requires a great deal of planning, maintenance, and replacement of the trees. Management goals need to be set for both long and short term management strategies. Planning ordinances and annual budgets have to be set for implementation (Schoeneman and Ries 1997). In the 1970s street tree inventories became more common primarily due to the availability of federal urban forestry funds. Some of these inventories are still in use but most of them are not due to the lack of understanding, accessing, and updating the data (Smiley and Baker 1988). In the mid-1980s the use of tree inventories had increased again. Most of these inventories were funded by the cities from their general revenue funds. Also, improved technology and lower cost of microcomputers have made tree inventories more economically feasible.

B. Benefits of the Urban Forest

Trees in the urban setting are often taken for granted. Most people are not aware of the many benefits that urban trees provide. Urban forests are an essential element in the physical, economic, visual, and the psychological well-being of our communities.

The physical benefits of the urban forest are tempering climate, purify air, reduced noise levels, and providing windbreaks. Trees also affect the hydrologic cycle by reducing erosion and protecting watersheds. Bare soil directly exposed to rain has the potential for serious erosion. Rainfall is a primary contributor to soil erosion. Leaves help prevent erosion by intercepting and softening the impact of the rain droplets. Leaf litter or organic mulches further reduce the potential for erosion. Trees and plants control solar radiation. Leaves are responsible for intercepting, reflecting, absorbing and transmitting solar radiation (Grey and Deneke 1978). The density of the specie, shape and size of the leaf, and branching patterns all determine how effective trees are in intercepting solar radiation. Trees also provide wind protection. Wind velocity is reduced on both the leeward and windward sides of trees (Grey and Deneke 1978). Conifers planted on a slope can slow down the movement of cold air that normally moves to low points, which prevents frost pockets .

Urban forests are typically not considered as an economic resource. However, urban trees are economically viable if they are strategically planted, reducing heating and cooling costs considerably. Trees and shrubs that are planted in a landscape can increase the market value of homes from 7 to 20 percent (Harris 1992). These plants also serve as food and habitat for our urban wildlife.

Aesthetically trees are very pleasing to the eye. The actual visual benefits are harder to describe than the other benefits but are still extremely important. Trees and shrubs provide beauty in all settings by adding diversity and a variety of color, form and texture in the landscape. Trees serve an architectural function by accenting and framing houses as well as other structures. The proper placement of trees can be used to provide focal points and form vistas. Trees offer a change from pavement and masonry (Miller

1992). Trees can be planted in rows or groups to provide a screen or to block unsightly objects.

Some studies indicate that trees and shrubs benefit the health and attitudes of people. Work productivity is much higher for individuals that can see trees and plants from their workplace (Miller 1992). The benefits of visual encounters of trees increase the overall health and help to maintain a strong positive influence on human behavior (Miller 1992). Urban forests are excellent places to educate the public, especially children, about the functions and benefits the forests provide.

III. TREE INVENTORIES

The management of any resource needs to begin with an inventory of that resource (Miller 1997). Traditional forestry textbooks provide extensive directions on how to obtain and calculate current and anticipated timber volumes, basing their methods on an inventory. Urban foresters must inventory their resources too. The principles of obtaining the information are very similar. However, the process is much more labor intensive in the urban setting than for traditional forest inventories where wood and fiber are the primary objectives (Bickmore and Hall 1983). This is due to the emphasis on the individual trees and the wide array of values and uses that need to be considered.

There are several reasons why a tree inventory should be conducted. The primary reason is to determine if there is a need for a tree management program. In other words, is there a need for tree pruning, planting, or removal, or are the trees growing well without any structural problems? Another reason is to determine the total value of the tree resource and benefits they provide. This information can be used to justify the need for, or the existence of, a tree management program (Smiley and Baker 1988). The objectives of the inventory should determine the information that should be obtained and the amount of detail to be included. It is important when collecting data for an inventory that enough data is collected for the job desired but no more than what is needed. Collecting too much or too little data can be very costly. It is very important to determine what your objectives are early in the planning process before the data collecting process begins. Tree inventories can be quite simple or complex depending on ones needs and objectives. These inventories can be used to manage the resource, predict species diversity and age classes in a urban setting. There are several different types of inventories that are used, including street tree surveys, sample surveys and computerized systems. The costs of tree inventories vary depending on the amount of data collected and the number of trees inventoried.

A. Tree Inventory Uses

a. Management Programs

There are several different uses that a tree inventory can serve. Tree inventories can be used to determine the need for a tree management program. Trees that are publicly owned must be properly maintained to avoid hazardous conditions. Negligence regarding tree maintenance may result in a lawsuit. The defense costs of a judgment against a community or municipality, or the defense costs in a lawsuit could easily pay for a tree care program for many years (Tate 1985). Data can be organized and presented in a neat and concise manner illustrated with graphics, to indicate the importance of a well maintained urban tree population. There are three items that should be included: planting needs, maintenance requirements, and potential hazard to life and property (Tate 1985). Collecting these data can help achieve a long term management plan.

