AN INDEX OF GAINESVILLE'S URBAN FOREST ECOSYSTEM SERVICES AND GOODS

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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To the people that join me in this path

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Urban ecosystem have been shaped by time, human behavior, land use patterns and socioeconomics. Since this type of ecosystem is directly related to humans, the services and goods they deliver become highly relevant. An index for the urban forest ecosystem services and goods of Gainesville was developed and its distribution across socioeconomics, morphology and landscape were assessed. To develop the index the description of the composition and structure of the urban forest was done. Then indicators for services, goods and disservices were recognized and calculated according to field data collection, the UFORE model and available literature. Finally the indicators were aggregated using three weighting schemes.

Results show that residential areas located in older parts of the city have the highest index for the delivery of ecosystem services and goods, that the equal weight index delivered the most robust values and that the estimations of the index using ordinary kriging technique delivered reliable estimates at the city level.

CHAPTER 1
INTRODUCTION

Urban ecosystems include cities, suburbs, towns and peri-urban areas and represent the array of possible combinations of stresses, disturbances, structures, and function occurring in ecological systems (McDonnell and Pickett, 1990). They represent localities with increased population density within a dense network of non-natural built environments (Williams et al., 2009). These built environments are composed of hard surfaces such as roads, sidewalks, roofs and buildings. Urban environments rely on vegetation and soils to provide ecosystem functions (Bolund and Hunhammar, 1999). Therefore, understanding how urban ecosystems functions, how they change from their natural condition, and how their performance may be limited, can lead to a better understanding of the actual impacts of urbanization (Vitousek, 1994). The effects of urbanization can change ecosystem structure and function as previously pointed out by several authors (McDonnell and Pickett, 1990; Vitousek et al., 1997; Grimm et al., 2008; Alberti, 2009).

The concept of ecosystem services and goods has two main definitions and approaches; one comes from the field of ecology and the other from the discipline of economics. As defined by economists, ecosystem services are components of nature that are directly enjoyed, consumed or used to improve human well –being, and require some interaction or at least appreciation by humans. An economic value can then be assigned to them (IPCC, 2001; Boyd and Banzhaf, 2006; http://www.ecosystemvaluation.org/Indicators/economvalind.htm). Ecosystem goods are the tangible material products that result from ecosystem processes (Brown et al., 2007). Conversely from an ecological point of view ecosystem services are the range of conditions and processes occurring in an ecosystem that help sustain and fulfill human life. This definition is focused on ecosystem functions, so ecosystems services are not solely valuable to humans beneficiaries, they are also valuable for maintaining natural resources. They are seen as the processes by which the ecosystem produces resources (Daily, 1997; ESA, 1997). De Groot et al. (2002) identified 32 ecosystem services that included biological, physical, aesthetic, recreational and cultural. Butler and Oluoch-Kosura, (2006) also identified several cultural, psychological and other non-material benefits that come from contact with nature. The definition as applied by economists will be used in this study, since the evaluation of the state of the environment in urban ecosystems is directly related to human well-being as they are the main drivers of its composition and structure.

Ecosystem disservices are processes that have negative impacts on human life. These are commonly found in urban and agricultural ecosystems (Abenyaga et al., 2008; Lyytimäki et al., 2008; Zhang et al., 2007). They affect how urban areas are experienced, valued, used and developed. Ecosystem disservices become highly valuable when they appear in everyday life of the urban residents (Lyytimäki et al., 2008). Disservices of urban ecosystems have been rarely considered in urban studies, but they can be easily found in urban areas.

Trying to describe the state of the environment is a very difficult task, since ecosystems are dynamic and in constant change. Other studies/efforts have used criteria and indicators to provide a tool that simplifies this system and allows a means for obtaining comprehensible information. Indicators could help in compiling a vast amount of information that will reflect the dynamics occurring among humans, physical, biological properties and processes. Indicators provide a way to evaluate the progress towards environmental goals and to overcome the complex information given by indices, delivering an overall picture of the system's performance (UNEP, 2006).

The development of an urban forest ecosystem services index might provide urban planners with an easy and understandable tool to evaluate the state of the urban forest. The index will deliver a picture of how the different arrangements of urban forest structure and composition affect socio-ecological function and subsequently the provision of ecosystem services and goods. The index will show which are the variables driving the value of the index. In this study the economic definition of ecosystem services and goods as applied by De Groot et al. (2002) will be used and based on the premise that the services and goods provided by the urban forest are associated with human well-being.

The chapters proceed following Figure 1-1. In the 2nd chapter, the structure and composition of Gainesville's urban forest is established. Urban soils and tree structure data were sampled, urban tree function and leaf biomass and area were then obtained using the Urban Forest Effects (UFORE) model. The relationships among socioeconomic and city morphology were then explored. Second, the 3rd chapter used the data obtained in the 2nd chapter and available information from the literature to assign values to the services and goods found in urban ecosystems. The ecosystem services and goods are defined and classified by the respective ecosystem function group belonging to De Groot et al. (2002). These function groups correspond to: regulation, habitat, productivity and information. Indicators for ecosystem services and goods were developed to evaluate the state of the urban forest of Gainesville, FL.

Indicators also explored and account for ecosystem disservices. Thirdly in the 4th chapter, I illustrate the overall state of ecosystem services and goods by aggregating the indicators into an index. Three methods for developing the index are evaluated: 1) equal weight, 2) double weighting of the information function indicators and 3) assigning weights based on a principal components analysis. The value of the index is explored spatially by analyzing the distribution of the index based on urban morphology, socioeconomics, and site legacy.

An index of urban forest ecosystem services and goods provides a way to evaluate the state of urban green areas. It will present a value that can be easily understood by the community. The weight of each of the indicators that builds the index will depend on the priorities that the community has in relation to the services and goods they can obtain from their urban forest. The analysis of the index will be limited to changes in the provisioning of a certain service or good. The consequence on human well-being, due to those changes in the index, will not be analyzed or established and should be included in future studies since different humans, societies and communities will perceive the effects on their well-being in different ways.

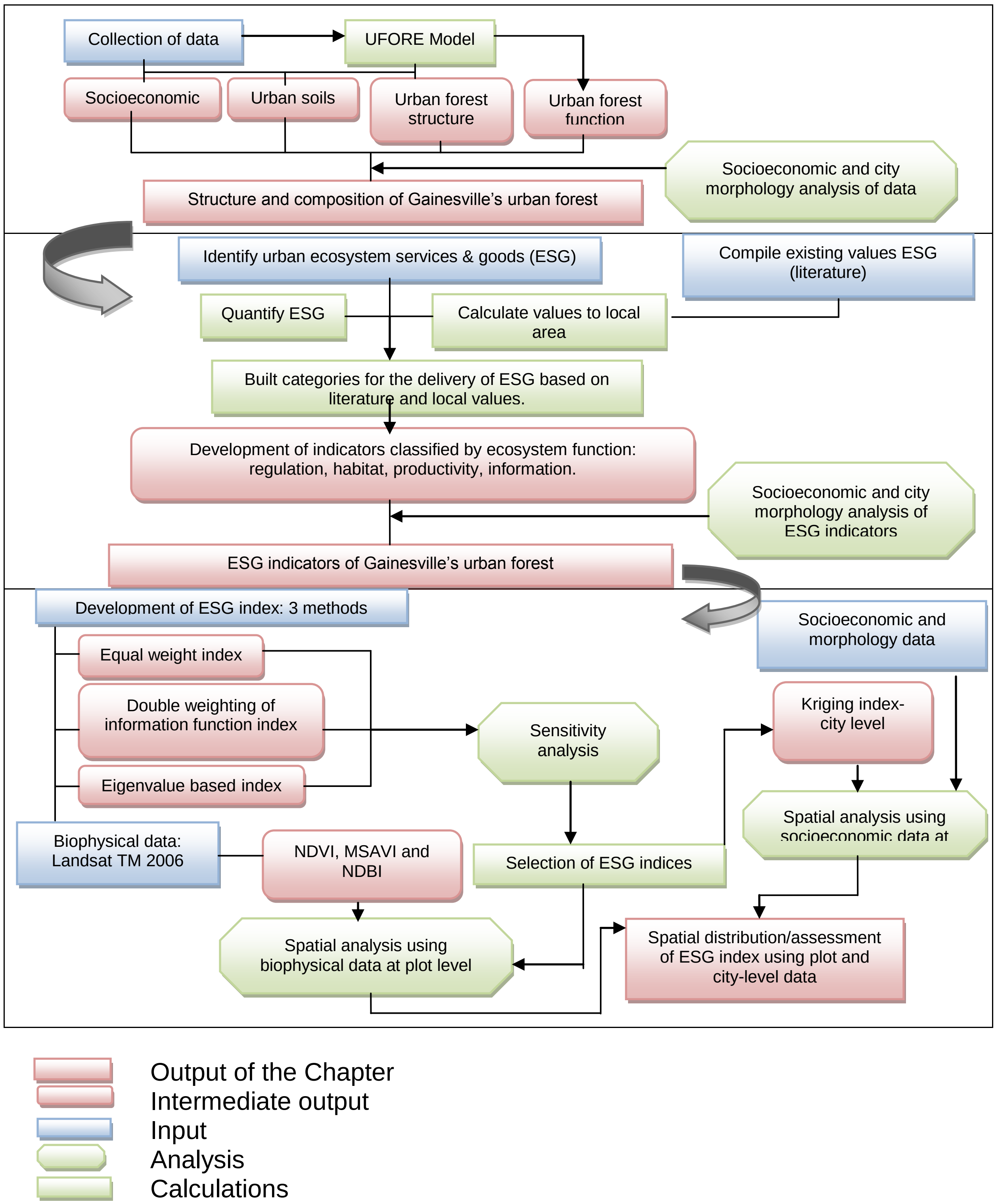

Figure 1-1. Flow diagram for the development of an index of ecosystem services and goods.

CHAPTER 2
STRUCTURE AND FUNCTION OF GAINESVILLE'S URBAN FOREST

Introduction

The majority of Florida's population resides in areas that are classified as urban. Florida is one of the most populous states in the U.S, and as of 2008 was forecasted to be one of five fastest growing states during 2000-2030. The climate and landscape provided by Florida motivates people to move to its urban centers. These people provide billions of dollars statewide in economic benefits through tourism, industry, recreation, and sport fishing activities (TBNEP 1996). Urban areas and their associated ecosystems often differ from natural areas in respect to climate, soils, hydrology, vegetation dynamics, human population dynamics and flow of energy and material because of the ecological patterns, process and disturbance effects associated with urban lands (McDonnell et al., 1993; Alberti, 2009). Understanding the role of human influences on the urban environment (Alberti, 2009) could help inform policy makers on urban planning, development and morphology (Campbell and Landry, 2000). Urban morphology patterns emerge from the interaction between the human and ecological processes acting at multi-temporal and spatial scales. Drivers such as population growth, economic growth, and land use policies create patterns of land use, land cover, transportation, artificial watersheds and biogeochemical cycles which in turn affect natural productivity, biodiversity, community dynamics and human behavior (Alberti, 2009).

Urban forests offer substantial environmental, social, and economic benefits (Tyrväinen et al., 2005). Urban forests are defined as natural or planted, individual trees, group of trees or woodlands located where people live (urban and peri-urban).

Urban forests are also defined as ecosystem characterized by the presence of trees and other vegetation and pervious soils in association with people and their infrastructure (Nowak et al., 2001). Urban forests contribute to the physiological, economical and sociological well being of urban inhabitants (Carter, 1995) and improve environmental quality and thereby enhance human well being via the flow of several ecosystem services. Urban forests could also have costs such as pruning, pest and disease management, increase crime risks or produce volatile organic compounds (Escobedo and Seitz, 2009).

Urban forests as defined in this study (i.e. the sums of trees and pervious soils) can mitigate many environmental quality problems associated with urban development by moderating climate, reducing building energy use, improving air quality, reducing storm water runoff and reducing noise levels (Aylor, 1971; Carter, 1995; Tyrväinen et al., 2005; Chen and Jim, 2008; Alberti, 2009). Trees in the urban forest are also perceived to enhance the social and economical environment of a city by improving aesthetics and property values (Anderson and Cordell, 1988; Tyrväinen and Miettinen, 2000). Urban forest structure is influenced by socioeconomic characteristics, for example, plant diversity has been found to increase with income (Hope et al., 2005) and land cover has a high correlation with household income and household density (Iverson and Cook, 2000; Escobedo et al., 2006).Understanding the composition, structure, and the environment of urban forests can help planners maximize benefits.

Urban forests are highly influenced by urban soil condition; as they are a medium for plant growth and support urban habitats (Jim, 1998). Urban soils are highly heterogeneous, having different levels of compaction, nutrients, infiltration rates, and incorporated amounts of manmade materials (Craul, 1999). Characteristics of urban soils can affect inter-specific plant competition, community composition and growth. Vegetation growth is constrained in urban habitats by the presence of impervious surfaces such as concrete, asphalt or other subsurface material that affects the aggregation, porosity and structure of the soil (Jim, 1998). Other factors that play a significant role in shaping the biological, physical and chemical characteristics include plant cover (Hope et al., 2005), urban morphology and time since urban development (e.g. site legacy) (Scharenbroch et al., 2005). Urban soils are also affected by the human socioeconomic conditions. Understanding the various elements that comprise effective soils' management could be used to help develop practices that maximize urban forest benefits, since the soil-physical and nutrient needs of vegetation is necessary for the improvement of the urban forest and its benefits (Jim, 1998).

In this study we explored if the urban forest structure, composition and soils might be affected by socioeconomics and urban morphology. To answer this, the following objectives were pursued:

- Describe the composition and structure of the urban forest, specifically the soils, and tree components, socioeconomics, and morphology for the City of Gainesville, Florida.
- Establish the interrelationships between the components of the urban forest for the city of Gainesville, Florida.

Statistical relationships are expected to occur between urban soil and tree variables. The distribution of the structure and composition of trees and soils in the urban area of Gainesville is expected to differ across land uses, land cover and quadrants of the city.

Methods

Study Area

The City of Gainesville is the largest city in Alachua County, Florida. In 2000, Gainesville had a population of 113,942 inhabitants (US Census Bureau, 2000) and is located at approximately 29°39'N and 82°20'W in North central Florida and covers an area of near 127 km^2. The economic base varies from agricultural to manufacturing, however academic research, education and health care are the main activities. Gainesville's climate is considered humid, subtropical with an annual average temperature of 19.4ºC in January and an average temperature of 33ºC in June with an annual of 1,228 mm of precipitation. Summer is the wettest season, with 496 mm, while fall is the driest season, with only 230 mm of precipitation (Metcalf, 2004).

Northern areas of Gainesville are located on the Hawthorne geologic formation and Plio-Pleistocene deposits in the Southern areas (Chirenje et al., 2003) which form part of the Ocala Uplift (Phelps, 1987). The predominant soils are sandy siliceous, hyperthermic aeric hapludods and plinthic paleaquults (Chirenje et al., 2003). The major drainage basins include the Suwanee, Steinhatchee, Encofina and Aucilla which are generally below 100 feet above sea level in elevation and are characterized by seasonally high water tables (Metclaf, 2004).

Gainesville is located near the boundary of the Northern Highlands and the Alachua Lake Cross Valley physiographic provinces. In the north, the topography is gently rolling and transitioning to flat areas in the south characterized by the presence of prairies containing ephemeral lakes (Phelps, 1987). Gainesville natural vegetation is temperate evergreen forest and is characterized by species such as evergreen oaks and members of the magnolia and laurel family. The understory includes ferns, small palms, shrubs and herbaceous plants. Lianas and epiphytes such as “Spanish moss” are abundant (Bailey, 1980).

Field Sampling

A total of 98 sampling plots of 0.04 ha were established during 2005 and 2006 inside the city limits of Gainesville. Plots locations were randomly selected and captured an array of land uses including commercial, industrial, institutional, transportation, high and medium density residential, park, open areas, forests and wetlands. Land use designations are based on the classification of the City of Gainesville’s Planning and Development Department (www.cityofgainesville.org). The samples were aggregated into residential, forested, commercial/industrial and institutional categories. Wetland land use was not included in this analysis.

Following methods outlined by Nowak and Crane (2000), a circular plot was established at each random location (Figure 1). General information such as percentage of tree cover, plantable space, shrub cover, and bare soil was recorded. Data on the types of existing surface covers was recorded, including pervious and impervious surface. Diameter at Breast Height (DBH; 1.37 m above surface) was measured as well as location and condition of every tree on the plot. Total height, crown height, crown diameter, percent canopy dieback, percent canopy missing, and crown light exposure were also measured following Nowak’s et al. (2003) methods.

Of the 98 plots, 78 were sampled for soils. Soil plots were selected based on Pouyat’s (2007) criteria that: 1) more than 25% of the plot surface was pervious; 2) permission was granted to collect soil samples; or, 3) the soil was not too wet to collect the sample. Soil samples were taken from a 3.14 m^2 subplot located in the center of the 0.04 ha vegetation plot (Figure 2-1). In case of the presence of a tree, building, or impervious surface being located at the plot center, the soil subplot center was moved 1 meter north. Two kinds of soil samples were obtained within the soil subplot (3.14 m^2). One sample consisted of three undisturbed 5 cm diameter by 4.5 cm deeper soil tins, which were used to soil physical properties. A second was a composite soil sample consisting of 15 soil cores obtained from the first upper 10 cm of the soil surface using a soil sample probe.

Soil Analyses

Fresh bulk density samples were weighed to obtain the volumetric water content and then oven dried at 105°C for 48 hours to obtain dry weight. The weight of the inert and organic material greater than 2 mm was removed and discounted from the volume of the sample to obtain total soil volume. The composite samples were air dried and sieved with a stainless steel 2 mm mesh sieve, and sent to the University of Florida Soils Laboratory for chemical analysis (Table 2-1). The analysis included Total Kjeldahl Nitrogen (TKN), extractable phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), copper (Cu), sodium (Na), zinc (Zn) and concentrations of lead (Pb), cadmium (Cd), nickel (Ni), as well as organic matter content and pH.

Chemical analyses for heavy metals were done for only nine plots located in the forested, commercial and residential land uses. Three samples for each of these land uses were chosen since previous studies indicated a lack of high concentrations of heavy metals in Gainesville's soils (Chirenje et al., 2003, 2004).

Tree Analyses

The data was analyzed using the UFORE (Urban Forest Effect) model (Nowak and Crane, 2000). The model calculates urban forest structure, environmental functions and values of the urban forest. The model was developed by the USDA Forest Service

Northern Research Station to help managers and researchers to quantify urban forest structure and functions. The program incorporates vegetation data, local hourly meteorological and pollution concentration data. The program is divided into four modules. The first one quantifies urban forest structure such as species composition, tree density, tree condition, leaf area and leaf biomass, and also calculates species richness. Leaf area and leaf biomass are calculated using regression equations incorporated into the model developed by Nowak (1994).

The second module estimates the volatile organic compound (VOC) emissions focusing on the ones that contribute to ozone and carbon monoxide formation (Nowak and Crane, 2000). The estimates are based on tree species, leaf biomass and other meteorological factors. The module estimates the emissions for each species by land use and for the entire city by multiplying leaf biomass with genera-specific emission factors and adjusting for meteorological factors. The third module deals with above-ground carbon storage and sequestration. Carbon storage is calculated using allometric biomass equations from the literature for 84 different species (Nowak et al., 2000). This value is multiplied by 0.8 to adjust for trees growing in urban areas (Lawrence et al., 2008, McHale et al., 2009) and then the total carbon stored is obtained by the multiplication of total biomass by 0.5 to transform dry weight biomass to carbon values. To estimate carbon sequestration, the model calculates the diameter growth depending on the genera, the diameter class, and adjusts for the land use by where the tree is growing. Increments in height are computed by Fleming’s equations (1988) and the proper growth factor of the tree adjusted by the tree condition and number of frost free days. The estimated carbon sequestered is the difference between carbon storage between year one and year two.

The fourth module estimates the hourly dry deposition of ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and particulate matter less than 10 microns (PM10) to leaf surfaces. The average of hourly dry deposition is based on tree cover and meteorological data such as temperature, wind speed, relative humidity, and pollutant concentration monitored by the Environmental Protection Agency (EPA) data. The pollutant flux is calculated based on deposition velocity and the specific pollutant concentration (Nowak and Crane, 2000).

The CO, O_3, NO_2 and SO_2 and PM_{10} removal for urban trees in the City of Gainesville were estimated using the UFORE model and field data collected in 2005 and 2006, weather data from 2000, and pollution concentration data from 2004. Air pollutant removal flux of square meter of tree cover is obtained by multiplying grams of air pollutants removed per square meter by the tree cover of each plot.