b. Budgets

Funding has always been a problem for urban forestry. Little recognition was given to urban forests until Dutch elm disease *(Ophiostoma ulmi),* introduced from Europe in the 1930s killed so many urban trees, costing local governments millions of dollars for removal and replantings. Quantitative information is essential to have when proposing a budget. It is very difficult to compete for funding with other departments in a municipality when they have concrete data to support their funding needs and you do not. Knowing tree values or the total value of the forest resource can be used to justify the need for, or the existence of, a tree management program (Smiley and Baker 1988). The use of inventory data can show the need and importance of the amount of routine maintenance that is required of urban trees. The lack of funding for urban tree programs is not usually seen by the residents over the short run, but has a tremendous effect over the long term (Tate 1985). Tree inventories can provide information on how the current budget was spent and help predict how much money will be needed in the future to sustain a healthy tree population. Information pertaining to the number of trees that were planted and need to be planted in the future, trees that require maintenance, and dead and dying trees that should be removed can be used to demonstrate accomplishments with the current budget. Also, data describing the conditions of the trees vigor, for example age classes, the ratio of newly planted trees compared to trees that are removed or the established tree population, insect and disease severity and extent, can be used to justify the future need of funding and the detrimental effects that would occur should the required plantings, maintenance and removals not be accomplished.

c. Work Efficiency

The ability to efficiently dispatch work crews minimizes travel time by knowing which trees in a particular area need work. Also, one can reroute crews to other types of work if weather becomes a factor. For example, if tree climbers are unable to climb trees due to inclement weather the crew can spend their efforts pruning or shaping small trees from the ground or any other tasks that will not put the crew in danger. Inventory data can be used to determine the number and size of a crew that will be needed to perform certain tasks. Existing and future work can also be determined with the use of an accurate inventory system. The ability to update the inventory system after the completion of a task is essential. The tree inventory will only be effective if it is updated on a regular basis.

d. Education and Public Information

Residents are often interested in trees but generally know very little about them as a resource (Tate 1985). Certain tree inventory information when presented graphically provide information to citizens and the news media about the trees in their community. The data can show residents about the benefits, tree conditions, costs of urban trees, and the entire urban forest system. Information on tree species, tree value, hazard potential, planting priority, canopy cover, and tree density may all be extracted from an inventory (Smiley and Baker 1988). Providing this type of information to the citizens allows the community to gain interest and hopefully become actively involved in the preservation and management of the urban forest resource. Community involvement is essential for the preservation of the urban forests. Programs such as Arbor Day have been an excellent method of involving and educating the community regarding their trees. Local trees can be monitored for hardiness and disease and pest resistance. Tree hardiness is how a particular species endures climatic changes. A list of disease and insect resistant and hardy tree species can be provided to local nurseries and interested citizens. Providing this information to the public can help prevent planting trees that are not suitable for a particular site or do not meet the specified objectives of the tree planting project.

B. Inventory Objectives

a. The Need for Tree Inventories

The selection or designing of an inventory system should be developed with the overall objective to provide essential information to help managers in the decision making process. Both time and costs need to be considered when designing the inventory system. In considering a tree inventory system one should continually remind oneself of the primary objective of an inventory, which is to provide decision making information that cannot otherwise be made available.

There are two different types of information that can be collected, transitory information and permanent information (Miller 1997). Transitory information describes information that can change; for example, pruning needs of a tree or a specific trees condition. Permanent information includes items such as the species and location. The species will remain the same as long as that tree is there. The objectives of tree inventory again determine the type of information that will be collected, whether it be transitory, permanent, or a combination of both types of information. If the primary objective of the inventory is to schedule maintenance activities, transient information such as where maintenance needs are greatest may be the most important to collect. Knowing which information is going to be collected will determine whether transient or permanent information is needed. Again, depending on the objectives, decisions have to be made on which data will be collected and most relevant, remembering that the data to be collected must relate to overall goals of the inventory.

Tree inventories are used to review the current state of your urban forest. The information that can be acquired from an inventory is invaluable in program planning and subsequent management. Tree inventories help the user realize and accomplish a number of goals. The inventory can be used to improve the response to public inquiry regarding specific trees. When a citizen calls regarding a tree related question or request, you can look up the tree in the tree inventory, while the citizen or client is on the phone. Tree inventory can enhance relations among other city and private services. Accurate knowledge of the urban forest provides an effective tool for coordinating the activities of the public service departments such as engineering, transportation, utilities, and parks and recreation.

b. Data Collection

There are many tree attributes that are identified and measured in a tree inventory that will be helpful in managing specific urban forest trees and the urban forest in general. The following paragraphs will identify and describe important tree attributes that have shown to be important in urban tree inventories and should be considered when formulating an urban forest tree inventory.

Species. There are several different ways of naming tree species. Using the scientific name both genus and species as well as the variety or cultivar is essential because it will eliminate any confusion that common names may have because of regional variations. However, it is also important to include a listing of often used common names. These common names will assist in communicating with local residents and in various educational endeavors. The ability to accurately identify cultivars is very difficult even with experienced crews (Smiley and Baker 1988). Numeric codes can be used but this method can also lead to confusion. Abbreviations can be based on the first two letters of both the genus and species. The most important things to remember are to be consistent and to provide a complete list of names and/or codes to those collecting data to ensure uniformity.

Size. There are several measures of tree size that are often used, including diameter at breast height (dbh) or tree caliper, height, crown spread, and biomass. Diameter, either dbh or caliper is used most frequently. Diameter at breast height (dbh) is usually measured in inches or centimeters around the tree at 4.5 feet from the ground. The Council of Tree and Landscape Appraisers (CTLA) recommends that trees caliper under 12 inches in diameter be measured at 12 inches above the ground and trees caliper less than 4 inches in diameter be measured at 6 inches above the ground when making tree appraisals (Miller 1997). Diameter classes are often measured in one or two inch classes up to six inch classes. Regression equations can be utilized to make species specific predictions on tree height and crown spread, which eliminates the need for collecting this information in the field and storing it in a data base.

Tree height is sometimes measured when there are utility wires overhead, and used for scheduling future pruning needs. Tree heights can be obtained by using a clinometer, Abney level, hypsometer, or an altimeter.

Crown spread may be one of the most important inventory variables. Natural crown spread or the spread of an unobstructed grown tree determines how valuable the tree is in providing shade, visual affects, wind protection, and water uptake. Crown spread can be measured using aerial photographs.

Biomass is important information to collect because it allows the urban forester to determine the volume of waste wood that will need to be disposed of, or when there is a market for wood products (Miller 1997). Wood chips used for either energy or mulch and quality veneer logs are common wood products in the urban forests.

Tree Location. The ability for crews to be able to accurately locate a tree that needs work is essential. There are several methods that can be used to perform this task and the method used does not matter as long as it is effective and efficient. Sackteder and Gerhold (1979) provide the following list that can be used independently or in combination to describe tree location:

Area division, or section number
Street name
Address, house number, or lot number
Block number
Distance from an intersection

Number of nearest utility pole
Sequence number, within addresses or within blocks
Coordinates of various kinds
Grid system for the entire city
Distances from the street or curb
Tag number
Map number
Aerial photography
Geographic information systems

The most common method of tree location are based on block and sequential number, or address and sequential number (Miller 1997). One problem with this method is locating the trees that are found on corner lots since they could have two addresses, confusing the street assignment. The data collectors have to decide on a method for these situations and consistently collect the data with the method they use to locate the trees, carefully documenting their methods to minimize confusion. Other information that will be collected, such as species and tree size, and distance from a specific street or curb will also help crews to locate trees.

Site characteristics. An accurate description of the local or micro-site environment determines the species or type of tree that is suitable for growing at a particular location. These characteristics can also be used in analyzing the performance of species or cultivars in relation to site variables, and in planning work such as planting, tree maintenance or pruning, or tree removal. Limited root space is the most critical elements in the urban setting. Gerhold et al. (1987) listed several site characteristic variables:

Site class or land use, i.e. residential, commercial,
Planting space dimensions, above and below ground
Type of ground cover, pavement, or impermeable surfaces.
Infrastructure, i.e. sewage, utilities, buildings
Condition of paved walkway
Street width, or amount of traffic
Soil compaction

One of the most important site characteristics is planting space dimensions. This is extremely important because it deals with how much space is available for the root system. Overhead wires are a major concern in species selection. Recording the height of the wires could help considerably when selecting species for a specific area.

Tree Condition. Tree vigor, health or damage are common descriptors of tree conditions. Condition does not necessarily reflect the maintenance needs of the tree (Smiley and Baker 1988). The following condition classifications may be used according to Smiley and Baker (1988):

Alive or dead
Considered hazardous
Excellent good, fair, poor, dead/dying
Foliage color, relative to other trees of the same species
Life expectancy - estimated number of years before removal will be required
Percentage factor - for use in the International Society of Arboriculture (ISA) CTLA valuation formula

A tree is considered hazardous if there is a direct target, meaning if the tree fell would it hit cars, houses, power lines, or people. Naturally, the location of the tree is going to help determine how hazardous the tree is. The International Society of Arboriculture formula for tree valuation, rates condition as a percentage with 100% as perfect and 0 % as dead (Smiley and Baker 1988).

Damage or Injury. Today, living in a litigious society it is very important to be able to accurately detect damage or injury in trees to prevent or correct future hazardous conditions. Different types of injuries can be recorded in an inventory (Table 1).

Table 1. Classification of injuries commonly used in tree inventories (Smiley and Baker 1988).

Mechanical injury
- <u>Branches</u>
  - Utility or improper pruning damage
  - Breakage due to wind, snow, lightning or people
- <u>Trunk</u>
  - Mower, string trimmer
  - Auto
  - Construction
  - Vandalism
  - Fire
  - Lightning
- <u>Roots</u>
  - Sidewalk replacement

Underground utilities
Construction

Pest injury

Insects
Disease
Decay/Cavity
Dieback
Mistletoe
Rodents
Birds

Often information about insects, diseases and other injury information is collected but never used. If there is not a management action in plan to use this type of date then do not collect this information in the inventory. It is only useful to collect information pertaining to pests if treatments will be executed in the future. However, if a management action will be used this information can be helpful to show trees or areas that are more susceptible to certain insects or diseases. Insect and disease data may also be used to predict future maintenance or removal costs if necessary.

Maintenance Needs. Maintenance needs are transient information that may change frequently, making inventories quickly outdated. Since this information is transient it is important that the inventory is kept up to date. An example of the data that will be collected may include, types of pruning: small tree training, dead wood removal, hanging branch removal, elevating lower limbs, and sanitation pruning which removes diseased or insect infested limbs. However, a tree inventory that is continuously updated makes recording the maintenance activity a pertinent piece of information on an individual tree basis. This information can help prepare budgets, schedule work, and assign crews along with making sure the proper equipment is available for a specific job.

Actions Recommended. Any work that needs to be done is typically decided on the site at the time the inventory is conducted. The information that is collected should include the date and who recorded the information. Gerhold et al. (1987) suggests the following information may be needed on:

planting
watering
fertilizing

mulching
spraying
trimming
removal
repair of pavement
priority of the work

Some of these tasks may be completed on a regular basis, in which case noting only when each task has been completed may be sufficient. This data will vary depending on how the tree department conducts its operations.

c. Updating the System

There are several approaches that can be taken for updating information. Periodic inventory is one approach, this means either all of the trees in the inventory or a portion of the trees are reinventoried at some predetermined interval. This approach allows inventory to be included in the annual budget, maintaining an even annual expenditure (Miller 1997). Periodic inventory of the entire city or a portion of the city provides current information on a periodic basis. This means that either all or part of the information becomes obsolete until the next inventory is completed. Another approach is to update information in those blocks where crews are currently working. Continuous updating is another approach that is often utilized. Continuous inventories provide the most current information regarding the tree population. This type of inventory implies that the crews are qualified to take and record data accurately and that the office staff are trained and have additional time to actually update the inventory. Thus, continuous updating a part of the regular work routine and inventory is a part of the annual budget (Miller 1988). How the inventory data is collected indicates how much time is required in the office. The use of hand held computers in the field to record and collect data can eliminate the tasks of entering the data in the office since they can easily be downloaded to a computer.