Socioeconomics

Previous studies have used socioeconomic variables such as population density, household size and median income to analyze the urban ecology of a city (McIntyre et al., 2000; Hahs and McDonnell, 2006). Socioeconomic data for Gainesville were obtained from the U.S Census Bureau's census block data for the year 2000 (www.census.gov). Census block geographical units are the smallest homogeneous subdivision derived from the U.S Census and group approximately 1,500 persons into each unit. The Topologically Integrated Geographic Encoding and Referencing (TIGER) data (www.arcdata.esri.com/data/tiger2000) from the 2000 Census were used to connect each plot sample to its respective census block unit. These variables have been used in other studies to see how urban forest characteristics differ across urban areas (Pickett et al., 1997; Iverson and Cook, 2000; Heynen et al., 2006; Szantoi et al., 2009). Population, race, education, household income, percent of ownership, number of households per unit, and mean age of the population were obtained for each census block existing inside the limits of the City of Gainesville. Urban morphology variables such as time since the property was developed and value of the property were obtained from the Alachua County Property Appraiser's Office (http://acpafl.org). Forested plots on vacant land uses and forested land use plots with no building or urban development were assigned zero years since the development of the property. Land cover data was obtained from the most recent Florida Fish and Wildlife Conservation Commission land covers derived from classification of 2004 Landsat TM satellite imagery (www.fgdl.org). Classes included agriculture, bare soil, wetland, forest and urban land cover.

Values for race were classified as White, African American and Others. The other category groups all other races (e.g. Asian, Hawaiian, multiracial, Hispanics and others). Values for education were calculated according to the percentage of the census block population over 25 years old that had a post high school degree, including a Bachelor's, Master's, professional degree or Doctorate. Land use associated with each plot was assigned in the same way as described for soils. To group similar areas quadrants were subjectively delineated a priori based on analyses of the geographical distribution of Claritas social group characteristics, which is based on household and geographical levels (www.claritas.com). City quadrants also include in its delineation the property ages and urban development patterns found in Gainesville (http://www.fhwa.dot.gov/planning/megaregions4.htm, Stanilov, 2007). These quadrants roughly correspond to local nomenclature for the different demographic areas in Gainesville, such as the zoning map of Alachua County (http://growth-management.alachua.fl.us/gis/gis_mapatlas.php). Quadrant location and corresponding plots are shown in Figure 1-2 and corresponded to North-West, North-East, South-West and South-East. The quadrants are delimited by 13th Street on the East-West direction and by University Ave North-South direction. Population characteristics in each quadrant are listed in Table 2-2. The NE covered 43.8 km^2 and included 35 sampled plots, the NW cover an area of 56.5 km^2 and 37 plots. The SW had an area of 13.2 km^2 and 13 plots and the SE 13.9 km^2 with 13 plots.

Statistical Analyses

Basic statistics for socioeconomic, soil, and urban forest data were calculated. Data were checked for normality using the Kolmogorov-Smirnov test (p-value=0.05) (Lilliefors, 1967). To test for differences across land uses and quadrants of the city an Analysis of Variance (ANOVA) was performed including a categorical ANOVA for demographic analysis. Location of the plot by quadrant was included in the analysis to explore if the location of the plots influenced their characteristics. To explore the correlation between social variables, a Pearson correlation procedure was performed with $\alpha=0.05$ using the SAS Proc CORR procedure. To determine which variables explain most of the variability of social properties, a factor analysis was performed using Proc FACTOR. Previous studies have used this technique to reduce the amount of demographic data and to select the most relevant variables (Lo and Faber, 1997; Vyas and Kumaranayake, 2006).

In addition, a principal component analysis (PCA) was performed using Proc PRINCOMP with a correlation matrix (SAS Institute, 2007) for soils and vegetation data.

This procedure simplifies the statistical relationships with minimal information loss (Wackernagel, 2003), since it shows the variables that explain the highest amount of variance in the data. The first principal component explains the highest amount of variability of the data, and each following component accounts for the remaining variability (Vyas and Kumaranayake, 2006). The explanatory variables that characterized most of the variance within each principal component or factor was chosen by an eigenvector or factor value greater than 0.7 (Garten et al., 2007). The PCA correlation matrix accounted for differences in measurement units (Fox and Metla 2005; Grunwald et al., 2007). This procedure is commonly used for soil analyses (Fox and Metla, 2005; Garten et al., 2007; Grunwald et al., 2007) and discloses relationships among soil variables. Highly correlated variables for soils and vegetation were modeled using a stepwise selection method using PROC Reg (SAS Institute, 2007) to distinguish the variables that explained most of the behavior of the dependent variable.

Results

Socioeconomics

Gainesville's population density is 897/km^2 with a predominance of Whites (67% of the total population), followed by African Americans (24%). The remaining percentage is composed mainly of Hispanics and Asians. In terms of education, for the population of 25 years old and older, 88.2% of the population had completed high school, of those, 42.0% have completed a Bachelor's or a higher degree (U.S Census Bureau, 2008). The average family size is composed by 2.9 people and the average household size for the city of Gainesville is 2.16 people of which 19,738 (42.0%) were owner occupied and 27,122 (68%) were renter occupied. The amount of labor force is 55,768 habitants, giving a per capita income of $19,122, while household income of $34,327.

All the variables were normally distributed (α=0.05). The greatest variability existed in property values as seen by a coefficient of variation over 100% (Table 2-3). Of the total population, 20% had a higher educational level. Urbanized properties in Gainesville were not old as their average age was 30 years, with a few properties over 100 years of age (Table 2-3).

Factor analyses of socioeconomics showed that 73% of the variance of the data was explained by the first three factors, which points to a high correlation between the analyzed variables. The first factor explained 36% of the variance, the second factor explained 24% of the variance and finally, the third factor explained 13% of the variance. The contribution to the factor is dominated by four variables, the main ones were household units (0.48) and population (0.48), for the second factor the main contribution was by household income (0.57) and the average age of the block population (0.55), other variables showed only a small contribution (<0.20). The third factor and remaining variability was mainly determined by the property value (0.53) and by the presence of African-Americans (-0.58).

Significant correlations were found among the social variables. The variables that were correlated with the highest amount of social variables were household income and population, while the ones that were more independent were years since the property was developed and value of the property (Table 2-4). These variables will be used to explore differences between environmental variables in this study. Population density was negatively correlated with higher levels of education. The same relationship arose between household income and population of African-Americans. Older people (>60 years) tended to inhabit newer properties.

Results from the ANOVA (Table 2-5) did not show significant differences among land use categories. Income was the greatest in residential areas and was also the one with the highest variability. Several areas had incomes of $10,000, whereas other areas had values greater than $70,000. Older areas were found in commercial and vacant land uses showing high variability, resulting from different land use histories. African-American population density was higher in land uses classified as forested areas, while other ethnicities had higher concentrations in areas classified as vacant and commercial. Institutional areas had the higher prices by acre but also had the highest variability. Lower levels of high degree education were found in land uses classified as vacant and residential.

City quadrants differed significantly in property value and education levels. The highest concentration of population per block (3,260 habitants) was in the SW area of Gainesville, while the lowest concentration of people/block (2,129) was in the NE. Household income was greater in the western part of the city, whereas the highest level of education was located in the SW area of Gainesville which had the highest student population. The lowest levels of education were located on the NW side. Property values showed differences among quadrants. The highest values were located on the NW and SE and high values on average found in the SE was mainly due to the existence of three properties with very high property values. Greater numbers of older people (>60 years) can be found in the SW and NW parts of the City. White concentration was greater in the western part of the city, while African-Americans were concentrated in the southern part of the city; a higher amount of other races were located in the SW, a region of the city that contained a high concentration of students.

Soils

High variability was found in soil nutrient concentrations, as indicated by a coefficient of variation (CV) of over 100% showing great dispersion of the data. The P concentration showed a negative normal distribution. The same situation occurred with Ca where there was an accumulation of values in lower levels of concentration. Physical properties had lower levels of variability, especially for bulk density (CV of 29.9%) and total porosity (CV of 18.6%). Variation of soil chemical properties was relatively high, with the exception of pH where 70% of the data can be found between pH's 5 and 7 (Table 2-6).

The PCA for soil properties showed that 69% of the total variance of the data was explained by the first three principal components. The first component explained 30% of the variability, the second 25% and the third only at 14% (Figure 2-3). The first two components did not show a strong contribution to the explanation of the variability of the data. The majority of the soil properties contributing to the explanation of the variance had eigenvalues between 0.25 and 0.45. The higher eigenvalues in the first principal component were bulk density (0.46), water content (0.39) and organic matter (0.35). The second principal component behaved similarly but the highest contributions were made by TKN (0.45) and magnesium (0.43). Finally, the third principal component showed a positive contribution of Ca (0.5) and a negative contribution by K concentration (-0.47) in explaining the remaining variance.

The correlation matrix (Table 2-7) shows TKN as the most dependent variable. It is positively correlated with the other nutrients in the soil, the pH, and organic matter content. The variable that showed the highest influence in chemical concentrations was pH. Moreover, neutral pH's delivered higher concentrations of nutrients as expected.

Organic matter content was highly related to the physical variables of the soil, as higher levels of compaction were associated with low levels of organic matter. Organic matter was associated to Na concentrations, bulk density and TKN. The concentration of Mg is correlated with P, K and Ca concentrations ($\alpha=0.05$). The linear regression for pH shows that bulk density, soil cover and Ca concentration were significant (p-value<0.0001) with a variance inflation factor of 1 and explained 79% of the variability of the soil. Also this regression equation was associated with a low RMSE (0.5) (Figure 2-4).

Results from the ANOVA showed that 7 of the 11 soil variables were significantly different among land uses (Table 2-8). Forested areas have the lowest bulk density values and therefore have the highest value for total porosity. Bulk density was similar among other land uses, as was total porosity.

Nutrient concentrations in forested and vacant areas had the lowest level of P. Forested areas show the lowest concentrations for K, Ca, Mg and one of the lowest for Na. Levels of P were high on residential and commercial areas. On the other hand, K in residential areas shows the highest concentrations of all the land uses. High levels of Ca were found in residential and vacant areas. TKN was the lowest in residential and commercial areas even though their differences were not significant (p-value>0.05). Heavy metal concentrations were low in all land uses with the exception of residential areas, where Zn concentration was higher than other land uses. The pH values presented a small but significant difference between land uses, especially in forested areas which were more acidic. Land cover had more significant differences than the land use analysis, where 10 of the 11 analyzed variables had significant differences.

The differences between land cover and land use are attributed to agricultural and bare soil covers. Nutrients, in general, had low concentrations in bare soil areas and high concentrations in wetlands, forests and urban areas. Values of pH are acidic in bare soils areas while wetlands are more alkaline.

Physical soil properties show significant differences across all surface covers. High bulk density values are found to exist in grassy surface covers, while the lowest values are observed in areas covered by duff/mulch and shrubs. Greater soil water contents are found in shrub surface covers, while areas covered by grass had the lowest value. Total porosity behaves opposite to bulk density, finding the lowest values for shrub areas. Higher amounts of nutrients are related with the presence of herbaceous cover, while low amounts are found in areas covered by shrubs. Surface cover type explained little of the variation in nutrient concentration with the exception of Na.

Significant differences can be seen among city quadrants. The highest soil water content is found in the NE quadrant, which is more than twice that of other areas in the city. The concentrations of K, Ca and Mg are the greatest in the South of the city. The SW quadrant of the city showed soils with higher pH (6.9). The rest of the city is generally acidic. Overall concentrations of heavy metals are insignificant for our limited sampling when compared to the EPA threshold for residential areas (http://www.epa.gov/oppt).

Urban Forests

Structure and composition

The estimated number of trees in Gainesville is 3,000,000. The mean number of trees per plot is 19 and the city has a tree cover of 52.3%. Trees with diameters between 2.5 cm and 6 cm account for 28% of all trees. The mean diameter at breast height (DBH) was 17 cm with a maximum diameter of 63 cm. Larger diameters are found in *Quercus virginiana (Mill)* (live oak) () and *Liquidambar styraciflua (L.)* (sweetgum), 99 cm and 90 cm respectively. Mean tree height is 10 m with a maximum of 25 m. The tallest trees are *Pinus* sp. and *Quercus laurifolia (Michx)* (laurel oak). The three most common species are slash pine (13.3%), laurel oak (11.9%) and water oak (6.4%) and the 10 most common species accounted for 64% of the trees (Figure 2-5). The majority of the plots are composed of a high percentage of native trees (71%) (Table 1-10). In Gainesville around 88% of tree species are native to the state and 10% are exotic species of trees. Leaf area and biomass present high variability across plots.

Most of the variables show high levels of positive correlation to each other (Table 2-11). A strong correlation exists between leaf biomass and tree density. The first three principal components of the PCA for tree structure variables explain 87% of the variance of the data. The first component explains 59%; the second component explains 18% and the third component explains only 8% of the variance. The first principal component did not identify single factors explaining the variance; however the main variables are tree height (0.40), leaf area (0.44) and leaf biomass (0.44). The second principal component shows a positive dominance of DBH (0.67) and a negative influence of tree density (-0.59), whereas the third component shows a value for the eigenvector over 0.8 for native tree species' density in the plot. Dominant ground cover corresponds to herbaceous type (including grasses and herbs) (48.4%) followed by duff or mulch (16.3%).The least abundant types of cover are water and buildings.

Tree mean height is larger in forested areas (13 m) and smaller (8 m) in institutional areas. Variability of tree height is higher in institutional and residential areas. Institutional areas have the highest density of exotic species, whereas forested areas are associated with the highest densities of native tree species. Variability within data is also higher for residential and institutional areas. Higher tree densities are found in vacant and forested areas, while the lowest tree densities are in institutional and residential areas. The highest amount of leaf area occurs in forest areas and plantations. At the plot level, significant differences in leaf area existed among land uses (p-value=0.022). The highest mean leaf area (1,910 m^2/ha) is found in forested areas and the lowest (642 m^2/ha) is in institutional areas.

In land cover, significant differences appeared for all the structure variables. Highest values are found in areas classified as agricultural and bare soil, while the lowest values are found in areas classified as wetlands (Table 2-12).

Native species' abundance differed significantly among city quadrants. The NE quadrant has the highest percentage of native tree species (88%), whereas the SW quadrant shows the lowest percentage (39%). Tree cover is higher in the NE quadrant, whereas the other quadrants' values are similar. The largest DBH for a single tree is found in the SE quadrant, while smaller diameters are found in the SW. Tallest trees are found in the NE. The highest leaf area and leaf biomass is located in the NW and the lowest leaf biomass and area is found in the SE quadrant (Table 2-12).

Function

Variability in the data is low among plots for all the forest functions explored with the exception of VOC's emitted and carbon sequestered and stored. This is evident due to low standard error values (Table 2-13). Net carbon sequestration across Gainesville is 9,885 tons a year; the total amount of stored carbon for the city of Gainesville was 389,843 tons. The species with greatest estimated carbon sequestration are live oak, laurel oak and loblolly pine. For the entire city, the mean net carbon sequestration (accounting for tree death, removal, and subsequent C emissions in forested land uses) is estimated at 1.5 tons of carbon per year per ha. Carbon sequestration estimates are based on DBH, growth and condition. Smaller DBH's and those over 60 cm in DBH size classes for *Pinus* sp. sequester less than trees in the middle range between 20 and 60 cm DBH. Smaller amount of carbon sequestered for DBH class 72 cm is due to the lowest amount of individuals existing in that size class in relation to the other size classes (Figure 2-7).

Since all the pollutants removed depend on tree cover, the correlation matrix shows a direct relationship among them. The CO_2 sequestered and carbon stored also show a strong correlation between each other and among air pollutants.

Upon performing a principal component analysis, the first two components explain most of the variance of the data (92.3% and 5.7% respectively). The first component has no dominance of a factor explaining the variability of the data, all data is positively influencing the variability of the first component, however in the second component, pollutants had a negative influence and carbon and CO_2 are positively influencing the variability.

The highest volatile organic compound (VOC's) emissions estimated are in forested areas followed by vacant areas. Low emissions occur in institutional areas which are related to low densities of trees. The greatest air pollutant concentrations are removed in vacant areas while the lowest in institutional areas. Estimated carbon storage in the different land uses show significant differences due to low tree densities found in institutional areas and very high values for commercial areas. Analysis of tree functions by land cover shows significant differences in all the explored functions. The highest amounts of removal of air pollutants are found in agricultural cover, while the lowest amounts were found in wetland-classified covers. According to city quadrants, the highest emission of VOC's is produced in the NE quadrant, whereas the lowest is in the NW quadrant. Estimates of air pollutant removal, sequestered and stored C are highest in the NE quadrant. Lowest removal of air pollutants and lowest levels of carbon sequestration occurred in the SE quadrant. Carbon storage estimates are significantly lower in the SW quadrant.

Soil-Tree Relationships

Carbon sequestration and carbon storage were positively correlated with bulk density and organic matter respectively. Leaf biomass and leaf area are related with the same soil variables. Positive relationships occur with water content, total porosity and the content of soil organic matter and negative relationships are evident in more acidic sites which show lower amounts of biomass and leaf area. Significant relationships between soil and tree properties are shown in Figure 2-10.

Soil-Tree-Socioeconomic Relationships

In general the correlation matrix did not show statistical correlations that are biologically realistic. Some significant relationships do exist. The carbon sequestered and stored is related with the average age of the inhabitants of the property. The water content is positively related with the years since the property was developed, and the concentration of Na and the organic matter content is positively related with the proportion of Whites.

Discussion

Socioeconomics

Population in Gainesville has increased by 11% during the last 6 years, and the city has expanded from 124.3 km^2 to 140 km^2 (US Census Bureau, 2008). The expansion of the city towards the edges has had an effect on the natural ecosystem with environmental impacts such as reduction in open space, increase of air pollution; increases in energy consumption rates, decreased of landscape aesthetics, reduction in flora and fauna diversity, increased of runoff and flooding, excessive removal of native vegetation, and ecosystem fragmentation (Johnson, 2001).

The biggest changes in land use in recent years have occurred on agricultural and forested areas. Changes in forested areas occur both outside and inside the city limits leading to a change in canopy coverage. During the period from 2000 through 2004, canopy coverage had decreased 9% while building cover has increased about 5% over during the same period (Szantoi et al., 2007).

Socioeconomics in Gainesville is substantially influenced by the presence of the University of Florida. A high percentage of the educated population with advanced degrees living in Gainesville is concentrated in the more expensive areas. Given the large concentrations of student apartments around the University, highly educated people (including non-U.S. citizens) are concentrated in this area (SW). There is a large range in socioeconomic status in Gainesville, with household incomes as low as $25,000 to as high as $86,000 per year. Property values range from $100,000 to more than $1,000,000. The NW quadrant of the city shows the highest variability for socioeconomic variables with old and new properties, suburbs and forested areas, and is currently the main area of city expansion.

Some of the resolution of the data used for the analysis could be giving misleading results. Land use classification and census block information vary in resolution in relation to the plot size. Land use classification was done using a Landsat with a 30x30 m of pixel size (0.09 ha), the census block minimum size is 0.3 ha and a maximum size of 0.37 ha and the area of the plot is 0.04 ha. This may produce flawed results as demonstrated by vacant areas with household income or forested areas with dense populations.

Soils

The mean value for bulk density (1.01 g cm^3) for Gainesville's urban soils are similar to surrounding natural areas (1.21 g cm^3 -1.34 g cm^3) (http://public.ornl.gov/ameriflux/Site_Info/siteInfo.cfm?KEYID=us.slash_pine_mid.01, Gregory et al., 2006). Values for bulk density are within range of other urban areas (Baltimore 0.71 g cm^3 -1.74 g cm^3) (Pouyat et al., 2007). Soil nutrient values were compared with data available from the literature. Whitcomb (1987) recommends necessary soil nutrient concentrations for maintaining landscape trees and when compared to Gainesville, median values for almost all the nutrients were outside the recommended range; 1,663, 27, 79 and 61 mg kg^{-1} respectively. Values of Ca over 1,000 mg kg^{-1} could imply the presence of concrete around the soil sample (de Miguel et al., 1997), due to paved roads or the presence of calcareous limestone parent material (Cooke, 1945). High levels of Ca were found in residential and vacant areas. The Baltimore soil study (Pouyat et al., 2007) obtained comparable Ca values and higher concentrations for K, Mg and P. In Gainesville heavy metal concentrations when compared to other urban studies, is low. Areas with a longer history of urbanization such as Baltimore showed higher mean concentrations of 92, 17.3, 0.56, 2.8 and 100 mg kg^{-1} for Zn, Ni, Cd, Cu and Pb respectively than Gainesville (Short et al., 1986). In general, cities have been found to be sinks for nitrogen and phosphorus, besides some metals (Faerge et al., 2001; Groffman et al., 2004).

In forested areas TKN was highly variable with high values associated with fertilized plantations. Also high variation in TKN can be found in residential areas where the types of surface cover fertilizing regimes are variable among properties. This existence of variability was found in other studies, where more expensive areas showed higher levels of nitrogen (Hope et al., 2005). Differences also were found in residential areas with older properties with concentrations of P and K 45% higher than recently urbanized areas (Scharenbroch et al., 2005). Analyses of surface cover showed high variability in water content where values of duff cover varied in relation to levels of water content (related to the depth of the duff layer), which also leads to high differences in the amount of organic matter and therefore TKN. Highly variable levels of Ca and TKN could be related the existence of impervious surfaces or vegetative surfaces in the plots since concrete makes the soil increase its Ca concentration and vegetation increases the concentration of N in the soil. Differences in organic matter content in relation to surface cover was related to the additions of mulch or leaf litter and herbs to the soil that help increase soil organic matter (Craul, 1999).