C. Types of Inventories

There are three general categories of tree inventories systems: street tree surveys, sampling, and computer inventories (Miller 1997). Each of the three inventory types will be discussed in detail.

a. Street Tree Surveys

Street tree surveys provide a great deal of useful information. This survey is a count of the trees in a community either all of the trees in small cities or by sections or work units in larger cities. The minimum amount of information that needs to be collected in these inventories includes: species, diameter class, tree condition, the number of available planting spaces, and removal needs. The information collected in street tree surveys is usually collected by three to five people from a moving vehicle (Miller 1997). Usually, there are two trained foresters in the front seat that report the data while two people in the back seat record and tally the information. Other people can be used to record specialized data if it will help management needs. Once the data is collected it is reduced to a useable form then analyzed to aid in management decisions.

b. Sample Survey

This method of sampling is commonly used in collecting data for traditional forestry applications, but only recently has it been applied to urban forestry. The objective of sample surveys is to gain information about a population (Avery and Burkhart 1994). This type of survey is a means of reducing the amount of data that is collected. Depending on the percentage of the tree population sampled, sample surveys can be completed quickly and inexpensively. However, there is a drawback with sampling the population in contrast to measuring every tree. You do not have specific information on any tree individually, only an overall picture. It is helpful in evaluating the general condition and allowing you to make initial budget and planning estimates.

Inventorying urban trees by sampling has several applications, such as estimating parameters in windshield survey or sampling technique to provide special data, for example wood volume or average tree diameter. Also, other parameters can be determined as well, including tree conditions, frequency, and management needs for the entire or a portion of the entire population (Miller 1997). Sample inventories are updated on a periodic basis once it has been determined that new inventory information is needed.

c. Computer Systems

Street tree inventories were first used on mainframe computers in the 1970's. The use of these computers allowed city foresters to access data more efficiently and provide summaries of specific tree parameters for management (Miller 1997). These systems turned out to be highly labor intensive, requiring a great deal of maintenance and time. Also, the computers had to be shared with the other departments within the local government.

By the 1980's the development of microcomputers increased the use and access to computerized inventories. Microcomputers now have enormous memory capacity and the speed has increased greatly while the costs have dropped. Microcomputers can also be used for other in house work such as word processing and managing finances which may help justify the initial cost of the system. Urban foresters have the option of designing their own inventory program or purchasing one of the many street tree inventory programs that are available commercially. Choosing tree inventory software should only be made if you have clear management objectives and the software chosen will meet those management needs. The software that is chosen should not confine you but allow you to expand and grow if necessary or include variables that were left out or have shown to be important. However, it is cheaper to purchase an existing program than developing your own as long as that program meets your needs.

There are six functions that inventory programs should have and also should be assessed by the buyer as described by Smiley (1989).

1. <u>Tree data files:</u> manages the tree data and makes the data be easily available so the information can be updated, new trees added, and tree removed as necessary.

2. <u>Work history files:</u> store work records by activity, amount of time required to complete work, equipment used, date, and crew.

3. <u>Service request files:</u> store requests from citizens for tree service, date of response, and services rendered in response to the request.

4. <u>Planning and management summary:</u> the three data files above are

summarized for planning and management, and to prepare reports and budget requests.

5. Lists of tree: these lists of trees in need of service are to be generated in the form of work orders, includes trees that need to be removed immediately, require cabling, or need specific types of maintenance.

6. Computer mapping: available on some systems allows the user to produce maps showing tree location.

More recently, Wagar and Smiley (1990) describe some of the computer assisted management capabilities that are commercially available for urban trees. These capabilities are described in order of importance.

1. Retrieving, displaying, and reviewing records. The ability to respond to homeowners requests by address or location code to retrieve inventory and work information instantly. Also, for other management needs, retrieving information by tree species, date, crews, or work codes are essential.

2. Creating work orders. These are lists of selected work needs that are to be completed for a given area and responses to homeowners requests or complaints. Space should also be provided to note once the work has been completed.

3. Computing tree values. By applying the CTLA valuation formula to inventory data such as species, diameters, ratings for tree condition and location the dollar value for any tree can be determined. This information is often useful for reports and budget requests.[1]

4. Summarizing records. Summaries provide information on a group of trees in a specific area. Information that may be useful includes species, size, value, and condition, needed work, amount spent to perform various tasks.

5. Mapping tree locations. Using various mapping systems allows the trees to be mapped by location. (This will be discussed in greater detail in section IV D).

The Council of Tree and Landscape Appraisers which represents five landscape and horticultural industry groups, revised a guide for estimating the monetary value of woody landscape plants.

6. Creating graphs. Displaying tree population parameters such as, species diversity, diameter distributions, and tree condition graphically make the information easier to interpret and assimilate.