High variability of K, Ca, Mg and pH on the different quadrants of the city depended on the existing forest structure, which was highly variable in the NW part of the city. Agriculture and bare soil areas were the ones that showed the worst conditions when compare with tree growth recommendations, whereas urban areas had the highest concentrations of nutrients and were highly variable, similar to forested areas.

Trees

The overall tree density for the City of Gainesville was 475 trees/hectare, greater than that of other cities (McPherson et al, 1994; Nowak et al, 2000; Nowak et al., 2006). Values for Tampa, Florida, were around 257 trees/hectare (Andreu et al., 2008), while cities outside the state such as Minneapolis, MN, Baltimore, MD and Atlanta, GA had densities of 64.7 trees/hectare, 125.5 trees/hectare and 275.5 trees/hectare respectively (Nowak et al., 2006). In comparison to other cities in the U.S, Gainesville had a similar percentage of native species (88%), but more native species than the city of Tampa (50%). High variability in the data could be found in the NW part of Gainesville, especially for leaf biomass and leaf area. Leaf biomass and leaf area variability in vacant, residential and forested areas might be related to the differences in urban structure such as when a land classified as vacant may actually be an abandoned parking lot or a forested area.

Trees in the City of Gainesville sequestered a relatively high amount of carbon. Compared to a city with a similar amount of trees such as Baltimore which has 2.6 million trees and a carbon sequestration a year of 0.98 tons/ha/yr (Nowak et al., 2006), Gainesville showed high values since with 3 million trees sequestered 1.5 tons/ha/yr of carbon. The pollution removal was slightly lower than Baltimore in that 0.021 kg/ha/yr were removed (Nowak et al., 2006) whereas Gainesville only removed 0.020 kg/ha/yr.

The standing stock of tree carbon in Gainesville was 0.006 tons/m^2 of tree cover, whereas in Baltimore the stock was just 0.003 tons/m^2 (Nowak et al., 2006). The composition of Gainesville by quadrants showed differences in the percentage of native species of trees where more exotics can be found in the SW, related to large business areas. This situation is also repeated in institutional areas such as airports, school and parks that are not necessarily incorporating native trees in their landscape.

In vacant areas, high differences in tree density were due to different urban forest structures such as highly forested areas, bare soil or impervious areas. Land cover classification describes the most differences across the landscape, where all the tree variables across the different land cover had significant differences. Tree functions were less variable among land uses, except for vacant areas that were either completely forested or completely deforested, where such high differences in tree cover leads to high differences in VOC's and CO.

Conclusion

Gainesville has a variety of socioeconomics, urban morphology and environmental characteristics, that range from highly urbanized areas to less disturbed areas such as those on the periphery or in very old sections of the city. Given these complexities, beneficial functions –for humans- delivered by the urban forest and its surrounding environment are highly variable and are distributed according to urban morphology and time since the urbanization.

Gainesville is not a highly urbanized city, even though the rates of development have been increasing during recent years. Inside the city limits, tree cover was higher than in many cities in the U.S. Remaining forested areas make soil and forest characteristics similar to values found in natural areas. Highest soil quality, is found in institutional land uses. In terms of surface cover higher soil quality is found in grassy surface covers. The North quadrant shows the best soil quality, where less urbanization has occurred.

The highest calculated rates of air pollution removal are found in the NE quadrant. The size of the average tree in the NE quadrant was above the average for the entire city. This quadrant was also the one with the highest forested land use presence which corresponds to the highest air pollution removals by land use.

Relationships within components of the urban environment were found. Inter-relationships among urban ecosystem components (soil, trees and socioeconomics) were not evident and only soil-tree relationships were found. According to these findings, low levels of soil compaction will allow for adequate increments of leaf biomass and leaf area which is beneficial for maximizing urban forest function, since compacted soils are known to decrease tree functions by restricting root growth (Jim, 1998).

Urban forest management plans should maintain or increase tree cover by the inclusion of a vegetated landscape in new constructions. To maintain adequate soil quality, new constructions should incorporate sustainable management practices such as adding compost as a blanket to smooth the impact of machinery and add an organic layer to the disturbed soil to avoid soil compaction and nutrient deficit (McDonald and Beatty, 2008). These practices will accelerate a process that naturally will be reduced by synergistic processes improving the soil health and quality (Scharenbroch et al., 2005).

Understanding the urban forests and their surrounding environment will help in the recognition of the benefits delivered to the community. These benefits are named ecosystem services and goods, and are the products obtained from the ecosystem that affect the state of human well-being. The information obtained in this chapter could work as a baseline to develop ecosystem functions indicators to assess the condition of the forest existing in an urban area. Once the indicators for the ecosystem functions (regulation, habitat, production and information) are built they could be aggregated in an index of urban ecosystem services and goods.

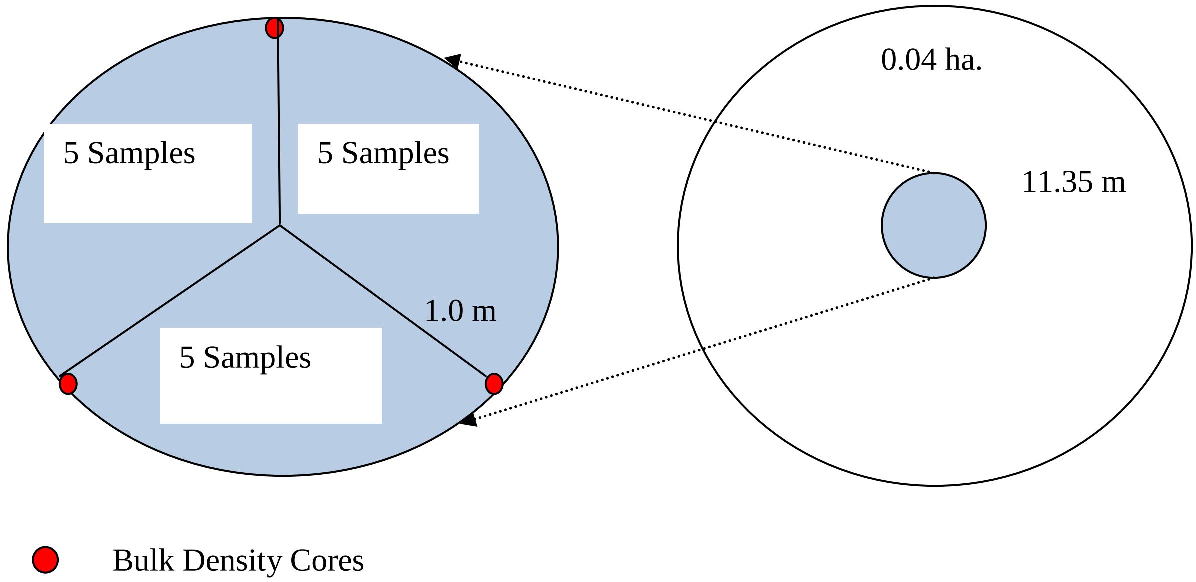

Figure 2-1. Plot layout for soil sampling and vegetation measurements.

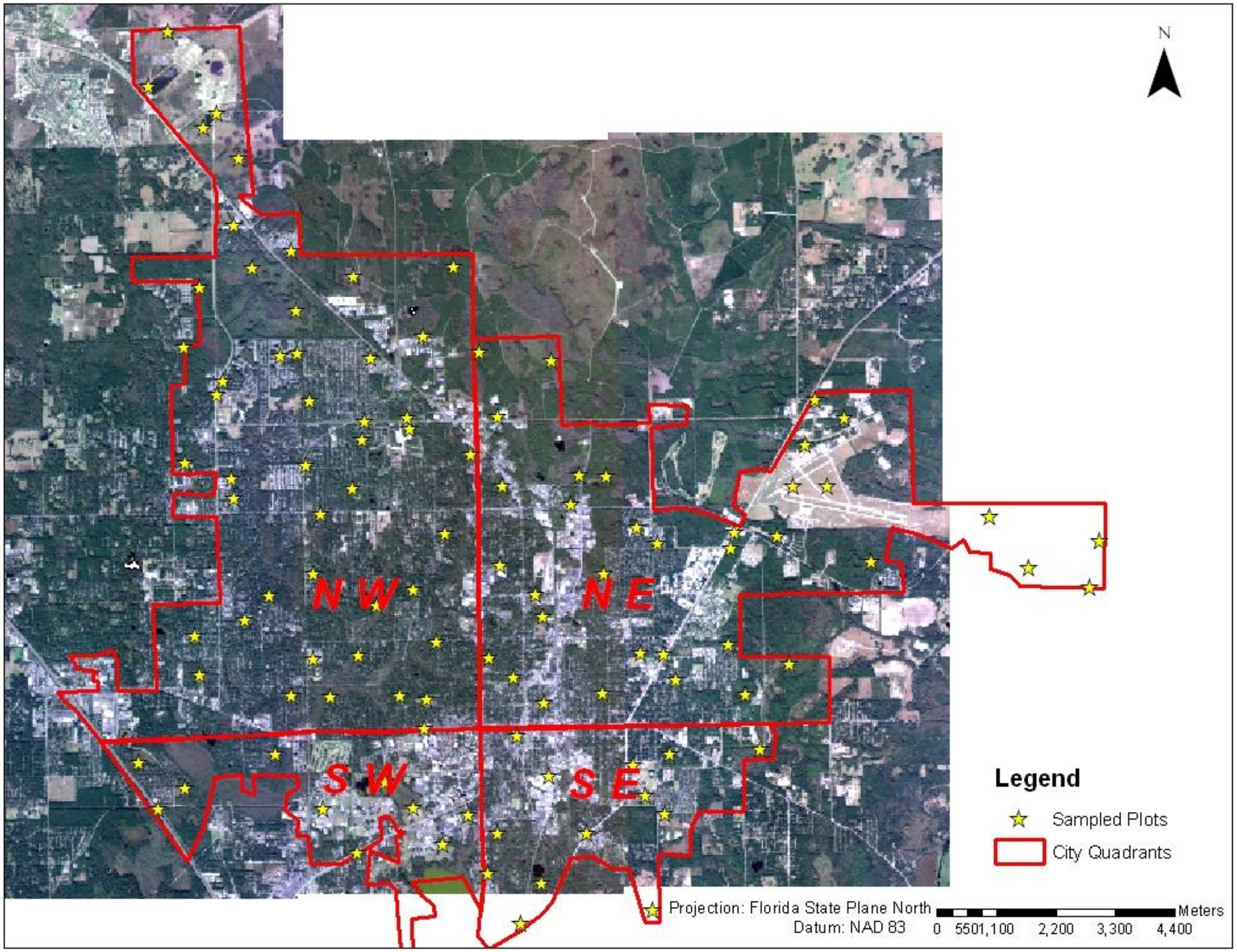

Figure 2-2. Distribution of sampled plots in Gainesville's four city quadrants. Note: imagery are two meter in resolution (2004)

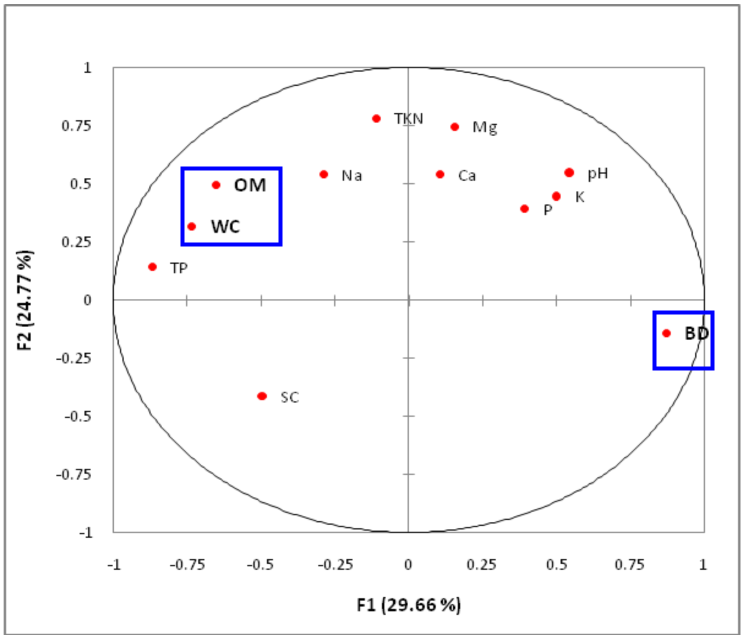

Figure 2-3. Diagram showing positive and negative correlations of the 12 soil variables analyzed for the city of Gainesville. BD Bulk Density, WC Water Content, TP Total Porosity, SC Soil Cover, P Extractable Phosphorus, K Extractable Potassium, Ca Extractable Calcium, Mg Extractable Magnesium, Na Extractable Sodium, TKN Total Kjeldahl Nitrogen, OM % Organic Matter. Note: first (F1) and second (F2) factor derived from the Principal Component Analysis to discriminate plots by land use. Highest correlations are inside the blue square.

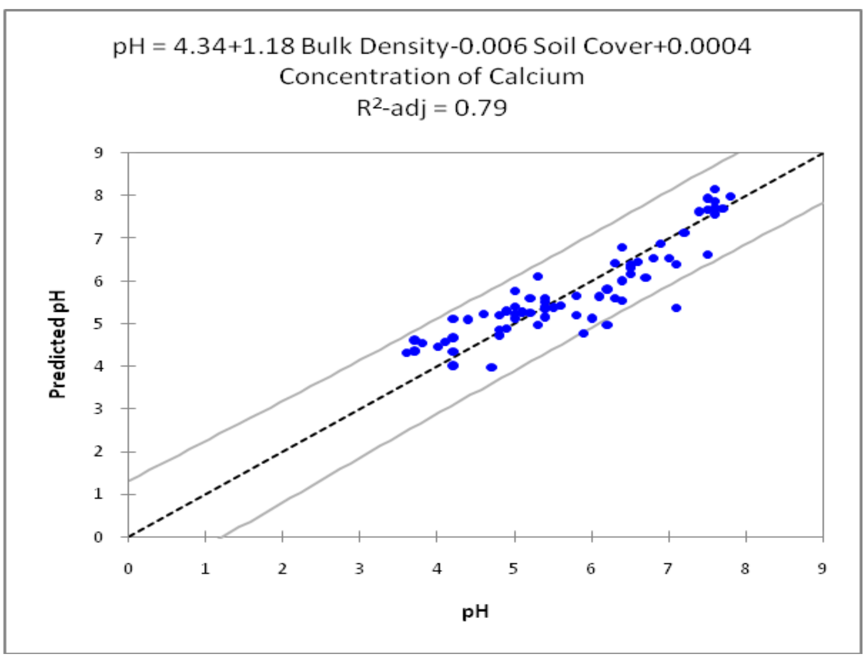

Figure 2-4. Multiple regression model for soil pH of observed vs. predicted values.

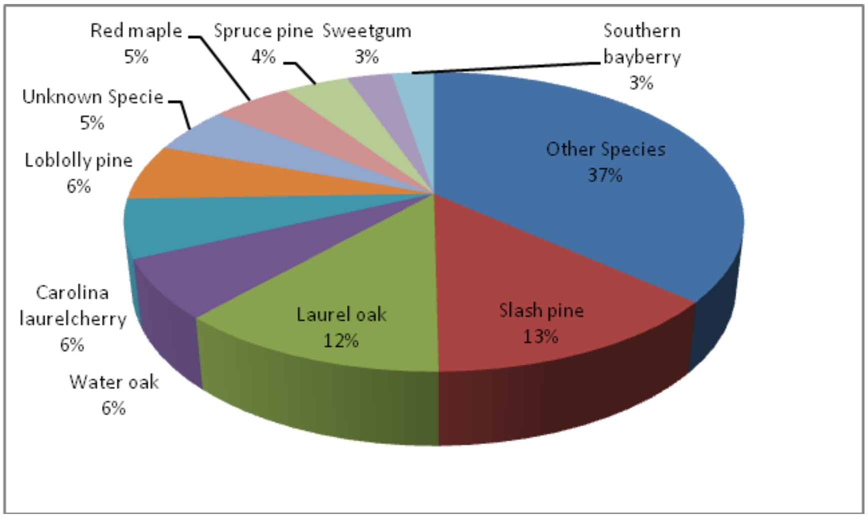

Figure 2-5. Ten most common tree species in the city of Gainesville, FL.

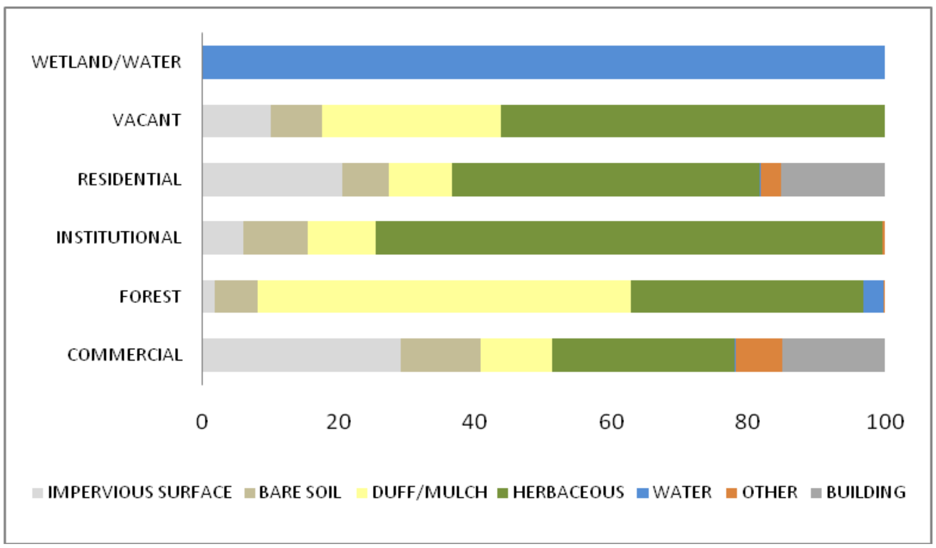

Figure 2-6. Type of land covers (% of the area) by land use for the city of Gainesville, FL.

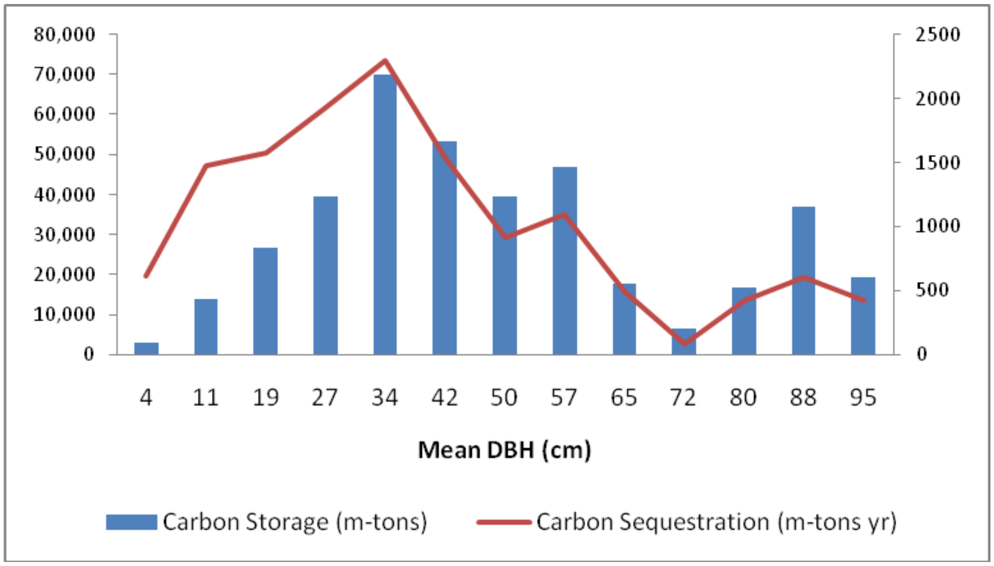

Figure 2-7. Carbon storage and sequestration by mean diameter at breast height in the city of Gainesville, FL.

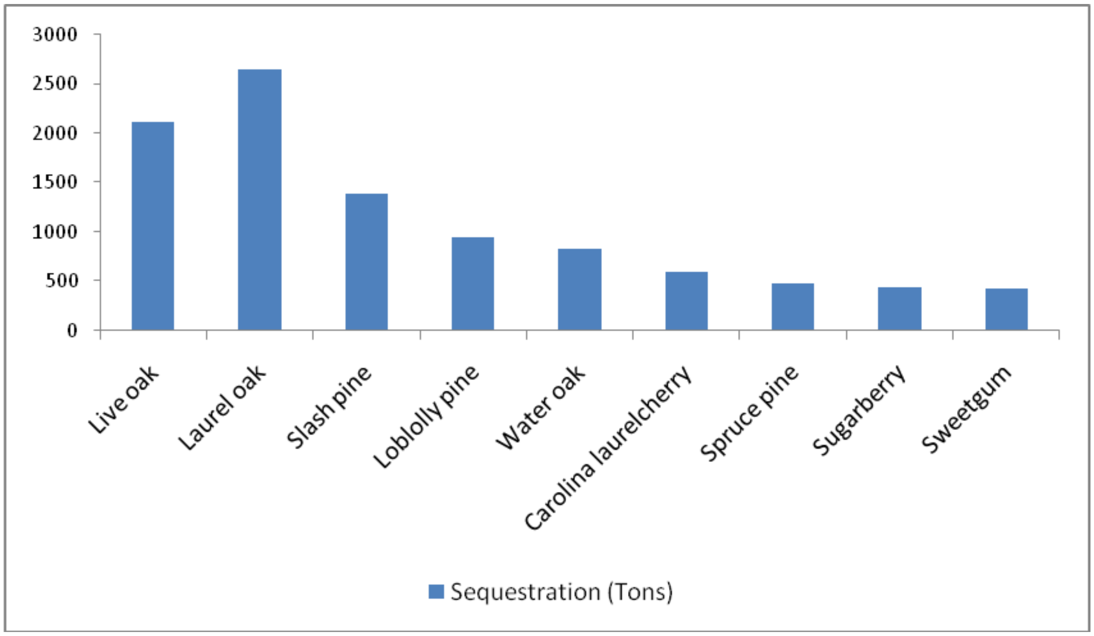

Figure 2-8. Estimated carbon sequestration by species for the city of Gainesville, FL.