7. Tracking costs and profiling species performance. The ability to determine how much is being spent to perform various tasks is very important. Recording information for each tree such as, work codes, costs, and labor allows the following types of information to be summarized; costs of various kinds of work, species that require the least amount of maintenance and costs, at what sizes or ages does a species require various kinds of work, and if costs of maintenance exceeds replacement costs. Recording actual performance of tree species or cultivars allows the urban forester to better match trees to a particular site.

8. Forecasting future workloads. Being able to forecast future workloads allows managers to plan ahead for personnel and equipment, prepare and justify budgets and determine replacement schedules and species.

Computerized tree inventories should also be "user-friendly" while having sufficient documentation and user support if needed. The use of HELP menus and a well designed and documented computer system eliminates most of the need for user support. However, it is often reassuring to the user to know that if they need help they can call someone that will be able to walk them through it. The costs of technical support will vary depending on the computer system. Some software support is provided for the first year while others charge an annual fee.

The ability to use a password or security system may be advantageous to protect tree records. Entering a password can be used to reduce the risk of someone either intentionally or unintentionally damaging important files.

D. Tree Inventory Costs

The primary cost of an inventory is the cost of collecting field data. The amount of time estimated for worker, depending on experience, to collect tree data is one to three minutes per tree. The costs of tree inventory software ranges from a few hundred dollars to several thousand dollars. The range in costs obviously is directly correlated to the number of tasks and options the software can perform (Wagar and Smiley 1990). Many of the companies that are selling the software will either give a demonstration of what their package does or give you demonstration disks, allowing you to try them out before making a decision.

Urban forestry consultants can be hired to complete a street tree inventory. The consultant will bid on the inventory by street mile, as a lump sum, or by the tree (Smiley and Baker 1988). However, the most common method that is used is to bid a fixed price per tree, which reduces the risk to the consultant of underestimating the tree population. Currently consultants are charging between $ .50 and $ 3.00 per tree, depending on location and the amount of data that needs to be collected. This price usually includes computer data entry and verification.

E. When to do an Inventory

Street tree inventories can either be completed when the foliage is on or off of the trees. Traditionally most inventories were completed during the summer when students are available and the weather is usually more conducive to field work. The advantages of collecting data with the foliage present is tree health can be easily observed. For example; the presence of diseases and insect infestations are often detected by looking at foliage color, size and condition. Collecting data while trees are dormant or during leaf off has advantages as well. These advantages include easily identifying dead wood, hanging limbs and other hazardous conditions that are often overlooked when trees are fully leafed out. Also, the dormant season is usually less hectic allowing personnel more time to spend on the inventory. However, conducting an inventory during the dormant season usually requires more training and/or experience.

IV. GEOGRAPHIC INFORMATION SYSTEMS

A. Background

A geographic information system (GIS) is a computer based information system that is designed to work with data referenced by spatial or geographic coordinates. The use of GIS is rapidly increasing, as city, regional and environmental planners, resource managers and the scientific community become aware of the capabilities these systems have to offer (Star and Estes 1990). A GIS is a tool for storing, manipulating, and displaying large quantities of geographic information in a microcomputer. The geographical data which is stored describes objects from the real world in terms of their position on the earth with respect to a known coordinate system, their attributes which are unrelated to their position, and their spatial interrelations with objects around them (Burroughs 1987). GIS is made up of three major components which include:

1. the digital map data
2. the hardware used to enter, store, retrieve, process, and display these data
3. all the computer software used to perform GIS operations

According to Avery and Berlin (1992) an ideal GIS should be able to execute the following capabilities:

1. Accepting data inputs in several formats (for example, analog map and overlay information, tabulations, and digital - image data).

2. The ability to store and maintain information with the necessary spatial relationships.

3. Manipulating data such as search and retrieval, computations, analysis, etc. in a timely manner.

4 Analysis that would take into account the interrelationships of data as well as cause-and-effect responses of the appropriate factors.

5. Produce several forms of data outputs (e.g., computer generated maps, video displays, graphics, and tabulations).

A GIS is a compilation of overlays for a specific geographic region. The overlays may consist of raw data such as topographic elevation or thematic information which could consist of soils, land use or geologic data, and many others. These data must share common geographic qualities, for example, a common geographic coordinate system. Sharing a common geographic coordinate system is essential so other data sets can be merged into a single system that permits use of the various data as an integrated unit. The data sets are stored in digital form, yet they can be visualized as a set of superimposed images.

Data can be stored in a GIS as points, lines, or polygons. Points could include features such as individual trees, utility poles, fire hydrants, campsite locations, and many other possibilities. Examples of lines include; streams, roads, electrical transmission line, and gas lines. Features such as building footprints, property boundaries, forest cover types and soil types are all examples of polygons. Data are most commonly represented as spatial components of GIS via two methods: (1) grid cell or raster , and (2) polygon or vector. In the raster model, the space is evenly divided into square cells. The location of the geographic objects is referenced by the row and column position which contains a numerical value representing the type or value of the attribute being mapped (Arnoff 1989). In the vector model, objects are represented by points and lines that define their boundaries, as if they were cartographically drawn on a map. Both vector and raster models have advantages and disadvantages (Table 2).

Table 2 Comparison of raster and vector data models (Arnoff 1989).

Raster Model

Advantages:

1. It is a simple data structure
2. Overlay operations are easily and efficiently implemented.
3. High spatial variability is efficiently represented in a raster format.
4. The raster format is more or less required for efficient manipulation and enhancement of digital images.

Disadvantages

1. The raster data structure is less compact. Data compression techniques can often overcome this problem.
2. Topological relationships are more difficult to represent.
3. The output of graphics is less aesthetically pleasing because boundaries tend to have a blocky appearance rather than the smooth lines of hand drawn maps. This can be overcome by using a very large number of cells, but may result in unacceptably large files.

Vector Models

Advantages

1. It provides a more compact data structure than the raster model.
2. It provides efficient encoding of topology, and, as a result, more efficient implementation of operations that require topological information, such as network analysis.
3. The vector model is better suited to supporting graphics that closely approximate hand drawn maps.

Disadvantages

1. It is more complex data structure than a simple raster.
2. Overlay operations are more difficult to implement.
3. The representation of high spatial variability is inefficient.
4. Manipulation and enhancement of digital images cannot be effectively done in the vector domain.

Both raster and vector data models could be used in urban forestry applications. However, the vector model would be better suited since the location of trees as points are needed. Vector data allows the user the ability to not only analyze data but also use a hard copy of a generated map in the field.

B. GIS in Urban Forestry

GIS has long been recognized as a useful tool in the management of natural resource development, land use planning, wildlife management, environmental planning, and forestry planning. The use of tree inventories are essential for the management of trees in an urban community as previously discussed. However, street tree inventories can be greatly enhanced by using a geographic information system. The ability to include various data sets in conjunction with tree inventory data allows urban foresters to make more thorough and cost effective management decisions in our urban forests (Goodwin 1996). A GIS allows the user the ability to quickly manipulate, analyze, display geographic or spatial data and take advantage of existing spatial information (Miller 1997).

C. Base Maps

A base map may vary by scale, content, and accuracy. There are many different sources where digital data can be obtained. The United States Geological Survey (USGS) and the United Census Bureau are excellent sources for obtaining digital data. Remotely sensed data from aerial photographs can be digitally scanned and georeferenced into GIS.

Parcel maps, orthophotoquad maps, topographic maps, street layout maps, utility maps, and thematic maps are all examples of a base map that can be used for a street tree inventory.

a. Scale

Choosing an appropriate scale for a base map is very important. If the scale is too small the user will not be able to distinguish one tree from the other. Conversely, if the scale is too large more detail than necessary is shown (Goodwin 1996). A scale of 1:1200 (1” = 100’) or 1:2400 (1” = 200’) often works very well, having enough detail to correctly identify tree species and display an individual tree. Parcel maps are usually drawn at this scale. Again, this scale is large enough to show a neighborhood yet small enough to show the location of individual trees (Goodwin 1996).

b. Accuracy

Accuracy can be measured via two methods; absolute and relative accuracy. Absolute accuracy is a measure of actual point location on the face of the earth where relative accuracy is a measure of location relative to other features on the map.

Since the location of a tree is not an exact science, relative accuracy is sufficient for urban forestry. It is very important to know where a tree is in relation to other features on the ground. These features include roads, sidewalks, building footprints, water bodies, utility lines and other infrastructure. Relative accuracy can also be very useful for determining the sufficiency of future planting sites.

c. Georeferencing

Before trees can be entered into a GIS the base map must be accurately geo-referenced. Georeferencing refers to a Cartesian coordinate system that relates points on the map to the corresponding points on the earth (Goodwin 1996). The most common coordinate system used is latitude and longitudinal degrees. Other coordinate systems include: state plane, universal transverse mercator, and many others are also available.

Most GIS software that is being used today will allow you to change image map projections, which allows the user to precisely overlay images. Latitude and longitude coordinate systems are most suited for urban forestry applications, especially when using a global positioning system (GPS) unit to locate or map trees.

D. Tree Location

Determining the most effective method of tree mapping to use is very important. Tree mapping is the actual process of locating individual trees on the base map. Aerial photo interpretation, Global Positioning Systems (GPS), surveying techniques, and manually drawing the trees on existing maps are all methods that can be used to accurately locate trees. All of these methods except for aerial photo interpretation have to be performed on the site.

Aerial photo interpretation can save a lot of time, but requires a highly skilled photo interpreter to accurately identify tree species assuming that you have the appropriate scale and up to date photographs. Acquiring photos that are the appropriate scale so that they are useable is essential as was previously explained. There are many factors that affect the type of information that may be obtained from a photo such as; photo scale, time of year photo is taken (i.e. leaf-on or leaf-off), film type (black and white, color, color infrared), age of the photo, and the quality of the photo (Goodwin 1996).

The urban foresters objectives will determine what type of aerial photos are most suitable. Since most trees in the urban forest are often standing alone, photos with leaf on can provide the photo interpreter with more useful information. Color photos are best to determine the trees health and vigor which is a major concern in urban forest applications. The age of the aerial photos are very important in forestry since the urban landscape changes so frequently. The most up to date photos are needed for the best accuracy. Photos more than 3 to 5 years old will probably be of very limited values.

Avery and Berlin (1985) define scale as the relationship between a linear distance on a vertical photograph and the corresponding actual distance on the ground; photographic scale thus indicates proportional distances. The scale then determines how accurately tree locations can be defined. Film type allows the interpreter to distinguish trees from their background or setting. Color infrared film has the greatest amount of contrast while black and white film has the least. Aerial photos taken with leaf-on are easier for tree identification, except when there are a cluster of trees growing close together. Also, dominant and co-dominant trees hide less dominant trees under their canopies. While photos taken with leaf-off are harder to identify tree species but easier to detect crown separation except for evergreens (Goodwin 1996).