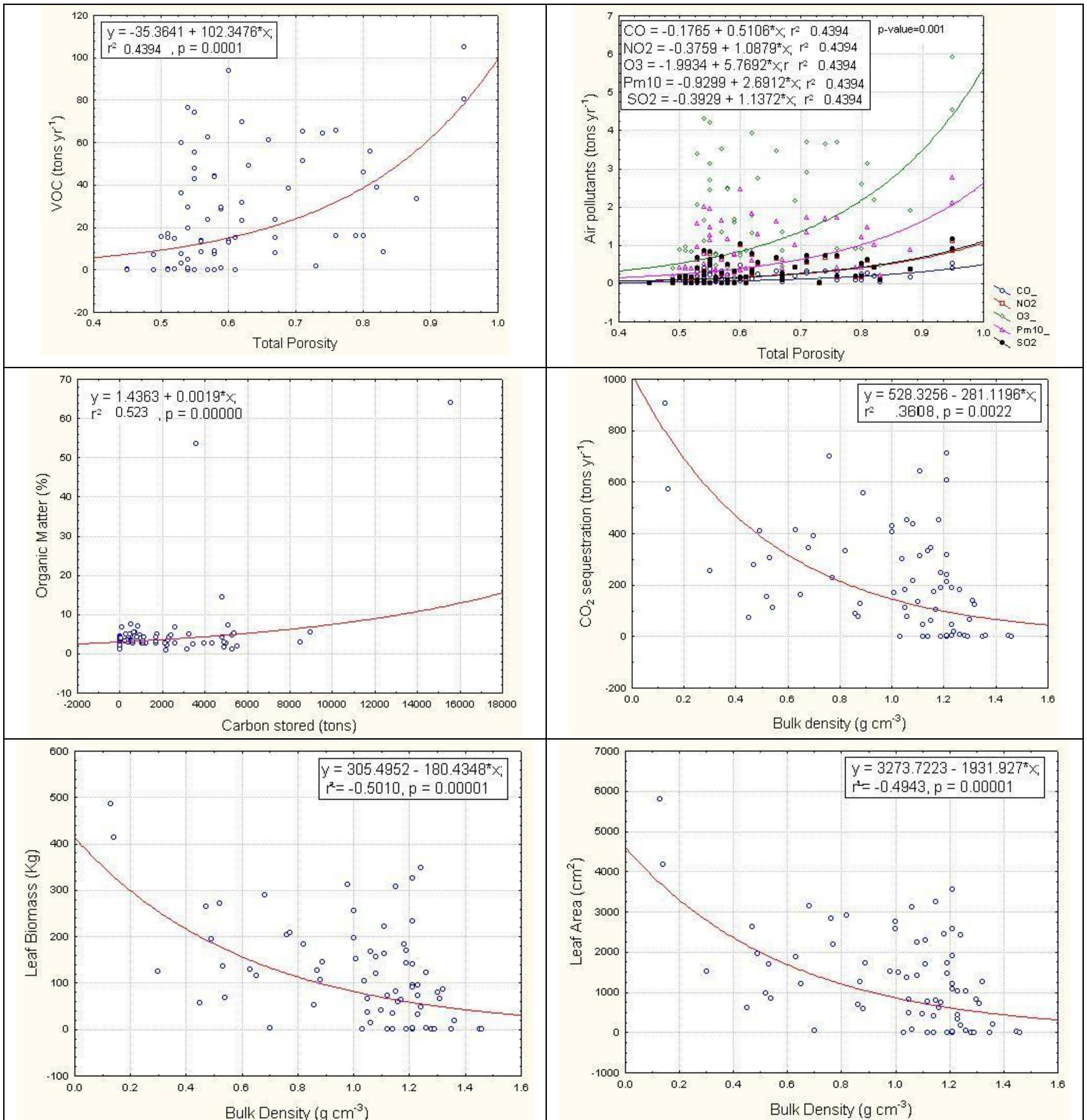

Figure 2-9. Significant correlations (R^2-adj>0.40) for soil-tree relationships in the city of Gainesville, FL. The line in each graph represents the best fit.

Table 2-1. Soil chemical analysis procedures[1]

Test	Soil variable	Procedure
pH		Uses 20 cm^3 of soil sample with 10 ml of pure water to obtain 1:2 soil water ratio and then pH is measured with a ph meter, which has been previously calibrated with the appropriate buffer solution at pH 4.00, 7.00 and 10.00 (Robertson et al., 1999).
Mehlich-1	Macro and Micronutrients	This procedure uses a 4 cm^3 sample of soil and 30 ml of Mehlich-1 extraction solution providing a soil solution ratio of 1:4. The Mehlich-1 extraction is a diluted double acid mixture of 0.0125 M H_2SO_4 and 0.05 M HCL. The mixture is then filtered after shaking for 30 minutes (Robertson et al., 1999).
Loss of Ignition	Organic Matter	The method exposes soils to a high temperature (350°C) in an oxygen atmosphere for a period of at least 2 hours to convert any organic carbon compounds to carbon dioxide and then weighed. This procedure has been reported to be consistent with sandy Florida soils (Mylavarapu and Moon, 2002).
Total Kjeldahl Nitrogen	Nitrogen	Extracts the amount of organic nitrogen in organic materials. It mixes the soil with 2.0 g of Kjeldahl solution and starts the digestion at 250°C in a digester, the 5 ml of Sulfuric Acid are added to the sample, after one hour the temperature is increased to 350°C and then digested for 2.5 to 3.0 hours (Robertson et al., 1999).

[1] Soil Analysis Laboratory University of Florida http://soilslab.ifas.ufl.edu

Table 2-2. Socioeconomic group description by quadrants for the city of Gainesville, Florida[2]

Quadrants		Household income ($)	Median Age (years)	Race	Education
NE	Group 1	34,000	>65	White	High school
	Group 2	30,000	>65	Multi-ethnic	Some high school
NW	Group 1	39,356	<35	Multi-ethnic	Some college education
	Group 2	23,545	<30	Multi-ethnic	College students
	Group 3	28,940	<55	Multi-ethnic	Some college education
	Group 4	50,000	<35	Multi-ethnic	Recently graduate from college
	Group 5	50,000	>65	White	College grads
	Group 6	70,000	<55	Asian-americans	College grads
	Group 7	77,000	35-64	White	Graduate education
	Group 8	50,000	45-64	Multi-ethnic	College grads
	Group 9	60,000	<55	White	College grads

[2] Claritas Socioeconomics 2009 www.claritas.com

Table 2-2. Continued

Quadrants		Household income ($)	Median Age (years)	Race	Education
SE	Group 1	39,356	<35	Multi-ethnic	Some college education
	Group 2	23,545	<30	Multi-ethnic with high concentration of African American	College students
	Group 3	26,000	>65	Multi-ethnic with high concentration of African American	Some high school
	Group 4	23,000	>65	Multi-ethnic with high concentration of African American	Some high school
	Group 5	28,940	<55	Multi-ethnic	Some college education
SW	Group 1	23,545	<35	Multi-ethnic with high concentration of African American	College students
	Group 2	80,000	40’s	Whites	Graduate degrees
	Group 3	60,000	<55	Whites	College grads
	Group 4	28,940	<55	Multi-ethnic	Some college education
	Group 5	33,100	40’s	Multi-ethnic	High school

Table 2-3. Descriptive statistics for socioeconomics of plots sampled in the city of Gainesville, FL by US Census Block (U.S Census Bureau, 2000) (n=70).

Socioeconomic variable	Mean	Min.	Max.	Std. Error	Coefficient of variation	Kolmogorov-Smirnov p-value
Population (habitants)	2,475.3	403	6,287	214.9	72.1	<0.010
Household income (US$)	34,326.9	10,897	86,641	2,029.3	49.1	<0.010
Household (units)	993	200	2,590	98.4	82.3	<0.010
Ownership Household (%)	61.8	0.9	94.5	3.3	45	<0.010
Population with higher level of education (%)	19.4	0	57.3	1.9	85.5	<0.010
White	1,766.6	20	4,980	185.5	87.2	<0.010
African Americans	516.6	3	2,240	57.5	92.4	<0.010
Other	346.1	12	1,158	41.5	100.2	0.004
Population Average age (years)	33.3	20.2	48.2	0.9	23.4	0.017
Property Value ($/acre)	131,344.7	15	7,116,718	192,908	141.6	<0.010
Years since urban development (years)	28.7	0	122	2.47	71.5	<0.010

Table 2-4. Correlation of social variables using the Pearson correlation matrix (α=0.05) for Gainesville, Florida.

	POP	HI	ED	R	YUD	PVAL	PYR	HU	OW
POP	1								
HI	NS	1							
ED	-0.24	0.26	1						
Whites	0.96	0.36	NS	1					
African Americans	0.30	-0.34	NS	NS	1				
Other	0.84	NS	NS	0.82	NS	1			
YUD	NS	NS	NS	NS	NS	NS			
PVAL	NS	NS	NS	NS	NS	NS			
PYR	NS	0.74	NS	NS	-0.35	-0.36	1		
HU	0.96	0.24	NS	0.96	NS	0.82	NS	1	
OW	NS	0.58	NS	NS	NS	-0.44	0.65	NS	1

NS, correlation not significant between variables. POP, population per census block (habitants); HI, household income (US$); HU, household units; OW, ownership of the property by block (%); ED, population with a high education degree (%); R, ethnicity (habitants); PYR, median age in the property (years); PVAL, property value (US$); YUD, years since urban development.

Table 2-5. Mean and ± standard deviations for socioeconomics of the city of Gainesville, FL classified by land use, and city quadrants. Analysis of variance for significant differences among land use and city quadrants (α=0.05).

		POP	HI	HU	OW	ED
Land Use	Commercial (n=10)	3,033±1,733	29,888±14,175	1,480±900.6	70±24.5	21±14
	Forested (n=30)	2,189±1,589	30,356±11,698	750±739	58±26.6	20±17.3
	Institutional (n=15)	1,641±1,543	30,688±16,436	898±568	56±30.7	27±19
	Residential (n=35)	2,934±1,954	41,816±20,335	1,066±905	68±27.6	16±16.2
	Vacant (n=8)	1,051±916	27,039±8,017	1,605±104	24±22	13±11.8
	p-value	NS	NS	NS	NS	NS
Quads	NE (n=35)	2,129±1,439	31,734±16,528	818±638	54±26.4	25±15
	SE (n=13)	2,433±1,382	32,053±17,715	872±765	63±35.9	18±18.7
	NW (n=37)	2,530±1,893	34,053±16,617	1,057±883	63±28.3	14±15.2
	SW (n=10)	3,260±2,415	45,951±16,656	1,348±1,017	78±4.4	29±18.6
	p-value	NS	NS	NS	NS	0.04

NS, not significant at σ=0.05 of probability level. LU, Land Use; Com, commercial; For, forested; Ins, institutional; Res, residential; Vac, vacant. POP, population per census block (habitants); HI, household income (US$); HU, household units; OW, ownership of the property by block (%); ED, population with a high education degree (%); R, race (habitants); PYR, median age in the property (years); PVAL, property value (US$); YUD, years since urban development.

Table 2-5. Continued.

		PYR	PVAL	YUD	R		
					Whites	African Americans	Other
LU	Commercial (n=10)	35±7.9	99,764±1,651,071	15.1±17.9	2,220±1,577	566±433.9	495±313
	Forested (n=30)	33±7.3	1,199,631±1,525,119	33±28.3	1,401±1,372	631±487.5	233±328
	Institutional (n=15)	33±9	1,773,117±1,797,724	32.2±37.1	1,114±1,223	349±385.9	339±398
	Residential (n=35)	34±8	963,553±1,667,258	27.2±15.9	2,270±1,647	427±498	385±341
	Vacant (n=8)	26±5	21,790±17,893	61±86.3	466±169	551±718.4	706±200
	p-value	NS	NS	NS	NS	NS	NS
Quads	NE (n=35)	31±7.6	895,275±1,410,569	37.2±32.8	1,482±1,389	473±479	301±302.7
	SE (n=13)	34±8.1	1,306,912±1,562,192	20.3±21.5	1,624±1,299	622±448	358±331.1
	NW (n=37)	31±8.2	1,641,075±2,401,302	31.2±25.4	1,836±1,633	494±491.8	362±383
	SW (n=10)	37±7.6	322,789±767,248	11.9±13.3	2,435±1,952	615±508	389±360.3
	p-value	NS	0.04	NS	NS	NS	NS

NS, not significant at σ=0.05 of probability level. LU, Land Use; Com, commercial; For, forested; Ins, institutional; Res, residential; Vac, vacant. POP, population per census block (habitants); HI, household income (US$); HU, household units; OW, ownership of the property by block (%); ED, population with a high education degree (%); R, race (habitants); PYR, median age in the property (years); PVAL, property value (US$); YUD, years since urban development.

Table 2-6. Descriptive statistics for soil properties in the upper 10 cm of the surface in the city of Gainesville, Florida (n=70)

Soil Property	Mean	Median	Minimum	Maximum	Standard Error	Coefficient of variation	Kolmogorov-Smirnov p-value
Bulk Density (g/m^3)	1.01	1.12	0.13	1.46	0.04	29.9	<0.010
Water Content (%)	10.99	9.15	0.6	45.7	0.94	71.4	<0.010
Total Porosity	0.62	0.58	0.45	0.95	0.01	18.6	<0.010
Soil Cover (%)	80.37	96.5	5	100	3.19	33.3	<0.010
Extractable P (mg/kg)	61.31	28.52	0.29	538.8	12.06	164.6	<0.010
Extractable K (mg/kg)	27.08	21.22	0	85.36	2.72	84.1	<0.010
Extractable Ca (mg/kg)	1,663.42	652.6	2.07	6232	243.14	122.3	<0.010
Extractable Mg (mg/kg)	78.89	66.18	0	292	8.33	88.4	<0.010
Extractable Na (mg/kg)	19.87	15.63	5.16	101.48	1.76	74.3	<0.010
TKN (mg/kg)	922.10	776.39	117.7	3546.74	65.62	59.5	<0.010
pH	5.76	5.55	3.6	7.8	0.14	20.5	0.04
Organic Matter (%)	5.34	3.19	0.91	64.06	1.13	177.4	<0.010

Table 2-7. Pearson correlation among soil variables (α=0.05)

	BD	WC	TP	SC	P	K	Ca	Mg	Na	TKN	pH	OM
BD	1											
WC	-0.58	1										
TP	-0.99	0.59	1									
SC	NS	NS	NS	1								
P	NS	NS	NS	-0.27	1							
K	NS	NS	-0.24	-0.28	0.37	1						
Ca	NS	NS	NS	NS	NS	0.64	1					
Mg	NS	NS	NS	NS	0.44	0.66	0.62	1				
Na	NS	0.26	NS	NS	NS	0.36	0.56	0.50	1			
TKN	-0.39	0.57	0.38	NS	NS	NS	0.29	0.42	0.27	1		
pH	0.49	NS	NS	-0.35	0.24	0.62	0.82	0.54	0.31	NS	1	
OM	-0.51	0.6	0.51	NS	NS	NS	NS	NS	0.39	0.72	NS	1

NS, correlation not significant between variables. BD, Bulk Density; WC, Water Content; TP, Total Porosity; SC, Soil Cover; P, Extractable Phosphorus; K, Extractable Potassium; Ca, Extractable Calcium; Mg, Extractable Magnesium; Na, Extractable Sodium; TKN, Total Kjeldahl Nitrogen; OM, % Organic Matter.

Table 2-8. Mean and ± standard deviation for soil properties for the city of Gainesville, FL classified by land use, land cover, surface cover and city quadrants. Analysis of variance p-values account for significant differences.

		BD	WC	TP	P	K	Ca
Land Use	Commercial (n=8)	1.2±0.1	9.3±4.5	0.5±0.05	116±166.7	24.3±17.3	1,732±2,111
	Forested (n=25)	0.8±0.3	13.7±9.3	0.7±0.1	12.5±18.6	13.1±14.3	1,020±1,872
	Institutional (n=9)	1.1±0.2	8.6±8.5	0.6±0.08	59.7±73.6	49.7±29.4	3,266±2,404
	Residential (n=25)	1.2±0.1	9.5±6.2	0.6±0.07	95.7±116	33.5±21	1,555±1,659
	Vacant (n=4)	1.2±0.8	14.5±6.7	0.5±0.1	11.7±6.3	27.7±9.9	3,619±3,694
	p-value	0.0002	NS	0.002	0.02	0.03	0.03
Land Cover	Agriculture (n=1)	0.77	9.8	0.71	1.7	10.5	60.1
	Bare Soil (n=2)	1.2±0.01	9.3±3.7	0.56±0.007	1.4±0.09	0±0.3	36.4±8.8
	Wetland (n=3)	1.2±0.2	12.2±6.1	0.5±0.09	15.8±8.4	25.6±7.8	3,017±2,812
	Forest (n=36)	0.9±0.4	12.1±7.5	0.6±0.1	66.9±106.1	26.1±22.8	1,486±1,887
	Urban (n=27)	1.1±0.2	9.6±8.9	0.6±0.08	66.8±105.4	31.6±23.9	1,981±2,200
	p-value	<0.0001	<0.0001	<0.0001	NS	0.004	0.02
Surface Cover	Duff (n=9)	0.6±0.6	15.8±14.9	0.74±1.14	15.1±16	14.5±8.8	814±1,518
	Grass (n=17)	1.2±0.1	7.5±4.8	0.55±0.05	53.4±64	36.5±26.3	2,072±2,300
	Herbs (n=3)	0.7±0.5	15.4±9	0.6±0.3	29.9±40.3	39.8±19.6	4,103±2,863
	Shrub (n=5)	0.5±0.06	21.4±6.4	0.8±0.02	4.1±4.1	7.7±6.4	215±220
	Tree (n=29)	1±0.5	10.3±6.5	0.6±0.09	66.7±107.4	27.3±22.8	1,574±1,860
	Wild Grass (n=5)	1.2±0.01	9±4.8	0.53±0.01	178±267	16.5±12.5	1,234±1,648
	p-value	1.1E-06	0.018	1.26E-06	NS	NS	NS

NS, not significant at σ=0.05 of probability.BD, Bulk Density (g/cm^3); WC, Water Content (%); TP, Total Porosity; SC, Soil Cover (%); P, Concentration of Phosphorus (mg Kg^{-1}); K, Concentration of Potassium (mg Kg^{-1}); Ca, Concentration of Calcium (mg Kg^{-1}); Mg, Concentration of Magnesium (mg Kg^{-1}); Na, Concentration of Sodium (mg Kg^{-1}); TKN, Total Kjeldahl Nitrogen (mg Kg^{-1}); OM, Organic Matter (%).

Table 2-8. Continued.

		BD	WC	TP	P	K	Ca
Quads	NE (n=20)	0.9±0.38	16.5±10.2	0.66±0.1	19.3±28.6	17.1±14.8	1,227.7±2,068
	SE (n=8)	1.1±0.2	7.6±6.7	0.59±0.06	82.2±78.5	42.7±22.2	2,534±1,780
	NW (n=33)	1.1±0.3	8.6±9.9	0.61±0.1	85.6±132.4	22.2±20.7	1,286.6±1,708.9
	SW (n=9)	1.1±0.2	6.4±4.9	0.58±0.06	28±23.7	51.3±29	3,603.8±2,700
	P-value	NS	0.001	NS	NS	0.0001	0.01

NS, not significant at σ=0.05 of probability.BD, Bulk Density (g/cm^3); WC, Water Content (%); TP, Total Porosity; SC, Soil Cover (%); P, Concentration of Phosphorus (mg Kg^{-1}); K, Concentration of Potassium (mg Kg^{-1}); Ca, Concentration of Calcium (mg Kg^{-1}); Mg, Concentration of Magnesium (mg Kg^{-1}); Na, Concentration of Sodium (mg Kg^{-1}); TKN, Total Kjeldahl Nitrogen (mg Kg^{-1}); OM, Organic Matter (%).

Table 2-8. Continued.

		Mg	Na	TKN	pH	OM
Land Use	Commercial (n=8)	86.4±93.7	17.9±9.9	777±358	6.1±1.1	3±0.6
	Forested (n=25)	52.5±67.2	19.8±19.5	953±777	5.1±1.1	8.3±5.5
	Institutional (n=9)	90.4±41	23.1±15.2	711±247	6.7±1.2	3.3±1.5
	Residential (n=25)	98.1±70.1	18.4±9.4	1005±402	5.9±0.8	4±1.4
	Vacant (n=4)	77.8±11.2	32.4±25.2	968±249	6.5±1.5	4.2±0
	p-value	NS	NS	NS	0.002	NS
Land Cover	Agriculture (n=1)	19.2	23.5	400.8	4.2	2.6
	Bare Soil (n=2)	1.7±0.6	5.5±0.03	520.8±407.3	5.2±1.1	2.1±1.4
	Wetland (n=3)	84.8±14.5	28.9±18.8	1006±187.8	6.6±1.1	4.3±0.2
	Forest (n=36)	83.2±78	20.4±16.5	914.5±487.3	5.5±1.2	5.4±8.5
	Urban (n=27)	82.4±62.7	18.3±11.8	960.8±665.1	6.1±1	5.6±11.8
	p-value	0.006	<0.001	<0.0001	<0.0001	NS
Surface Cover	Duff (n=9)	51.1±42.4	19.2±8.3	1183±1,177	4.7±0.9	13.7±24.7
	Grass (n=17)	77.5±55	17.5±9.7	842±316	6.1±1.1	3.6±1.3
	Herbs (n=3)	129.6±59	50.8±43.9	1414±316	6.8±0.7	20.4±29
	Shrub (n=5)	31.6±25	20.6±10	1033±283	4.1±0.5	5.1±1
	Tree (n=29)	83.9±77.8	17.7±11	894±528	5.8±1.1	3.91±2.6
	Wild Grass (n=5)	121.6±147	18.4±15.2	928±100	6.4±1.2	3.7±0.5
	p-value	NS	0.027	NS	0.00063	0.044
Quads	NE (n=20)	55.6±70.4	23.6±22	1082.6±782.7	5.2±1.1	9.5±17
	SE (n=8)	129±74.5	19.4±8.6	1052±575	6.6±0.5	4.8±3.9
	NW (n=33)	70±64.2	17.3±9.5	802±359.5	5.6±1.1	3.6±1.5
	SW (n=9)	118.9±52	23.4±16.5	893.9±443.3	6.9±0.9	3±0.9
	P=value	0.01	NS	NS	0.0008	NS

NS, not significant at σ=0.05 of probability.BD, Bulk Density (g/cm^3); WC, Water Content (%); TP, Total Porosity; SC, Soil Cover (%); P, Concentration of Phosphorus (mg Kg^{-1}); K, Concentration of Potassium (mg Kg^{-1}); Ca, Concentration of Calcium (mg Kg^{-1}); Mg, Concentration of Magnesium (mg Kg^{-1}); Na, Concentration of Sodium (mg Kg^{-1}); TKN, Total Kjeldahl Nitrogen (mg Kg^{-1}); OM, Organic Matter (%).

Table 2-9. Concentrations of soil heavy metals in the upper 10 cm of soils in the city of Gainesville, FL (n = 9).

Soil Property	Mean	Median	Min.	Max.	Std. Error	Kolmogorov-Smirnov p-value	Maximum concentration advise for recreational areas (Thornton, 1991)
Zinc (mg/kg)	5.41	1.21	0.045	38.12	3.67	<0.010	2,300
Copper (mg/kg)	0.37	0.26	0	1.44	0.14	0.101	3.10
Cadmium (mg/kg)	0	0	0	0	0	NA	3.9
Nickel (mg/kg)	0.58	0.30	0	2.14	0.24	<0.010	160
Lead (mg/kg)	0.49	0.005	0	2.97	0.31	<0.010	400

NA, not applicable.

Table 2-10. Descriptive statistics of urban forest structure and composition in the city of Gainesville FL (n=70).

Urban Forest Property	Mean	Median	Min.	Max.	Std. Error	Coefficient of variation	Kolmogorov-Smirnov p-value
Tree cover (%)	52.3	60	0	100	33.4	63.9	<0.010
Mean diameter at breast height (cm)	16.9	15.5	0	62.5	12.5	74.2	<0.010
Mean height (m)	10.1	10.1	0	25.6	6.4	63.1	>0.150*
Density (trees/plot)	19.2	11.5	0	100	19.8	108	<0.010
Native tree species (%)	71.7	82.8	0	100	34.5	48.1	<0.010
Leaf biomass (kg/ha)	122.4	100.2	0	487	109.2	89.2	<0.010
Leaf area (m^2/ha)	1,313.6	1057.9	0	5,805.7	1,184.8	90.2	<0.010

*Mean height fits an exponential distribution.

Table 2-11. Pearson correlation between tree structure variables using the Pearson correlation matrix (α=0.05)

	TC	DBH	TH	TD	NT	LB	LA
TC	1						
DBH	0.38	1					
TH	0.55	0.70	1				
TD	0.45	NS	0.29	1			
NT	0.46	0.39	0.55	0.46	1		
LB	0.55	0.42	0.59	0.61	0.56	1	
LA	0.57	0.36	0.66	0.67	0.52	0.92	1

NS, no significant differences. TC, tree cover; DBH, mean diameter at breast height; HT, mean height; NT, percent of native species; TD, tree density; LB, leaf biomass; LA, leaf area.

Table 2-12. Mean and ± standard deviations for tree structure by land use, land cover and quadrants for the city of Gainesville and ANOVA p-values. Analysis of variance p-values account for significant differences.

		TC	DBH	TH	TD	NT	LB	LA
Land Use	Com (n=10)	46.9±32	16.3±14.8	8±5.4	0.03±0.05	77±33.5	88.9±77.8	995±920.1
	For (n=30)	66.4±32	16.3±6.2	13±4.9	0.08±0.06	91.8±9.9	169.1±116.1	1910±1,334
	Ins (n=15)	31.1±34.5	9.4±12.6	5.8±7.1	0.02±0.03	34.2±44.7	56±110.7	641.9±1,223.4
	Res (n=35)	47.3±31	20.5±15.4	9.8±6.8	0.02±0.02	61.6±33.9	110.4±93.6	1,065.2±826.7
	Vac (n=8)	57.5±45.9	8.4±4.4	6.3±4.8	0.09±0.1	98.5±2.1	128.8±180.9	1,380.3±1,938
	p-value	NS	NS	0.024	1.97E-05	2.63E-05	NS	0.022
Land Cover	Ag. (n=1)	75±0	15.9±0	13.9±0	0.07±0	96.2±0	207.4±0	2,179.1±0
	BSl (n=2)	75±35.5	24.8±2.8	18.5±3.5	0.03±0.03	77.7±25	185.8±173.9	1,997±1,758.9
	Wet (n=3)	45±39.1	12.14±7.1	6.3±3.4	0.06±0.09	79.9±32.2	99.6±137.5	1,072±1,470
	For (n=36)	46.3±35.9	17.1±13.4	10.3±6	0.05±0.05	76.5±32.5	122.8±137.5	1,189.5±1,042
	Urban (n=27)	57.7±29.9	16.4±12.5	9.6±7.1	0.04±0.05	61.9±37.9	116.4±111	1,425±1368
	p-value	<0.0001	<0.0001	<0.0001	0.0008	<0.0001	<0.0001	<0.0001
Quad	NE (n=35)	55.8±31.6	17.8±13.1	12.5±6.1	0.05±0.04	85.7±15.4	110.9±66.8	1,236.9±723.7
	NW (n=37)	51.9±32.7	17.2±12.2	10.4±6.5	0.05±0.05	75.3±33.9	146.9±123.5	1,507.3±1,331
	SE (n=13)	50±38.1	19.3±14.9	8.3±3.5	0.05±0.05	67.6±34.8	58.6±45.4	660.3±514.2
	SW (n=10)	51.1±40.7	11.1±10.9	6.9±7.2	0.04±0.06	38.9±39.3	73.5±85.9	1,020.6±1,193
	p-value	NS	NS	NS	NS	0.01	NS	NS

NS, not significant at σ=0.05 of probability level. TC, total tree cover (%); DBH, mean diameter at breast height (cm); HT, mean height (m); NT, percent of native species (%); TD, tree density (trees/plot); LB, leaf biomass (kg/ha); LA, leaf area (m^2/ha). Quads, quadrants of the city; NE, NorthEast; NW, NorthWest; SE, SouthEast; SW, SouthWest; Com, commercial; For, forested; Ins, institutional; Res, residential; Vac, vacant; Ag, agriculture; Wet, wetland; BS, bare soil.

Table 2-13. Descriptive statistics for urban forest functions estimated per plot in the city of Gainesville, FL (n=70)

Forest function	Mean	Median	Minimum	Maximum	Standard Error	Coefficient of Variation	Kolmogorov-Smirnov p-value
VOC's emitted (kg yr^{-1})	27.6	189.9	0	105.1	3.2	96.3	<0.010
CO removed (kg yr^{-1})	0.14	0.08	0	0.5	0.02	96.3	<0.010
O_3 removed (kg yr^{-1})	1.56	0.91	0	5.9	0.18	96.3	<0.010
SO_2 removed (kg yr^{-1})	0.31	0.18	0	1.17	0.03	96.3	<0.010
NO_2 removed (kg yr^{-1})	0.29	0.17	0	1.11	0.08	96.3	<0.010
Pm10 removed (kg yr^{-1})	0.73	0.08	0	2.77	0.08	96.3	<0.010
C sequestered (kg yr^{-1})	24	10	0	90	24	97.16	<0.010
Carbon stored (kg)	2,100	104	0	15,500	32	126.86	<0.010

VOC, volatile organic compound; CO, carbon monoxide; O_3, ozone; SO_2, sulfur dioxide; NO_2, nitrogen dioxide; Pm_{10}, particulate matter less than 10 microns; C, carbon.

Table 2-14. Mean and ± standard deviation for tree functions for land use, land cover and quadrants for the city of Gainesville and ANOVA p-values. Analysis of variance p-values account for significant differences.

		VOCE	COR	OR	SOR	NOR	PM10R	COS	CS
Land Use	Com (n=10)	22.4±24.2	0.11±0.13	1.26±1.4	0.25±0.27	0.24±0.3	0.6±0.6	23±26	3,400±5,300
	For (n=30)	42.2±29.8	0.21±0.15	2.4±1.7	0.47±0.3	0.45±0.3	1.1±0.8	29±22	1,900±1,900
	Ins (n=15)	15.2±27.6	0.08±0.1	0.86±1.6	0.17±0.3	0.16±0.3	0.39±0.7	13±24	1,500±2,700
	Res (n=35)	18.9±15.6	0.09±0.08	1.1±0.8	0.21±0.2	0.2±0.2	0.49±0.41	24±25	2,100±2,200
	Vac (n=8)	35±49.1	0.17±0.2	1.9±2.8	0.39±0.01	0.37±0.5	0.9±1.3	20±29	1,900±2,800
	p-value	0.009	0.01	0.01	0.01	0.009	0.009	NS	0.032
Land Cover	Ag. (n=1)	51.4±0	0.25±0	2.89±0	0.57±0	0.54±0	1.35±0	23±0	2,100±0
	BSl (n=2)	37.8±34.8	0.19±0.17	2.13±1.9	0.42±0.39	0.40±0.3	0.99±0.91	22±17	2,100±1,500
	Wet (n=3)	25.8±38.2	0.13±0.19	1.45±2.1	0.29±0.42	0.27±0.4	0.68±1	18±21	1,800±2,600
	For (n=36)	25.8±23.8	0.13±0.12	1.45±1.3	0.29±0.42	0.27±0.25	0.68±0.63	22±23	2,000±2,200
	Urban (n=27)	28.8±30.4	0.14±0.15	1.62±1.7	0.32±0.34	0.31±0.2	0.76±0.8	29±26	2,400±3,400
	p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.001	0.008
Quad	NE (n=35)	34.8±28.3	0.17±0.14	1.96±1.6	0.4±0.3	0.36±0.3	0.91±0.7	34±28	2,400±2,900
	NW (n=37)	27.2±26.7	0.14±0.13	1.53±1.5	0.3±0.2	0.29±0.2	0.71±0.7	27±26	2,200±2,900
	SE (n=13)	15.4±16.9	0.08±0.08	0.87±0.9	0.17±0.2	0.16±0.1	0.40±0.4	15±17	2,300±2,100
	SW (n=10)	25.4±29.3	0.13±0.15	1.43±1.6	0.28±0.3	0.27±0.3	0.67±0.8	25±29	900±900
	p-value	NS	NS	NS	NS	NS	NS	NS	<0.001

NS, not significant at σ=0.05 of probability level. VOCE, VOC's emitted (kg yr^{-1}); COR, carbon monoxide removed (kg yr^{-1}); OR, ozone removed (kg yr^{-1}); SOR, sulfur dioxide removed (kg yr^{-1}); NOR, nitrogen dioxide removed (kg yr^{-1}); PM10R, particulate matter over 10 microns removed (kg yr^{-1}); COS, carbon dioxide sequestered (kg yr^{-1}); CS, carbon stored (kg). Quad, quadrants of the city. Com, commercial; For, forested; Ins, institutional; Res, residential; Vac, vacant; Ag, agriculture; Wet, wetland; BS, bare soil.

CHAPTER 3
ECOSYSTEM SERVICE INDICATORS FOR THE CITY OF GAINESVILLE

Introduction

An indicator is a tool for summarizing information about the environmental condition or state of an ecosystem (Segnestam, 2002). An indicator is a numerical value that provides information and describes the state of a phenomenon, environment, or area (OECD, 2001). Indicators have the advantage of reducing dimensionality of data, simplifying interpretations, and facilitating communication between experts and non experts (Segnestam, 2002). Environmental indicators condense information about conditions and may show trends, and provide clues about the conditions or viability of a system, and its state or health (UNEP, 2006).

Human well-being is characterized by the array of biological, sociological, economical, environmental and political factors that humans are exposed to (Tzoulas et al., 2007). The term, “well-being” is usually used when referring to health, from a physical, mental, and social point of view (WHO, 1998). The term can be defined by several socio-economic, psychological and psychosocial variables (Rioux, 2005) and may include feelings of connectivity towards nature (Mayer et al., 2004). The Millennium Ecosystem Assessment (MEA) (2005) refers to human well being as the conjunction between material security, personal freedoms, good social relationships and physical health.

According to Daily (1997),”Ecosystem services are the conditions and processes through which natural ecosystems, and the species that inhabit them, sustain and fulfill human life. These processes produce ecosystem goods and perform the actual life-support functions”. Ecosystem services and goods are defined by the presence of humans which act as drivers on the importance and value given to ecological structure and processes (De Groot et al., 2002; Brown et al., 2007). Ecosystem functions are related to the capacity of natural processes to produce services and goods for human beings. The processes are the result of interactions between biotic and abiotic systems through flow of matter and energy (De Groot et al., 2002).

Thus, ecosystem services are defined by their direct contributions to human well-being. Ecosystem services are therefore end products of nature and ecosystem function because they are enjoyed, consumed or used by humans (Boyd and Wainger, 2002). Ecosystem goods as defined by these authors are tangible material products that result from ecosystem processes and, are key elements for wealth (Brown et al., 2007). De Groot et al. (2002) identified 32 ecosystem services that are considered biological, physical, aesthetic, recreational or cultural. Butler and Oluoch-Kosura, (2006) also identified several cultural, psychological and other non-material benefits that come from contact with nature.

Conversely, ecosystem disservices are related to those processes and structures that have negative consequences on human life. These disservices are characteristic of heavily managed ecosystems such as urban and agricultural (Abenyaga et al., 2008; Lyytimäki et al., 2008; Zhang et al., 2007) and affect how urban areas are experienced, valued, used and developed. Ecosystem disservices become important when they influence the everyday life of urban residents (Lyytimäki et al., 2008). They can also be considered as the negative aspects of the services or functions (Agbenyaga et al., 2008). The perceptions of these disservices will depend on personal preferences. Usually negative services in urban ecosystems have not been taken into account when assessing ecosystem services. For example, increases in pathogen density such as rats, rabbits and raccoons can be considered a dis-service (De Stefano et al., 2005). Personal fears related with security within parks and green areas can be viewed as a dis-service (Koskela and Pain, 2000; Jorgensen and Anthropoulou, 2007). Various health risks such as allergies by pollen can also be classified as a dis-service (Lyytimäki et al., 2008).

An ecosystem is defined as healthy when processes and functions are in a normal range and resilient to stress (Costanza, 1992). The range of normal functioning for disturbed ecosystems such as urban areas cannot be expected to be the same as a natural area since the biophysical environment has been altered. The state of the urban ecosystem should be assessed in terms of how the ecosystem affects human well being. Therefore using indicators as metrics of the condition of service and goods could be a means for expressing the ecosystem services and goods-well being relationship. Problems arise when trying to establish a non-monetary relationship between ecosystem services and human well being (Carpenter et al., 2006).

Trees can provide multiple ecosystem functions and therefore services including reduction of air pollutants, through the functions of dust filtering and respiration. Nevertheless, air quality improvements by tree account for approximately 1% of the pollutants emitted in urban areas (McPherson, 1994; Nowak et al., 2004). Urban air pollution can pose serious risk to human health. Ozone (O_3), for example, increases asthma attacks (Bernstein et al., 2004) and carbon monoxide (CO) affects blood oxygen and fetal development (Hare, 2002). Furthermore, Nitrogen dioxide (NO_2) is involved in the creation of photochemical smog that could cause respiratory problems. Sulfur dioxide (SO_2) concentration in the air can trigger ischemic cardiac events (Sunyer et al., 2003) and asthmatic events (Bernstein et al., 2004). Trees also provide indirect benefits such as cooling of buildings through shading, which may reduce energy consumption (McPherson, 1998).

Trees can also block solar radiation to buildings and other impervious surfaces by reducing the heating and heat storage of those surfaces. The energy reduction could reach savings on energy of up to 12% (Simpson and McPherson, 1996). Urban heat stress could result in increased death due to heat strokes, especially in more vulnerable populations such as children or the elderly. These high temperatures provide a sense of discomfort for people in general (Fukuoka, 1997). Vegetation can reduce the level of noise in cities, which is important because excessive noise can decrease human comfort and can lead to hearing problems (Chen and Jim, 2008).

Urbanization influences hydrological processes by affecting runoff. Increases in impervious surfaces decrease the amount of infiltration and thereby increase flood risk (Booth, 2000; Paul and Meyer, 2001). A reduction in forest cover (e.g. structure) could reduce water retention (e.g. function) and as a consequence produce more frequent and intense flooding events (e.g. ecosystem disservices) (Konrad and Booth, 2002). Increased runoff can decrease water quality by washing off fertilizers such as nitrogen and phosphorus and increasing the concentration of dust particles (Brezonik and Stadelmann, 2002). Storm water runoff implies a higher risk for flooding (Chen and Jim, 2008). Soil organic matter is important for nutrient availability, air and water infiltration, decreased erosion potential and transport and mobilization of pollutants (Knoepp et al., 2000). Also organic matter is highly correlated with nitrogen availability for plants as indicated by Tisdale et al. (1993) and Smethurst (2000).

Biodiversity is a direct source of ecosystem goods and, supplies genetic and biochemical resources, including crops and pharmaceutical products. Biodiversity in natural ecosystems may include many potential new foods. The role of biodiversity is to maintain ecosystem services and functions (MEA, 2005).

Urban ecosystems provide unlimited opportunities for recreation and leisure; they are inspirational, educational, and provide opportunities for reflection and spiritual enrichment (De Groot et al., 2002). The existence of trees and maintained grass could improve human well being by providing the necessary environment for activities such as walking, jogging, cycling or enjoying nature (Matsuoka and Kaplan, 2007). Aesthetics determines the preferences of people to live in pleasant environments which are reflected in economy, since more attractive environments have higher house prices (Costanza et al., 1997; De Groot et al., 2002).

An indicator of the state of an ecosystem can be quantitative or qualitative, thus assessing ecological condition. Ecological indicators combine measurable characteristics of structure, such as habitat or landscape patterns with ecosystem functions and processes (Niemi and McDonald, 2004). Ecological indicators have to be sensitive to the stress of the ecosystem, have a known response to these human stresses, detect changes over time, and facilitate management in response to stress (Dale and Beyeler, 2001). The variables included in the indicator should be easily measured and commonly available, such as data from urban forest inventories. Since variables with multiple-scales and ranges of sensitivity are used, indicators can reflect a wide range of stress levels. The use of indicators provides decision-makers with an evaluation tool for different alternatives to improve the current situation or to decide what management activities are required to maintain the city's services and goods (Singh et al, 2009).

In this thesis, I will develop urban ecosystem services into indicators to assess the state of Gainesville's urban forest. This study will provide a framework to show how the development of indicators could be used to evaluate ecosystem services and goods. These indicators may allow the development of management strategies to improve the health of the ecosystem for different urban forest structures. Services and goods existing in urban areas will be quantified and grouped according to the specific functions of the ecosystem they are fulfilling. Disservices of the urban forest will be recognized as the ones that decrease human well being in urban areas.