GPS is a very accurate way to map tree locations. A GPS monitor records the location of a tree within 1 to 5 meters by tracking satellites. The user simply stands next to the tree with a GPS monitor recording point location information. The accuracy of the data is dependent on the GPS unit, the number of points gathered for each tree, the number of satellites available in the sky while collecting the data, and the data available at the base station. Computer programs are then used to correct the data and download the information directly into a GIS. However, one must consider the accuracy of the base map. Often data collected with a GPS unit is more accurate than the base map itself. This causes problems with mapping a tree for example that is located next to a building. The tree may actually be shown on top of the building instead of next to it due to the inaccuracy of the base map.

Surveying is another method that is often used to locate street trees. A known point or benchmark is needed for this method. From this known point, as many street trees that can be seen are measured recording distances and bearings with a transit and rodman holding a leveling rod. Today, many surveyors are using an instrument called a Total Station that uses infrared light to measure distance which automatically records and stores each reading. Then the surveyor moves to a tree that has already been surveyed and other trees within site of that one can be surveyed as well. Once this field work is attained the data can be directly downloaded into a computer and integrated into a GIS.

E. Integrating Data into a GIS

Several methods can be utilized to map tree locations, depending on which method is chosen will determine how to integrate this information in a GIS. The methods will be discussed below.

If the tree points were defined using aerial photographs or manually drawn on base maps, the points need to be transferred to the base map and then the tree point locations digitized with the GIS software. It is critical when digitizing tree locations that each tree is given the same identification number that was assigned in the field during the data collection. Once the tree locations are in digital form they can be joined or merged with the attribute database by using this unique identification number (Goodwin 1996).

If a GPS unit or a surveyor's Total Station are used to plot tree locations in the field the data can be directly imported into the GIS. This technique is the most efficient and requires the least amount of time. However, the initial costs of the equipment is higher and in heavily urbanized communities GPS units may have difficulty receiving sufficient satellite signals to accurately map all of the street trees.

F. GIS Applications in Urban Forestry

Geographic information in a GIS are stored as layers. Information or layers that are often applied in urban forestry include data such as; roads (centerlines), utilities, soils (Field mapping methods using national standards are used to construct the soil maps in the Soil Survey Geographic (SSURGO) data base. Mapping scales range from 1:12,000 to 1:63,360; SSURGO is the most detailed level of soil mapping done by the Natural Resources Conservation Service (NRCS). SSURGO digitizing duplicates the original soil survey maps. This level of mapping is designed for use by landowners, townships, and county natural resource planning and management. The user should be knowledgeable of soils data and their characteristics, land use, topography, hydrology, building footprints, and census tract/block information. The layers can be viewed to perform various analysis or generate hard copies of maps to better manage the resource in question. Many communities or municipalities already have or will soon have information such as; census tracts/boundaries data, land use, zoning, utilities, floodplanes, and more in a GIS. This data will allow urban foresters to integrate natural resource information or layers in the system, including vegetation, soils, wetlands, impervious surfaces, and critical habitat. GIS in urban forestry can be used to determine areas that will need more trees planted currently or in the future, cost benefit analysis for energy saving, future wetland and woodlot preservation ordinances, predicting future growth, budget requests, identifying critical bird habitat as a result of forest fragmentation and many other similar applications.

CITYgreen™

GIS in urban forestry is often used to perform urban ecological analysis. American Forests developed a GIS software called CITYgreen™ to perform various analyses that estimate the value of trees and other natural systems as part of urban infrastructure. CITYgreen™ is an application of ArcView, a GIS desktop computer software developed by Environmental Systems Research Institute, Inc. (ESRI) based in Redlands, California. This software allows the user to map, measure and analyze how the urban landscape affects: air pollution removal, household energy conservation, stormwater management, carbon storage and sequestration, and urban wildlife. This application is being used to analyze urban ecosystems and make better environmental and economical decisions not only for urban foresters as well as for planners, developers, citizens and more. CITYgreen™ can be used to measure, analyze, map, and present direct and indirect urban landscape values (Garner 1998).

CITYgreen™ has the capabilities to perform analyses at both the local and regional level. Regional analyses show how urban areas relate to the surrounding landscape. These analyses include changes in land cover over time, stormwater and air quality, and evaluating ecological changes. Local analyses provides detailed information on individual trees, buildings, roads, and walkways. CITYgreen™ can be used to better understand the role of vegetation, primarily trees, in the urban ecosystem.

CITYgreen™ is a cost/benefit tool that helps show the importance of urban forests in our growing society. According to Mr. Gary Moll with American Forests, CITYgreen™ provides a methodology to take a more comprehensive look at urban forests with an ecological perspective with the potential of encouraging budget increases for urban forestry. Both local and regional analyses can provide information on resources and the values they provide over time. Planners have a choice to either spend millions of dollars on storm water infrastructure or perhaps more trees can be planted and maintained, which costs much less to remediate the problem and has multiple benefits to the urban setting. Trees can be planted for little or nothing compared to the expense of infrastructure and cooling and heating systems while the returns and benefits in which trees provide are enormous.

V. CONCLUSION

The use of tree inventories and GIS applications in urban forestry are essential to better manage and maintain healthy urban forests. However, there is very little current literature available regarding this topic. Most of the literature that was found on tree inventories in the urban forests was written in the late 70's and early 80's with very few articles regarding GIS applications in urban forestry. Most of the articles that were reviewed for this paper had cross referenced the same literature, meaning the authors had just revised or rewrote articles with the same or very similar information. There are not many organizations that spend a great deal of effort and research on urban forestry; the largest organizations include; American Forests, Society of Arboriculture, and the Society of American Foresters. However, these organizations are growing and realize the importance that urban forests play in the society. While the U.S. populations is constantly growing the need to effectively manage the urban forests is a must. There are many U.S. cities that are employing urban foresters to manage the trees in their community. Yet, many cities do not have tree inventories or any management plans for these urban trees (Sharpe et al. 1995).

GIS applications in urban forestry are becoming effective tools to demonstrate how the urban ecosystem's natural and human made components interact and become a valuable community resource. The use of GIS to help manage all aspects of the ecosystem instead of just focusing on one particular section at a time is a major step in the right direction. More programs are needed that will preserve the existing trees in cities instead of the mentality of the past which has been cut everything down and replant a new landscape with one and two inch caliper specimens. The final effect is just not the same visually nor functionally. In addition we are seeing the maturing of many "planned communities" that were established in the 1960's and 1970's. As these communities and associated forests grow the need for tree maintenance and removal are surfacing and often very expensive for homeowner and local governments.

In municipal forestry many states and counties are currently using GIS in other departments, especially the engineering departments. Since much of the data that is being used in GIS applications in the engineering departments overlap with the data urban foresters would need, it would be relatively simple for urban foresters to implement a GIS by sharing data. By adding a few extra layers to the system urban foresters could provide a great deal of information regarding the trees in the cities, these systems are also an excellent means to justify for higher budget requests which are needed to manage the urban forests. The benefits of GIS would exceed the initial costs of the software and digital data that is needed. Updating data in a GIS is much more cost efficient and less time consuming than having to manually redraw maps. Also, the ability of GIS's to perform complex analyses by typing in simple queries or commands can provide the user with very valuable outcomes. Having multiple layers give the user the ability to look at the entire picture and make valuable management decisions that benefit our landscapes.

A. Where do we go from here?

This paper has indicated the importance of urban forests and the need for managing this natural resource. GIS is a tool that gives urban foresters and planners the ability to better manage and predict future growth of the urban forests. However, urban forests are very complex systems. Unlike large tracts of forest lands that are managed by one owner or organization with a set of goals, urban forests are broken up into many small tracts or plots with multiple owners and many different land uses. Urban land can be categorized into three different land uses; non-industrial or private, industrial or commercial, and public land. Due to the diversity in land uses, managing and maintaining urban trees is an extremely difficult task.

Urban forests are managed by a large number of individuals who have many different objectives and goals. Arborists, landscapers, horticulturists, planners, and wildlife biologists are among some of the professionals who are involved with managing urban forests. Homeowners, garden clubs, and other nature groups are also involved and interested in beautifying their community. In addition teachers are constantly looking for places where children can learn about the trees and forests, and the important biological role they play in our global system. The activities of all the different owners and multiple land uses influence the overall appearance and quality of the entire community. Having such a diverse group involved means there is a vast level of knowledge and understanding with regard to the trees and how all of their functions relate in the urban forest. It is up to urban foresters as well as other trained and educated professionals to provide the public with current and correct information regarding urban forestry. Educating the public regarding urban forestry issues and all of the associated benefits urban forests provide is essential to help improve the quality of life in the urban setting.

A large amount of money is spent each year on trees and landscaping in a community, from planting new trees to tree removals or take downs. All too often, new landscapes are over planted, meaning too many plants or the wrong plant species were selected for the area resulting in either the lack of growing space for the trees root system or the crown competes for space and interfere with overhead utility wires. It is very important to select the right tree species for the right site to meet the intended objective. When selecting a tree for a particular area in the landscape several components need to be considered such as shade tolerance, the amount of sun or shade that plant requires, how large the tree will grow when it is mature, and selecting trees that are healthy and have good form. Other problems that are commonly found in the landscape are that trees are not planted correctly, often the roots balls are planted too deep or too shallow. Trees that are planted incorrectly can cause the tree to decline or die. The importance of young tree pruning is very beneficial to improve tree form at maturity. The minor costs of correctly pruning a young tree can improve tree form which in turn can save a lot of money later on. Providing tree care for young trees can reduce future hazardous problems and liability.

Tree inventories are generally not conducted for the private sector or on a plot by plot basis because most of these areas only have a few trees on each plot. Street and park trees are primarily the only trees being inventoried and managed in the urban setting, these trees are located on commercial and public lands. However, trees that are on private land make up a large percentage of the entire urban forests and many of these trees are not being managed. Street and park trees only make up a small percentage of all of the trees that are located in the urban landscape. An ecosystem management approach would include all of the trees that make up the urban forests. Inventorying all the trees in the three land use categories would allow urban foresters to better predict the cost benefits and management needs that are required. GIS applications such as CITYgreen™ have the capability of analyzing the entire urban forested areas. They have the potential to predict future maintenance costs and to project future growth and energy savings.

Urban foresters and planners have to start working closely together to effectively plan the urban system. Construction sites in the past have often been cleared of all existing trees, shrubs, and the organic matter. There has been efforts to keep some of the existing trees which unfortunately usually die due to numerous problems such as soil compaction, root disturbance, change in soil grade, and impervious surfaces which reduces or prohibits infiltration and water uptake by tree roots. Urban planners and contractors need to work with urban foresters to determine which trees should be preserved on a given site and the best ways to minimize damaging these trees. In the planning stage planners have to make sure there is sufficient space to allow for trees to be planted if trees are included in a plan. For example; the area between sidewalks and roads needs to be wide enough to sustain the root system of a tree or planters in a parking lot should be large enough to ensure the tree will have enough nutrients and water to maintain tree vigor and health. Urban foresters and urban planners can work together using GIS to better manage this resource. Urban planners usually know very little about what conditions and space trees require, just as most urban foresters know very little about designing a city. However, the two disciplines working together can be very effective in producing a beautiful urban setting.

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VII. VITA

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