Indicators are expected to vary according to urban forest structures and composition. Tree cover is expected to be one of the most influential variables in determining the state of ecosystem services and goods of the urban forest. Also, the indicator is expected to be influenced by different types of urban socioeconomic and morphology factors. Variables such as household income, population density, property values and years since urban development should explain differences in the indicators of ecosystem services and goods.

Methods

Indicators

The study site is the City of Gainesville, previously described in Chapter 2. The indicators for ecosystem services are developed for the 4 groups of ecosystem function defined by de Groot et al. (2002): regulation, habitat, information and production in addition to ecosystem disservices. The values of ecosystem functions are composed of the average of all the ecosystem services that are included in each of the 4 function groups named above. The ecosystem services and goods selected for this study (e.g. maintenance of air quality, provision of habitat, and provisioning of biomass), combine the three definitions of an ecosystem: composition, structure and function that directly affect human well-being. The same method was followed for ecosystem disservices. The categories for each indicator of ecosystem services were established according to the level of delivery of ecosystem services and goods. Therefore, when there were no services or only small amount of services and goods were being delivered, then the category was defined as low and labeled with a number 1. In case of a moderate level of services and goods delivered, the category was named medium and labeled with a number 2. Finally, if a high delivery of ecosystem services and goods was recognized then the category was named high and labeled with a number 3 (Lun et al., 2006). Categories for ecosystem disservices were the opposite (e.g. 1 is low, and 3 is high).

Indicator values and the related ecosystem services were established at the plot level and all pertinent analysis was done at this scale of analysis. The scale differences in this study were addressed by building each indicator with variables at different scales since some of the data have a higher spatial scale. Since this analysis requires the use of multiple scales, variables chosen can be found at the scale of square meters (e.g. leaf area) or can be found as larger geographical units, such as in the case of soil series. These types of studies have been done previously for vegetation and soil analysis, using variables of analysis that occur at different spatial scales (Famiglietti and Wood, 1994; Bellehumeui and Legendre, 1998; Katul et al., 2001; Anderson et al., 2007). A Pearson matrix checked correlation among services of goods included in each ecosystem function.

Urban Forest Ecosystem Services Analyses

- *Urban development* - Plots were analyzed by categories of length of time since urban development (see Chapter 2). Forested areas were associated with zero years since urban development, since they were natural areas or plantations. The first category corresponded to plots with urban development less than 20 years, the second category between 21 and 40 years, the third category between 41 and 60 years, and the fourth category was greater than 61 years since urban development.

- *Land Use* – see Chapter 2.

- *Property value*- see Chapter 2. Values for properties were classified into categories, according to quartiles of the sample. The first group consisted of properties with values per acre less than $12,500, the second group corresponded to properties with values per acre between $12,501 and $210,000 and the third group classifies properties with values per acre over $210,001. To balance the frequency by class the second category aggregates two classes existing between $12,501 and $210,000.

- *Population density*- Analysis was done by classifying the values for Gainesville in four categories based on quartiles. The first category corresponded to densities of less than 953 inhabitants by census block, the second category groups densities between 954 and 1,698 inhabitants; the third category corresponded to densities between 1,699 and 3,503 and the fourth category included plots with over 3,503 inhabitants per census block (U.S Census Bureau, 2000).

- *Income*- Plots were separated by class of household income as determined by the quartiles of the sample. The first group corresponded to incomes of less than $21,000; the second group corresponded to incomes between $21,001 and $32,700; third group from $32,701 to $44,000; and in the fourth group income was over $44,000. Categories were grouped to balance the frequency among categories. Analysis of the indicator was done by comparing results according to the class of household income. Plot value was assigned according to the correspondence to census block.

Household income and population density by census block were chosen for the analysis since they are highly correlated with other social variables, as discussed in Chapter 2. These social variables have been used in other studies that relate urban forests with socioeconomic differences (Iverson and Cook, 2000; Kinzig et al., 2005;

Heynen et al., 2006). City morphology effects had been explored by Anderson and Cordell (1988), Geoghegan et al. (1997) and Tyrväinen (1997) in relation to property value. Kinzig et al., (2005) looked at the effects of years since urban development on plant diversity.

Developing Indicators for Regulation Functions

The processes and characteristics that regulate services in urban ecosystems are listed in Table 3-1 and details concerning the categories used to classify the processes are also discussed. Values at the plot scale for pollution removal were calculated by multiplying tons of pollutants removed estimated at the city level by square meter of tree cover (estimated by the Urban Forest Effects (UFORE) model) using the value of tree cover in each plot (Nowak and Crane, 2000). Categories for air pollutant removal were assigned according to the minimum and maximum value that could be achieved by a single plot. Category 1 (lowest) had the plots with the lowest 10% of air pollutants removal. Category 3 included the plots with the highest 10% of air pollutant removal. The same method was used to assign categories to CO_2 sequestration and temperature reduction. The regulation function is composed of the following functions: gas regulation, climate regulation, disturbance mitigation, water regulation, soil quality, soils health, dust particle filtration and noise reduction.

Gas regulation (maintenance of good air quality)

- *O_3 removed (O3R)* is the amount of O_3 that is removed from the atmosphere by tree leaf surfaces. O_3 is one of the major air pollutants of modern cities (Chen and Jim, 2008), and is formed by the combination of NO_2 and VOC (Nowak, 1994). Removal amount was related to the amount of tree cover in the plot (Table 3-1).

- *CO_2 sequestration (CO2S)* is the amount of CO_2 sequestered per year by the trees in a plot. The value was calculated by the amount of carbon sequestered per year as estimated by the UFORE model (Chapter 1); the values were transformed to CO_2 multiplying them by the factor 3.67 (Blasing et al., 2004) (Table 3-1).

- *CO Removal (COR)* refers to amount of carbon monoxide removed by tree canopy per plot as estimated by UFORE (Chapter 1) (Table 3-1).

- *Capture of SO_2 (SO2C)* amount of sulfur dioxide (SO2) that is captured by trees. The value was estimated using the UFORE model (Chapter 1) (Table 3-1).

- *Capture of NO_2 (NO2C)* amount of nitrogen dioxide captured by trees in the plot, estimated by the UFORE model (Chapter 1) (Table 3-1).

Climate regulation function (maintenance of favorable climate)

- *Temperature reductions by presence of tree (TR)* The estimation of temperature reduction accounts for the effects of shade, wind and evapotranspiration from trees. Temperature reduction was estimated by the UFORE model (Chapter 1). High amounts of temperature reduction by the presence of trees implied a higher delivery of services, resulting in energy use savings due to for cooling effects of trees (Table 3-1).

Disturbance mitigation (storm protection)

- *Tree Density (TD)* number of trees per plot. According to Escobedo et al. (2009), the greater the density of urban trees the lower the amount of tree debris produced by hurricane force winds. Categories were calculated by taking Escobedo et al.'s (2009) tree density by hectare to the size of the plot used in this study (0.04 ha) (Table 3-1). A high tree density implied a higher protection from storms due to decreased generation of tree debris.

- *Percent of dieback (DB)* is the measured tree condition that will result in a higher probability of breakage under a storm or hurricane. Higher percentages of dieback increased the amount of debris that could be produced after a storm increasing the cost for the clean-up (Table 3-1).

Water regulation function (drainage)

- *Storm water Runoff* was calculated using the curve number and soil hydrologic subgroup (Engel et al., 2004). The curve number depends on: land use, hydrological soil group, hydrological condition, management treatment, and the amount of impervious surface. This method has been used in other indicators for urban areas (Whitford et al., 2001). The soil hydrological group depends on the type of soil texture, runoff potential, infiltration and depth of each soil type in the plot (http://websoilsurvey.nrcs.usda.gov). The value for hydrological group was combined with the land use and the percentage of impervious surface of the plot was assigned according to methods outlined in TR-55, thus assigning the appropriate CN curve (Engel et al., 2004). A high value for the indicator means that the potential runoff in that plot is low (Table 3-1).

- *Infiltration* category values were calculated according to the infiltration curve developed by Friedman et al. (2001) for urban areas. Decreased infiltration can cause flooding, pollution of water or decrease of soil health (Chen and Jim, 2008).Infiltration was calculated using soil bulk density values from Chapter 1. The curve relates permeability of the soil with the value of plot soil bulk density. This highest probability of runoff could cause the wash-off of excess nutrients, the accumulation of heavy metals and nutrients in down slope areas such as ponds or lakes, or increase flooding potential in these same areas. The higher the bulk density value, the lower the rate of infiltration which leads to a higher probability of surface runoff (Table 3-1).

Soil productivity (maintenance of soil productivity)

- *Percentage of organic matter (OM)* is the variable used as an indicator for soil quality, since it is related to energy/C storage, as well as water and nutrient retention (Schindelbeck et al., 2008). Values for organic matter were obtained from soil laboratory analysis (Chapter 2). The categories were established according to recommendations for planting trees in urban areas (Craul, 1999) (Table 3-1). High values imply that the owner would not invest in fertilizers to have healthy trees.

- *pH* gives information on soil toxicity and nutrient availability (Schindelbeck et al., 2008). The measures of pH for the plots were obtained from soil lab analysis (See Chapter 2). Plots with a high indicator value were assigned according to neutral pH which implies a high level of fertility (Table 3-1). Recommendations for pH in urban areas were established by Craul (1999). High indicator values for in pH mean less investment on fertilizers.

- *Bulk Density (BD)* values determine how suitable the soil is for adequate plant growth and indicators were calculated from plot-specific field measurements of bulk density (Chapter 2). Thresholds were established according to reference values for ornamental trees from the literature (Mullins, 1991; Craul, 1999) (Table 3-1). Low indicator values may require special management activities that may not incur costs.

Nutrient regulation (maintenance of healthy soils)

- *Nutrients (NU)* refers to the concentration of nutrients in the soil often referred to as soil fertility. Macro nutrients include: phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca). The amount of extractable phosphorus indicates the availability of phosphorus. Nitrogen was not included since only TKN measures were obtained. Furthermore, available nitrogen is only a small fraction of TKN (Schmalzer and Hinkle, 1987, 1996) and is significantly correlated with the percentage of organic matter (Soil analysis Chapter 2; Reiss 2006). Micronutrient levels indicate soil fertility and toxicity (Schindelbeck et al., 2008). Values were obtained from laboratory results from soil sampling (Chapter 2). The categories were established according to the values in Roa et al. (2008) and Heckman (2006), which are used for the level of fertility for urban gardens (Table 3-1). Low categories of nutrients mean low soil fertility, therefore fertilizers should be used to improve the rate of growth and the state of the vegetation in the plot. The use of fertilizers implies a cost.

- *Concentration of heavy metals (HM)* refers to the concentration of: Zn, Cu, Ni, and Pb; Cd was not analyzed. The values for the concentration were assigned an average by land use, due to low variability in the concentration of heavy metals for the City of Gainesville. (Chirenje et al., 2003, 2004). Categories were established according to the highest acceptable concentration for heavy metals in soils used for recreation established by Thornton (1991), since it is related to human health (Table 3-1). Low indicator values were assigned to concentrations that were not acceptable for human health, medium values are lower than the limits acceptable. High values were zero to low concentration, much lower than acceptable limits.

Waste treatment (filtering of dust particles)

- *PM_{10} removal ($Pm_{10}R$)* is the amount of particles greater than 10 microns that a tree can capture in its leaves as calculated by UFORE (Chapter 2). Values in the city were estimated from the average removal of Pm_{10} per square meter of tree cover and this rate in g/m^2 was multiplied by the tree cover of each plot to obtain the Pm_{10} removal per plot. Categories were established following the same method as air pollutant removal (Table 3-1).

Waste treatment (noise reduction)

- *Leaf area and distance (LAD)* is the variable that determines absorption of sound by vegetation (Aylor, 1971). Values were weighed by the distance of the plot to the source of noise. Roads were used as the main source of noise in Gainesville, since noise generated by traffic is one of the main noise nuisance in cities (Ouis, 2001; Theebe, 2004) Leaf area was estimated by UFORE model for every tree existing on each plot, depending on species and sizes (Nowak and Crane, 2000). Categories were established according to the ranges found in Gainesville and distance to the noise source (Table 3-1). A low indicator was assigned to plots with leaf area less than 1000 $m^2$and at any distance from the source of noise (roads). High values account for the opposite effect, where the potential abatement of noise that plot could deliver was higher by having high leaf area and proximity to the source of noise.

- *Dominant type of foliage (FOL)* determines the continuity of noise reduction throughout the year. Evergreen trees should capture more noise than deciduous trees, thus noise abatement is constant in all seasons (Aylor, 1971). Values for this indicator were established according to the percentage of evergreen trees in the plot. The low category was defined when less than 25% of the trees of the plot were evergreen, meaning that the amount of noise reduction is going to be less (Table 3-1).

Developing Indicators for the Habitat Function

Refugium (maintenance of biological and genetic diversity)

- *Shannon diversity index (SD)* was used to characterize tree diversity in each plot using the formula $SD = -\sum_{i=1}^{s} p_i \ ln \ p_i$, where pi is the proportion of species in the i-sampling unit in relation to the total amount of individuals in the sample. This index accounts for richness and evenness. A high diversity indicator implied the existence of a high amount of evenly distributed species (Table 3-2). The existence of a high amount of species may be important since a diverse composition is commonly associated with enhanced ecosystem functions (Jensen et al., 2002; Luck et al., 2003; Elmqvist et al., 2003).

- *Ratio of native tree (RN)* The indicator was developed according to the percentage of native trees on the plot. When more than 75% of the tree species on the plot are native the plot has high value. Values under 25% were classified as having low indicator for the maintenance of biological and genetics. Plots with no trees were classified as having low indicator (Table 3-2). High indicator for this variable would ensure the maintenance of biologic processes and genetics of a certain environment (MEA, 2005).

Developing Indicators for the Production Function

The production of ecosystem goods in urban ecosystem is listed below. Details about the categories used to classify the processes and their effect on human well-being are also mentioned. The linkage to human well-being is the option of using the goods delivered by the ecosystem to meet human wants or needs.

Productivity (goods)

- *Tree Biomass (TB)* was calculated from the carbon storage value obtained from the output of the UFORE model chapter 2. The value of carbon storage for each tree on the plot was multiplied by two to convert it to fresh weight biomass. The biomass of dead trees and green waste was subtracted from the plot value to obtain the live biomass for each plot. The values of the categories were established according to the amount of biomass in a plot (Table 3-3). Low indicator for this service was defined as the plots with the lowest 10% of biomass. The highest indicator was assigned to the plots with the highest 10% of biomass.

- *Ground litter biomass (GB)* is the amount of litter present over the soil to protect against erosion (Bonan, 2002) and provide organic matter. The calculation was done at the plot level, using the depth of the litter in the plot, and then through the density of the litter the weight was obtained. Values were amount of litter by square meter. The categorization was done following the same procedure as the live biomass (Table 3-3). Low values for this service indicate that the soil has very low amounts of litter. Therefore, it contributes to increased investment in soil management.

- *Dead trees biomass (DTB)* is the variable that quantifies the amount of dead trees biomass in each plot. Classifications of dead trees come from on- site observations. Results were calculated the same as the biomass of living trees (Chapter 2). It is assumed that a lower amount of dead biomass increases the quality of the plot in relation to productivity, given to that wood obtained is probably not in good condition and therefore the timber products to harvest are less than if the tree was in good condition. However this is considered a service and not a dis-service because goods can still be obtained from the biomass of dead trees. High values of indicator were assigned to the plots that have values close to zero, when biomass of dead trees is taken into account. Low values, on the other hand, were assigned to the plots that have higher amounts of dead tree biomass (Table 3-3). Residues from dead trees can be used for goods such as fuels for bioenergy and chips for compost.

- *Green waste (GW)* this variable includes the biomass loss through leaf fall and pruning. Leaf fall was calculated from leaf biomass obtained from the output of UFORE model and existing literature. According to the findings by Rowntree and Nowak (1991), 25% of conifer leaves and 90% of hardwood leaves are lost in a year. It is assumed that all trees on plots were pruned. Values were calculated by plot and pruning was obtained based on tree crown area, since previous studies (Ho and McPherson, 1995) estimate the biomass loss by pruning in a year to be 0.081 kg m^{-2}. The total amount of biomass loss by pruning comes from the multiplication of this value with the square meters that each tree covers. A low biomass loss implies a higher value for this service. When, less biomass is lost, less waste management is required and therefore there is less expending of money and investment of hours getting rid of that waste (Table 3-3).

Developing Indicators for the Information Function

Recreation opportunities

The amount of tree cover in the urban environment can be associated with different recreational opportunities according to the level of human use. Lack of trees or maintained grass offers an unsuitable environment for recreation, and therefore does not improve human well-being. A medium amount of tree cover or medium to high amount of maintained grass cover will offer a suitable environment for recreation, leaving space for activities and providing sufficient trees cover to enjoy nature (Parsons, 1995; Kuo et al., 1998; Bjerke et al., 2006). Bjerke et al. (2006) found that densely vegetated scenes receive the highest ratings for recreational purposes, and Kuo et al (1998) found high preferences in areas with densities of 22 trees/acre. Tree density values were weighted by the type of land use in the plot, assuming industrial sites are unfit for recreational purposes.

Aesthetics

- *Replacement value (RV)* includes species, condition, size and location and is related to the expense of replacing a tree. It was calculated by the UFORE model which estimates how much the owner should received as monetary compensation for tree loss (Nowak et al., 2002). The higher the replacement values the more the contribution to aesthetics and increased property value (Table 3-4).
- *Real estate value (REV)* is based on the assumption that the value of the property increases with the presence of trees (des Rosiers et al., 2002) by 3 to 5% (Anderson and Cordell, 1985) and only when the tree cover is 25 to 75% because, more trees eventually become unpleasant (Table 3-4). Values in dollars from the Alachua County Appraisal (http://acpafl.org/) were used, following the same classes of property value previously defined in Chapter 2.

Developing Indicators for Disservices

Because of varying human perceptions of ecosystem processes, urban areas also have ecosystem disservices, such as air pollution due to emission from tree maintenance, decrease of biomass productivity, and negative effects to human health such as allergies from tree pollen. How different ecosystem processes result from different urban forest arrangements and how this relationships produce different levels of these disservices is important in order to have a complete analysis of the state of the ecosystem and to understand socio-ecological system processes (Zhang et al., 2007, Lyytmäki et al., 2008).

Damage to infrastructure and human safety

The existence of trees susceptible to breakage puts at risk the urban infrastructure and the well-being of humans. A high index for this dis-service implies that a high percent of certain species present in a plot have branches or trunks that are highly susceptible to damage (Gilman, 2007). Besides the inherent susceptibility of breakage, the value was weighted by the average tree condition for the plot (Table 3-5).

Allergenicity

The level of allergenicity of each plot was established according to the Ogren Plant Allergy Scale (OPALS) (Ogren, 2000). The value was estimated by the UFORE model, using land use and leaf biomass considering the different characteristics of the plants such as sex, disease resistance, smell (Ogren, 2000), that make them more allergenic. The highest level of allergenicity in a plot refers to a high allergenicity ranking (Table 3-5).

Decrease of air quality

- *CO emitted by trees (COE)* Amount of CO emission by trees estimated by the UFORE model (Nowak et al., 2002). Values were calculated per plot by dividing the total kg of CO emitted by total square meter of tree cover in the city. The CO emissions in kg/m^2 were multiplied by the tree cover existing in each plot. High values for these disservices imply an increase in the concentration of CO in the atmosphere that could have consequences for human health (Table 3-5).

- *O_3 emitted by trees (O_3E)* amount of contribution to ozone formation to the atmosphere by trees and, was estimated using the same method as for carbon monoxide. A high value for these disservices implies higher emissions of ozone and increased in concentrations that could have consequences for human health (Table 3-5).

- *CO_2 emitted by trees (CO_2E)* amount of CO_2 emitted by trees due to decomposition estimated by the UFORE model (Nowak et al., 2002). The emission is calculated by subtracting gross carbon sequestrated and net carbon sequestrated. This value was calculated by plot and is based on the DBH of the trees and land use. Higher values indicate high amounts of CO_2 emissions, therefore increased concentrations in the atmosphere in vacant and forested land uses (Table 3-5).

- *Emission of VOC's (VOCE)* is the amount of volatile organic compounds (VOC's) that are emitted by the trees. The value was estimated the same way as the emissions of CO. A high amount of VOC's could be increasing the production of O_3 (IPCC, 2001), therefore delivering a dis-service (Table 3-5).

- *CO_2 emitted by pruning (CO_2P)* Pruning activities result in CO_2 emissions. To estimate the amount of CO_2 emitted, one pruning per tree per year by plot was assumed with an average emission of 0.81 kg/m^2 (Jo and McPherson, 1995). This value was multiplied by the amount of square meter of trees in the plot (Table 3-5). High values for this indicator imply high emissions of carbon dioxide.

- *CO_2 emitted by mowing (CO_2M)* Mowing activity increase the emission of CO_2 to the atmosphere. Jo and McPherson (1995) suggest mowing emissions values of 113.2 g m^{-2}, were transformed to CO_2 multiplying it by 3.67, thus obtaining an annual emissions of CO_2 of 415.4 g m^{-2} of grass cover. Average of grass cover per plot by land use was measured in the field (Chapter 2 section tree sampling). High values for this indicator implied increased emissions (Table 3-5).

- *VOC's emitted by leaf blower (VOCEL)* the amount of VOC's were calculated based on Shipchandler (2008) value of 11.62 ton/yr/100,000 people for emission of VOC's by the use of a leaf blower. The value for each plot was calculated according to Gainesville's population at the census block level. Higher amounts of emissions implied high level for this indicator (Table 3-5).

- *NO_2 emissions from leaf blower* (NO_2EL) the value of NO_2 emissions was calculated following the same procedure as the VOC's emissions. The emissions of NO_2 found by Schipchandler (2008) were 1.165 tons/yr/100,000 people. A high value for this variable signifies a high level of emission (Table 3-5).

Fruit fall

Fallen fruit can damage infrastructure and property and needs to be cleaned which implies the expending of money and working hours on that activity. The variable was classified as high for dis-service when the dominant species existing in the plot had fleshy fruits including acorns. Low values for this dis-service were assigned when the majority of the species fruits in the plot were hard (Table 3-5). The type of fruit was established from Gilman's (2007) classification of for urban and suburban trees.

Statistical Analyses

A summary statistics table was developed for each ecosystem service indicator. Analyses include a Kolmogorov-Smirnov normality test using SAS UNIVARIATE procedure (SAS Institute, 2007) for each service. A correlation matrix was calculated to check for double counting among indicators for each function. Goods and services were analyzed according to land use, time since urban development, property value, population density per census block, and mean annual household income. The mean indicator value and its standard deviation were calculated. Analyses of Variance (ANOVA's) were performed to check for significant differences (α=0.05) between land uses, time since urban development, property value, population density and household income using PROC ANOVA (SAS Institute, 2007).

Results

Ecosystem Services and Goods Indicators

Regulation function

Indicators for maintenance of good air quality, on average, are medium for the City of Gainesville (Table 3-6). High values are found in 12% of the sampled plots and the minimum indicator value can be found in 5% of the plots. Medium levels occurred for the O_3 removed (Table 3-6). Sequestration of CO_2 is high for the City of Gainesville. Air pollutant removal by trees is similar among all the plots, where the medium indicator is the mean. Maintenance of favorable climate is also medium for the City of Gainesville. Of the sampled plots, 25% have the highest value, reducing in a higher amount of the temperature. Also 25% of the plots present the lowest value where few plots make an improvement effect on temperature.

Maintenance of soil productivity in Gainesville is classified as high. Values for bulk density are appropriate for almost all the plots, indicating low levels of soil compaction. Levels of organic matter in Gainesville are high. Soil pH values are around neutral with the majority between 5 and 7. Some of the plots had more acidic soils with values around 4, usually related to the presence of pine trees. At least 50% of the plots sampled have a high value indicator and 90% have medium to high value for the indicator. Chapter 2 provides specific soil characteristics of the study area.

Drainage for the City of Gainesville is medium, according to this study's definition. Values of the plots varied from medium to medium-high for 43% of the sampled plots. Storm protection for Gainesville qualifies as medium indicator, and only 10% of the sample has a low indicator. Tree cover is high in Gainesville and the percentage of dieback of the sample plots is low; plots with low indicator are related with little to no presence of trees. The service of filtering of dust particles for the City of Gainesville is medium-low. Low indicator values can be found in 50% of the sample plots and only 20% of the plots have high value for this service. The indicator for noise reduction for the City of Gainesville is medium and high indicator values are found in 10 % of the plots and 7% has low values. For the total regulation function, the plots in Gainesville have on average a rank of medium, where 10% of the plots have an overall of high indicator (>2.5), and only 10% have low indicator (<2).

An analysis of indicator values for the regulation function for ecosystem services across time since urban development shows few significant differences (Table 3-7). The time since urban development has an effect on the maintenance of favorable climate. Younger, less developed areas and older areas over 60 years since development have high indicator values. The filtering of dust particles also has significant differences between classes, where low values are found in the middle classes (20 to 60 years) and the highest values corresponded to older areas of the city. The overall trend of the regulation function shows low values for middle classes between 20 to 60 years since urban development. Areas with less than 20 years of urban development, show medium values, while old areas (more than 60 years) have a high indicator for all the services.

When exploring indicators according to land use, more significant differences appeared (Table 3-7). The maintenance of a favorable climate is higher in forested and vacant areas. Storm protection is also high in forested areas, where the presence of trees contributes to this service, but also the fact that those trees are in good condition. Noise reduction is also high for forested areas, even though they are far from the source of noise they could however eventually get closer to noise sources due to urban sprawl. Commercial areas in Gainesville have a high value for this service, since they are near the source of noise and they also have enough leaf area to reduce urban noise. Services related with soil condition do not show the same trend as the previous services. High values are attributed to institutional areas which indicate they might be better irrigated and fertilized. Forested areas have the lowest value which could be related to the presence of large areas covered by pines that reduce organic matter and increase the level of acidity found in less fertile soils. The overall value for the regulation function across land uses is medium. Forested areas are the highest for this function and institutional areas the lowest.

The indicators for the regulation function follow a clear trend across property values (Table 3-7). More expensive areas have lower indicator values for all the services. However services related with soils have higher indicator values. Lower indicators could be related to lower tree densities and the existence of younger trees, since several of these more expensive areas correspond to new urban developments. High soil indicators in more expensive areas could be due to the possibility of using fertilizers in yards, parks or institutional areas. Significant differences are found among soil services for drainage, maintenance of favorable climate and soil productivity. The overall trend for this function is that more expensive areas have higher values than less expensive areas, but their values are generally classified as medium. Household income shows the same trends. More expensive areas have lower indicators than less expensive areas, due to the presence of more trees. No significant differences arise from household income analyses. Population density shows a significant effect in the noise reduction service, where less populated areas has a higher value than more dense areas (Table 3-7). This trend is the same for all the services and the overall function, probably since less populated areas have a lower effect on the state of the ecosystem (Nelson et al., 2009).

Habitat function

The Shannon index for trees in the study area is low, since only 15% of the plots have medium values and no plot had a high value (Table 3-8). The amount of native trees present in Gainesville increased the indicator, since most plots were classified as high, with more than 75% of the species being native. Only 15% of the plots present low values. The habitat function has low values in Gainesville, and no plots present high values. Tree diversity is low and unevenly distributed, but the majority of species are native (Table 3-8).

No significant differences were found among the different years since urbanization of the properties (Table 3-9). Shannon's diversity index does not have significant differences across time since urban development but increases its indicator value in older properties. On the other hand, the amount of native trees increases with time since urban development of the property, which shifts the indicator from a medium value to a high one after 20 years since urbanization. No significant differences were found for the overall function, however the indicator value increases with years since the property was developed.

The diversity index shows low indicator values according to land uses, and significant differences were found in all explored variables at $\alpha=0.05$ (Table 3-9). The ratio of native trees in the plot varies by land use; institutional areas show the lowest whereas forested and vacant areas have the highest indicator. In general, the overall indicator of the habitat function is low-medium through all land uses. Vacant land use has the highest value, while institutional land use shows the lowest value for the function. The habitat function shows significant differences across land uses (Table 3-9), probably due to differences between vacant and institutional areas.

No significant differences can be seen in any of the services ($\alpha=0.05$) when differences are explored among different property values (Table 3-9). However a general trend can be distinguished where less expensive areas have a higher indicator. Diversity index is the lowest for areas that are more expensive, while the highest values are for the less expensive areas even though differences were not significant. The ratio of native trees follows a similar trend. Population density does not show any particular trend across the habitat function indicator, and no significant differences arose (Table 3-

9). A small increase of the indicator for all the variables can be seen with the increase of household income. Shannon’s diversity is low for all household income classes, and the ratio of natives for the indicator is quite different, moving towards high values for all the classes.

Production function

Biomass production is medium for the City of Gainesville. High indicator values (>2.5) are found in 10% of the plots, while 10% show the lowest value. Biomass of trees has a low value on average, according to the categorization of this study where 25% of the sampled plots have the lowest value (1). Ground biomass has as mean high value, with 50% of the plots having a value of 3 and only 1% having the lowest indicator value. Only 10% of the plots have the lowest value, whereas more than 50% of the plots have all of their trees alive. Green waste biomass has a low indicator implying that a big amount of waste could be produced. Only 10% of the plots present a high value, while more than 50% of the plots have a low indicator.

The overall production function does not show significant differences in services or goods across time, except for ground biomass (Table 3-11). Biomass of live trees decreases with time since the property was developed but always maintains a low indicator, between 1.5-1.8. The other goods that can be obtained from the urban forest follow the same trend. There is an increase of the indicator with the older developed properties, and decreases for properties over 60 years since they were developed. Highest indicator values for the production function are for plots that are between 40 and 60 years where older trees are in good condition. In terms of goods, the highest indicator is achieved by the soil biomass.

All goods across land uses in the productivity function show significant differences (α=0.05). The live tree biomass indicator is obviously higher in forested plots and the lowest in institutional areas. Values of the indicator for this good varied from medium to low. Lower indicators exist in forested areas qualifying them as medium, which is probably related to the existence of pine plantation or natural pine forests that have less litter. A low amount of dead biomass is found in residential and institutional areas, where trees were probably removed. Vacant and forested areas increase in the amount of dead trees decreasing the indicator to a medium value. Green waste shows the lowest value in forested areas which is, principally related to the existence of natural forests that produce higher amounts of waste. Areas where trees receive management treatments produce lesser amounts of leaf waste and require less pruning, therefore achieving a higher indicator.

The general trend followed by the production function indicator is that increases in property value increase the value of the indicator, but differences are not significant (α=0.05). Significant differences for the production function and dead tree biomass do exist across household incomes categories (Table 3-11). There is a small decrease of the indicator from the lowest income to incomes less than US$44,000. The indicator increases for the highest income category. The same trend exists for the other goods, but no significant differences appear among indicators.

Information function

Forested areas, residential areas and institutional areas (all of which include parks) have the highest value for the indicator, while industrial/commercial areas have the smallest values because they do not offer proper places for recreation. Vacant areas have a medium value since potentially they can be transformed to a recreational opportunity area, which in this case was assumed to be to a park (Table 3-4). Recreational opportunities in forested areas are medium for less than 10% of the plots. Most of the plots show high indicator values with a high average indicator. Aesthetics have a lower average value than recreation. The 25% of the plots have the highest value and also a 25% have the lower indicator values, which includes 1% of the plots with an indicator of 1 (Table 3-12). The higher indicator for real estate value is in more affluent areas. Less affluent areas are not related to low replacement values since they have several natural areas and therefore higher tree cover. Areas with medium real estate values have the lowest replacement indicator values which are related to fewer amounts of trees. The overall value for the information function is medium (Table 3-12), where 10% of the plots are concentrated in the highest value for the indicator and 25% showed the lowest values.

Recreation in institutional areas has on average a high indicator, but 40% of the plots have medium values. Residential areas have a high variability in recreation opportunities, 5% of the plots have a low indicator, while 50% of them have a high value showing a suitable vegetation structure for recreation. Vacant areas that could be transformed to recreational areas have low values, since the tree cover is over 75% and no maintained grass was found in the plots. Independent from their tree or grass cover, commercial areas are defined as not suitable for recreational opportunities so the lowest value was assigned. As an overall indicator for recreation service, 25% of the plots have the highest indicator and only 10% have the lowest indicator. Significant differences appear among land uses for aesthetics (Table 3-13). Aesthetics is highest in residential areas, where values of real estate are high assuming the presence of trees increases their value. Forested areas have the lowest indicator since they are not perceived as places to live. Overall the information function has a medium indicator for all the plots, with the highest values located in residential land uses and the lowest in forested areas.

Recreation indicators are not affected by the age of the property during the first 60 years since urbanization and have an indicator value of medium. There is a decrease in value for the recreation indicator in plots with more than 60 years of being urbanized (Table 3-13). Aesthetics slightly increase in the indicator value along the first 60 years, and decrease again when plots are over 60 years since urbanization. Differences across years are not significant. (Table 3-13).

Property values show a significant trend in aesthetics and the overall information function. Increases in the value of the property leads to an increase in indicator values from low to medium. No significant differences arose with population density. The indicator is medium for the information function and slightly decreases in densely populated areas. The same trend can be seen in recreational opportunities with the increase of household income, even though no significant differences appear (Table 3-13). Aesthetics and the information function had almost the same values for all the household income categories.

Disservices

The overall indicator for disservices is medium. Only 3% of the plots show a high value for the overall disservices. Of the sampled plots 5% have values with low disservices (Table 3-14). When performing the correlation matrix, no relationships were found between the different disservices. The dis-service that has on average the highest indicator is the decrease of air quality. The VOC's and CO_2 emitted by pruning are the variables increasing the average indicator for this dis-service. This indicates that several species in Gainesville produce high amounts of VOC's. Also, CO_2 released is probably overestimated since it was assumed that all trees in the plot were pruned, which is not likely. For decreases in air quality, the less significant emissions corresponded to NO_2 emissions by leaf blowers. The total indicator for decreases in air quality shows that 25% of the sampled plots have high indicator values, while only 10% of the sampled plots have a low category.

Fruit fall is the dis-service that has the least negative effect since 50% of the sampled plots show the lowest value for this dis-service while only 5% have the highest value. This is showing that the majority of the trees in Gainesville do not have fleshy fruits that could be making inhabitants spend resources and time cleaning streets or yards. Allergenicity for the entire city has medium indicator. All the land uses are qualified as medium since their range spans 5 to 7 on the OPALS scale, with 10 being the highest value of allergenicity (Table 3-14). A relationship of the allergenicity level to tree cover could probably improve results. The damage to infrastructure indicator is low. The majority of the plots present conditions that should keep damages to a minimum in the case of a disturbance. However 25% of the sampled plots present a high value which implies that there is a high probability for those plots to cause damage to infrastructure or humans in the cases of natural disturbances.

When years since urban development and land use were analyzed, no significant differences arose (Table 3-15). The value of the overall dis-service maintains a medium value. Highest reductions of the indicator occur in vacant areas especially by the effect of the increase of air pollutants and the possibility of damage to infrastructure and humans in the case of a windstorm.

Property values show that an increase in the price per acre results in a lower indicator for aesthetics, which implies a minor decrease of ecosystem services. Significant differences occur only for damage to infrastructure and humans where affluent areas have lower risks of causing damage. The only different trend is for fruit fall, where more expensive properties have a higher amount of trees with fleshy fruits. Neither particular trends nor significant differences can be seen in the variation of disservices according to population density. Overall disservices show a medium indicator value. Household income behaves similarly to property value, in that the higher the household income the slightly lower the indicator becomes. No significant differences appear for household income (Table 3-15).

Discussion

Comparing Functions

Regulation, habitat, information and productivity functions for the City of Gainesville have medium to medium-low indicators across all plots (Table 3-16). The habitat function presents the lowest value, while the regulation function has the highest one. Productivity and information functions behave the same as the regulation function and the overall average is low-medium. In the case of disservices the highest amounts of values are found in the medium-low category (Figure 3-1).

Ecosystem Services and Goods Analyses

Regulation function

The city of Gainesville is densely forested and temperatures may be milder than urbanized landscape of other climates and larger areas of impervious surfaces. The presence of a high tree cover could be providing the service of climate amelioration. In hot areas, an increase in canopy cover of 10% could reduce the temperature of a city in

1.4°C (Konijnendijk et al., 2005), also in Phoenix, AZ a decrease of 0.28°C in an early summer day was associated with greater vegetation cover (Jenerette et al., 2007). The calculation of this service could be improved by increasing the resolution of the estimations of temperature reduction and linking those reductions to tree cover instead of land use. This could cause an increase in undesirable factors such as: summertime peak energy demand, air conditioning costs, air pollution and greenhouse gas emissions and water quality infringements (EPA, 2008).

The City of Gainesville has relatively low air pollution. Levels of ozone and carbon monoxide removal in Gainesville are close to the ozone removals obtained in Jacksonville, FL. The amount of SO_2 removed is around the average for the country (Nowak et al., 2006). In general, areas with higher tree coverage capture more air pollutants and CO2 than areas with less tree cover; forested and vacant areas, very young or very old areas, and less affluent areas have a better indicator since they consist on denser urban forests.

Maintenance of soil quality is related to fertility, and therefore plant growth. Values for city of Gainesville for bulk density seem to be appropriate for plants to have suitable conditions to grow. Levels of organic matter in Gainesville are high, probably due to the presence of several areas that are not urbanized and the high level of tree cover.

Nutrients in Gainesville are inside the recommended ranges for optimal ornamental tree growth. Phosphorus levels are over the optimum range for fertilization regimes that could lead to wash off and become not available for plants. The presence of high levels of calcium and phosphorus could be related to the Hawthorne Formation (Gilliand, 1976). Usually areas with a longer history of urbanization have better soil services (Scharenbroch et al., 2005) since they have been subjected to fertilization over the years, compensating for the lack of nutrients existing in undisturbed areas (forested and vacant land uses). As this study only used soil physical and chemical properties in the indicator, more complete measurements of soil biota should be incorporated since they are the key to understanding the interaction between physical and chemical interactions within the soils (Ritz et al., 2009). Also information on soil fertilization regimes could help in understanding the drivers of nutrient concentrations.

The service of filtering dust particles had high values in forested areas. This could be related to high leaf area. The lowest values for institutional areas could be related to a low tree density. This service in the City of Gainesville probably does not have high importance, since this area does not have problems with dust particles. In a semi-arid area PM10 can become a problem and the indicator for this service become important. An increase in the accuracy of the valuation for this service could be obtained by weighting the indicator by the distance to the source of pollution, which is also a more efficient method. If a tree is by itself or is part of a group of trees, this could increase accuracy, since single trees filter less than trees in groups (Nowak et al., 2006). The storm protection service is probably more important in some cities than others. A survey done in Hillsborough County, FL, points out that one of the highest costs perceived from urban forests is the damage of trees caused by hurricanes (Escobedo et al., 2008). Alternatively, the results of a National survey do not show hurricane-related damage to urban forests as a main cost of urban trees (Lohr et al., 2004). Gainesville is a city that is frequently threatened by strong wind storms or hurricanes. Attention should therefore be given to increase this service so that, trees can be managed to maximize storm protection and decrease the risk of damage to humans and infrastructure.

Habitat function

Usually cities increase in tree species diversity with urbanization, due to the introduction of exotic species (Zipperer, 2002). Gainesville has maintained a high percentage of native trees. Several of the plots were found in remnant forested land covers located in the middle of the city, and therefore the ratio of native to non-native tree species is high. This phenomenon is not typical of more urbanized cities. Older properties have higher diversity indices probably related to the presence of ornamental species that are usually non-native. The same happens in newer areas where new constructions include non native species as ornamental trees. The increase of the number of native species through the years of urban development could depend on existing trends in ornamental trees. It could be that 20 years ago when several of these properties were built the use of no native species as ornamental trees was the trend. The ratio of native trees in the plot varies by land uses. Low values for native trees could be due to the inclusion of exotic species for ornamental use in institutional areas, parks or residential areas.

Production function

The production of goods is probably not seen as important in Gainesville, but the use of green waste tree material could imply revenues for home owners or institutions. Waste from trees can be transformed to firewood, chips or mulch, or possibly even turned into larger wood products (Plumb et al., 1999). The recycling of green waste could reduce the environmental and economic costs related to landfill disposal (McPherson, 2006), especially after storm disturbances. The accuracy level of the indicator could be improved by taking out of the analysis the plots corresponding to natural areas or plantations since waste from those areas are used in different ways or are not used at all. Accuracy could also be improved by surveying landowners to determine if management activities such as pruning are applied to trees on the plots.

Information function

The valuation of recreational and aesthetics services of urban forests needs to include the different types of users that can be found in a city (Matsuoka and Kaplan, 2008). Improvements to this indicator should be done by collecting information about the preferences of people in terms of the different structural arrangements that urban forest can provide. In one example, forested areas could be good for outdoor activities, while public parks could be used to play sports or for children to play. Values for pleasure that urban trees deliver also should be included. Effects of the presence of trees on the emotional and psychological states of inhabitants should be explored in more detail.

Disservices

Each ecosystem function has associated disservices, and the valuation of these disservices should be established according to what the inhabitants of a city consider as relevant to decreases in their well-being. The priority of these disservices will depend on the economical and sociological contexts of the city, and what their environmental priorities are (e.g. polluted cities with low risk of hurricanes will probably give more importance to the decrease of air quality than to the damage to infrastructure). Disservices such as hurricane damage by trees, habitat suitability for the existence and movement of biological vectors, crime-related fears associated with treed landscapes, and other nuisances should be considered. More research on the environmental costs related to the existence of urban forests is necessary. Differing structure and composition of urban forests will deliver different types and amounts of disservices. Management plans should look towards the finding of the better structures of urban forests to minimize dis-service while maximizing the urban forest functions that increase services and goods.

Conclusion

These proposed indicators can be used to depict the environmental state of a plot or site in terms of the services and goods it can deliver in the City of Gainesville, Florida. Since the indicators for each function are an aggregate of services, the drivers of change of these services can potentially be identified. This could help in evaluating policies related to urban forests or management regimes that have been applied in the city. Also the information obtained from the indicators could be useful to prioritize management objectives associated with certain services or goods. Clearly the inclusion of additional services and disservices is necessary to have a better picture of the environmental state of a city.

Once urban forest data has been obtained, the calculation of the indicator is repeatable and easy to compute and results are simple numbers that are suitable and understandable for comparison. This study's results are in agreement with Whitford et al. (2001) that, the ecological state of a city depends heavily on the state of the urban trees. The establishment of indicators could help in the understanding development regimes and their impact on ecosystem services and goods.

An analysis of different years since the plots were urbanized could help in forecasting the future values of the indicators, but heterogeneity between plots is too great in terms of structure and composition. Shifts in land use deliver a randomness factor related with changes in urban planning policies and human behavior that could limit forecasting. The indicators are useful to show the present condition of representative plots in relation to ecosystem services, and to derive from them which structural arrangement of urban forests deliver the best indicator values for ecosystem services and the lowest indicator value for disservices. Forecasts of the change in the indicator by plot could only be done by assuming that human behavior and conditions of the plot will remain the same. The indicator would then change if a certain management regime is applied to the different urban forests structure to maximize ecosystem services. Future predictions of the indicator for changes in land use or major changes in the plot would almost certainly give results low in accuracy.

The use of the indicator to compare cities should also be done carefully, since indicator categories were established using the distribution of Gainesville-specific results, such as air pollutants emissions and removal. To compare values standardization of the air pollution values should be done before assigning an indicator category (Saisana et al., 2005). Another constraint is that the indicator will depend on the type of city and whether it is large or small, and more or less economically developed. The value that citizens give to the different services will be likely different.

The use of indicators in evaluating ecosystem services is a useful tool since it provides a snapshot of the environmental state of a city. The indicators developed here are based on available urban forest and soils data as well as extraction of some of the key drivers of urban ecosystem services. These indicators could be used as tools to communicate to the public the conditions of the services in the city, given an awareness of what information was included and the significance is explained. This could be used to develop policies of urban planning in concordance with the delivery or improvement of ecosystem services provided by urban forests.

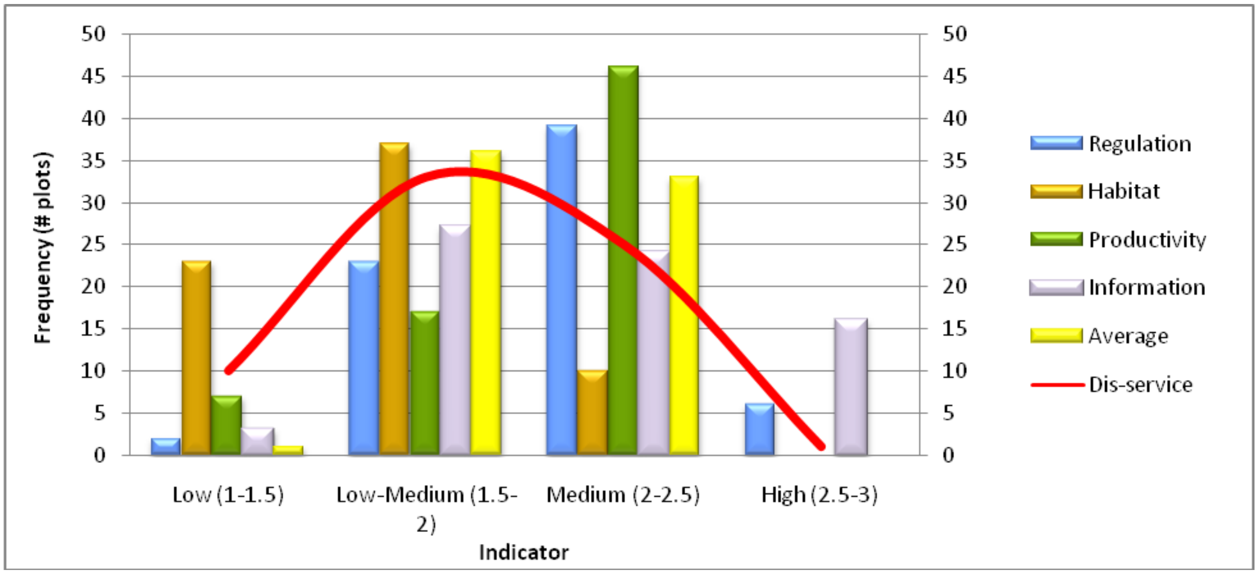

Figure 3-1. Histogram for ecosystem functions and disservices in the city of Gainesville

Table 3-1. Categories of Indicators for Regulation Function

Service	Low	Medium	High
Maintenance of good air quality			
O_3R (tons yr^{-1})	[0-0.0001]	[0.00011-0.001]	[>0.0011]
CO_2S (tons yr^{-1})	[0-0.05]	[0.05-0.2]	[>0.2]
COR (tons yr^{-1})	[0-0.00001]	[0.00001-0.0001]	[>0.0001]
SO_2C (tons yr^{-1})	[0-0.0001]	[0.0001-0.001]	[>0.001]
NO_2C (tons yr^{-1})	[0-0.0001]	[0.0001-0.001]	[>0.001]
Maintenance of favorable climate			
TR (°C)	[0-1.6E-06]	[1.6E-06-1E-05]	[>1.1E-05]
Storm Protection			
TD (trees/plot)	[0-2]	[2-4]	[>4]
DB (%)	[>50]	[25-50]	[0-25]
Drainage			
CN	[<30]	[30-60]	[>60]
IN (in/hr)	[<0.55]	[0.55-7.8]	[>7.8]
Maintenance of soil quality			
OM (%)	[<1, >15]	[5.1-15]	[1-5]
pH	[<3.5, >7.5]	[3.5-4.9]	[5-7.5]
BD (g cm^{-3})	[>1.6]	[<1.1, 1.41-1.6]	[1.1-1.4]
Maintenance of healthy soils			
P (mg kg^{-1})	[<3, >100]	[3-15]	[15-100]
K (mg kg^{-1})	[<40]	[40-100]	[>100]
Mg (mg kg^{-1})	[<8]	[8-74]	[>74]
Ca (mg kg^{-1})	[<200]	[200-700]	[>700]
Zn (mg kg^{-1})	[>300]	[150-300]	[0-150]
Ni (mg kg^{-1})	[>70]	[35-70]	[0-35]
Cu (mg kg^{-1})	[>130]	[75-130]	[0-75]
Pb (mg kg^{-1})	[>500]	[250-300]	[0-250]

O3R, ozone removal; CO2S, carbon dioxide sequestered; CO, carbon monoxide removal; SO2C, sulfur dioxide capture; NO2C, nitrogen dioxide capture; TR, temperature reduction; TD, tree density; DB, percent dieback; CN, drainage; IN, infiltration; OM, organic matter; BD, bulk density; P, concentration of phosphorus; K, concentration of potassium; Mg, concentration of magnesium; Ca, concentration of calcium; Zn, concentration of zinc; Cu, concentration of copper; Ni concentration of nickel; Pb, concentration of lead; Pm10R, particulate matter less than 10 microns removal; LAD, leaf area and distance to source of noise; FOL, type of foliage.

Table 3-1. Continued.

Service	Low	Medium	High
Filtering of dust particles			
$Pm_{10}R$ (tons yr^{-1})	[0-0.000005]	[0.000005-0.00002]	[>0.00002]
Noise Reduction			
LAD	[<1,000 m^2 leaf area-any distance to source of noise]	[1,000-2,000 m^2 leaf area-(10 to 20 m) distance to the source of noise, >1,000 m^2 leaf area-(> 20 m) distance to noise source]	[>2,000 m^2 leaf area-(< 20 m) to source of noise, 1,000-2,000 m^2 leaf area-(< 10 m) distance to the source of noise]
FOL	[<25% of trees evergreen]	[25-50% of trees evergreen]	[>50% trees evergreen]

O3R, ozone removal; CO2S, carbon dioxide sequestered; CO, carbon monoxide removal; SO2C, sulfur dioxide capture; NO2C, nitrogen dioxide capture; TR, temperature reduction; TD, tree density; DB, percent dieback; CN, drainage; IN, infiltration; OM, organic matter; BD, bulk density; P, concentration of phosphorus; K, concentration of potassium; Mg, concentration of magnesium; Ca, concentration of calcium; Zn, concentration of zinc; Cu, concentration of copper; Ni concentration of nickel; Pb, concentration of lead; Pm10R, particulate matter less than 10 microns removal; LAD, leaf area and distance to source of noise; FOL, type of foliage.

Table 3-2. Categories of Indicator for Habitat Function

Categories	Low	Medium	High
SD	[<1]	[1-3.5]	[>3.5]
RN	[<25% of trees native]	[25-75% of trees native]	[>75% trees native]

SD, Shannon diversity Index; RN, ratio of natives.

Table 3-3. Categories of Indicator for Production Function

Categories	Low	Medium	High
TB (Kg.)	[<1.0]	[1.0-10.0]	[>10.0]
GB (Kg.)	[<0.0005]	[0.0005-0.001]	[>0.001]
DTB (Kg.)	[>0.100]	[0.001-0.100]	[<0.001]
GW (Kg.)	[>0.100]	[0.01-0.100]	[<0.01]

TB, tree biomass; GB, litter biomass; DTB, dead tree biomass; GW, green waste biomass.

Table 3-4. Categories of Indicators for Information Function

Categories	Low	Medium	High
Recreation opportunities			
Forest recreation	[no tree cover]	[1-25% of tree cover; 75-100% of tree cover]	[25-75% tree cover]
Institutional recreation	[no cover of tree or maintained grass cover]	[1-25% of tree cover and 1-25% maintained grass cover; 75-100% tree cover and 1-25% maintained grass cover]	[25-75% of tree cover and more than 25% of maintained grass cover]
Residential recreation	[no cover of tree or maintained grass cover]	[<50% maintained grass cover; 25-75% tree cover and <50% of maintained grass cover	[50-100% maintained grass; 25-75% tree cover and over 50% of maintained grass cover]
Aesthetics			
RV (US$)	[<1,000]	[1,000-10,000]	[>10,000]
REV (US$)	[0-12,500]	[80,000-350,000]	[>350,000]

RV, replacement value; REV, real estate value.

Table 3-5. Categories for Indicator for Disservices

Categories	Low	Medium	High
Fruit Fall (FF)	[<25% of the species have fleshy fruits]	[25-75% of the species have fleshy fruits]	[>75% of the species have fleshy fruits]
Allergenicity-OPALS (AL)	[1-4]	[4-7]	[7-10]
Damage to humans and infrastructure (DI)	[<25% of the tree species have branches or trunks susceptible to breakage and excellent, good or fair average tree condition or 25-75% of the tree species have branches or trunk susceptible to breakage and in average excellent tree condition]	[<25% of the tree species have branches or trunk susceptible to breakage and poor average tree condition; 25-75% of the tree species have branches or trunk susceptible to breakage and good or fair average tree condition; >75% of the tree species have branches or trunk susceptible to breakage but on average they are in excellent condition]	[>75% of the tree species have branches or trunk susceptible to breakage and in average they have good, fair or poor conditions or 25-75% of the tree species have branches or trunk susceptible to breakage and bad average tree condition]
Decrease of air quality			
COE (tons yr^{-1})	[0-0.0001]	[0.0001-0.001]	[>0.001]
O_3E (tons yr^{-1})	[0-0.01]	[0.01-0.05]	[>0.05]
CO_2E (tons yr^{-1})	[0-0.001]	[0.001-0.01]	[>0.01]
VOCE (tons yr^{-1})	[0-0.001]	[0.001-0.01]	[>0.01]
CO_2P (tons yr^{-1})	[0-0.001]	[0.001-0.01]	[>0.01]
CO_2M (tons yr^{-1})	[0-0.0001]	[0.0001-0.0005]	[>0.0005]
VOCEL (tons yr^{-1})	[0-0.001]	[0.001-0.3]	[>0.3]
NO_2EL (tons yr^{-1})	[0-0.025]	[0.025-0.05]	[>0.05]

O_3E, ozone emission; CO_2E, carbon dioxide emitted; COE, carbon monoxide emission; VOCE, volatile organic compound emitted; CO_2P, carbon dioxide emitted because of pruning; CO_2M, carbon dioxide emitted because of mowing; VOCEL, volatile organic compounds emitted by leaf blowers; NO_2EL, nitrogen dioxide emitted by leaf blowers.

Table 3-6. Indicator value, statistics and normality tests for ecosystem services of the regulation function for the city of Gainesville

Stats.	Maint. of good air quality	Maint. of favorable climate	Maint. of healthy soils	Maint. of soil productivity	Storm protection	Filtering of dust particles	Noise Reduction	Drainage	Regulation Function
Mean Indicator	2.0	2.2	2.6	2.2	2.3	1.8	2.2	2.2	2.2
Variance	0.25	0.66	0.12	0.19	0.33	0.77	0.30	0.06	0.1
Min value	1	1	1.6	1.4	1	1	1	2	1.5
Max value	2.7	3	3	2.8	3	3	3	2.5	2.8
p-value	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010

Maint, Maintenance.

Table 3-7. Mean for ecosystem services included of the regulation function and p-values ANOVA (α=0.05)

		AQ	C	HS	SP	STO	DUST	NOI	DRA	Mean REG	St. dev.REG
YUR	0-20	2.1	2.7	2.6	2.0	2.4	2.2	2.3	2.4	2.3	0.31
	20-40	1.9	1.9	2.7	2.2	2.3	1.6	2.1	2.2	2.1	0.27
	40-60	1.8	1.9	2.6	2.3	2.1	1.5	2.1	2.2	2.0	0.33
	>60	2.3	3	2.8	3	2.5	2.5	3	2.3	2.6	0.01
	p-value	NS	0.001	NS	NS	NS	0.01	NS	NS	0.01	
LU	Forested	2.2	2.8	2.5	1.9	2.5	2.2	2.4	2.4	2.4	0.21
	Residential	2.0	1.6	2.8	2.3	2.3	1.5	2.1	2.0	2.1	0.29
	Institutional	1.5	2.1	2.9	2.4	1.7	1.4	1.7	2.3	2.0	0.39
	Commercial	1.7	2.2	2.8	2.2	2.2	1.6	2.4	2.0	2.1	0.43
	Vacant	1.8	3	2.3	2.4	1.7	2.0	1.8	2.3	2.1	0.37
	p-value	NS	<0.0001	0.005	0.002	0.003	NS	0.004	<0.001		
PVAL (US$/acre)	<12,500	2.1	2.5	2.6	2.0	2.5	2.1	2.4	2.3	2.3	0.27
	12,501-210,000	1.9	2.5	2.5	1.9	2.2	2.1	2.2	2.3	2.2	0.34
	>210,000	1.9	1.8	2.7	2.8	2.2	1.5	2.2	2.0	2.1	0.31
	p-value	NS	0.002	NS	0.0003	NS	NS	NS	0.005	NS	
POP(hab./census block)	<953	2.0	2.5	2.7	2.2	2.4	2.0	2.4	2.3	2.3	0.32
	954-1,698	2.0	2.2	2.6	2.2	2.3	1.9	2.4	2.2	2.2	0.28
	1,699-3,503	2.0	2.2	2.5	2.2	2.3	1.8	2.1	2.2	2.1	0.25
	>3,503	1.8	1.9	2.6	2.1	2.1	1.5	1.9	2.1	2.0	0.33
	p-value	NS	NS	NS	NS	NS	NS	0.003	NS	0.003	
HI(US$)	<21,000	2.1	2.3	2.6	2.1	2.5	2.1	2.3	2.2	2.3	0.26
	21,001-32,700	2.0	2.3	2.7	2.1	2.3	2.0	2.4	2.2	2.2	0.26
	32,701-44,000	1.9	2.2	2.6	2.2	2.4	1.5	2.2	2.2	2.1	0.38
	>44,000	1.9	2.0	2.7	2.3	2.0	1.6	2.0	2.2	2.0	0.34
	p-value	NS	NS	NS	NS	NS	NS	NS	NS	NS	

NS, no significant differences (α=0.05). YUR, years since urban development; LU, land use; PVAL, property value; POP, population density; HI, household income. AQ, maintenance of good air quality; C, maintenance of favorable climate; HS, maintenance of healthy soils; SP, maintenance of soil productivity; STO, storm protection; DUST, filtering of dust particles; NOI, noise reduction; DRA, drainage; REG, regulation function.

Table 3-8. Indicator value, statistics and normality test for ecosystem services indicators of the habitat function for the city of Gainesville

Stats.	SI	RN	Habitat Function
Mean Indicator	1.1	2.5	1.6
Variance	0.12	0.54	0.11
Min value	1	1	1
Max value	2	3	2.3
p-value	<0.0001	<0.0001	<0.0001

SI, Shannon's diversity index; RN, ratio of native tree species

Table 3-9. Mean for ecosystem services included in habitat function and p-values ANOVA (α=0.05)

		SI	NAT	Mean HAB	St. dev. HAB
YUR	0-20	1.2	2.4	1.6	0.41
	20-40	1.1	2.6	1.5	0.27
	40-60	1.2	2.5	1.6	0.37
	>60	1.5	3	1.8	0.24
	p-value	NS	NS	NS	
LU	Forested	1.3	2.6	1.8	0.25
	Residential	1	2.3	1.4	0.25
	Institutional	1.1	1.8	1.3	0.39
	Commercial	1	2.6	1.5	0.25
	Vacant	1.5	3	2	0.47
	p-value	0.005	<0.0001	<0.0001	
PVAL (US$/acre)	<12,500	1.3	2.6	1.6	0.40
	12,501-210,000	1.2	2.8	1.7	0.28
	>210,000	1.1	2.4	1.5	0.31
	p-value	NS	NS	NS	
POP (hab./census block)	<953	1.1	2.5	1.6	0.34
	954-1,698	1.2	2.5	1.6	0.29
	1,699-3,503	1.3	2.5	1.6	0.44
	>3,503	1.1	2.6	1.6	0.30
	p-value	NS	NS	NS	
HI (US$)	<21,000	1.1	2.5	1.5	0.35
	21,001-32,700	1.1	2.5	1.6	0.27
	32,701-44,000	1.3	2.7	1.7	0.40
	>44,000	1.1	2.5	1.5	0.35
	p-value	NS	NS	NS	

NS, no significant differences (α=0.05). YUR, years since urban development; LU, land use; PVAL, property value; POP, population density; HI, household income. SI, Shannon diversity indexes; NAT, proportion of native species in the plot; mean HAB, mean habitat function.

Table 3-10. Indicator value, statistics and normality test for ecosystem services included of the productivity function for the City of Gainesville, Florida.

Statistic	TB	GB	DTB	GW	Production Function
Indicator Mean	1.7	2.6	2.6	1.6	2.1
Variance	0.36	0.34	0.54	0.61	0.09
Min value	1	1	1	1	1.25
Max value	3	3	3	3	2.5
p-value	<0.010	<0.010	<0.010	<0.010	<0.010

TB, tree biomass; GB, ground litter biomass; DTB, dead trees biomass; GW, green waste biomass.

Table 3-11. Mean for ecosystem services included in production function and p-values ANOVA (α=0.05)

		TB	GB	DTB	GW	Mean PROD	St. dev. PROD
YUD	0-20	1.8	2.3	2.5	1.6	2.1	0.33
	20-40	1.6	2.6	2.6	1.7	2.2	0.29
	40-60	1.7	2.8	2.8	1.8	2.3	0.19
	>60	1.5	2	2	1.5	1.8	0.35
	p-value	NS	0.02	NS	NS	NS	
LU	Forested	1.6	2.8	2.6	1.8	2.2	0.32
	Residential	2	2.2	2	1.3	1.9	0.34
	Institutional	1.3	2.6	2.8	2.4	2.3	0.17
	Commercial	1.6	2.8	3	1.7	2.3	0.11
	Vacant	1.5	3	2.5	2	2.3	0.35
	p-value	0.02	0.004	<0.0001	0.004	<0.0001	
PVAL (US$/acre)	<12,500	1.7	2.4	2.3	1.8	2	0.29
	12,501-210,000	1.7	2.6	2.7	1.6	2.2	0.26
	>210,000	1.8	2.7	2.7	1.6	2.2	0.26
	p-value	NS	NS	NS	NS	NS	
Pop (hab./census block)	<953	1.7	2.3	2.6	1.6	2.1	0.37
	954-1,698	1.8	2.5	2.6	1.5	2.1	0.26
	1,699-3,503	1.5	2.6	2.5	1.9	2.1	0.27
	>3,503	1.7	2.8	2.5	1.7	2.2	0.29
	p-value	NS	NS	NS	NS	NS	
HI (US$)	<21,000	1.4	2.7	2.9	1.9	2.2	0.16
	21,001-32,700	1.7	2.6	2.8	1.6	2.2	0.25
	32,701-44,000	1.9	2.3	2.1	1.4	1.9	0.40
	>44,000	1.8	2.7	2.5	1.8	2.2	0.31
	p-value	NS	NS	0.04	NS	0.03	

NS, no significant differences (α=0.05). YUR, years since urban development; LU, land use; PVAL, property value; POP, population density; HI, household income. TB, tree biomass; GB, ground litter biomass; DTB, dead trees biomass; GW, green waste biomass.

Table 3-12. Indicator value, statistics and normality test for ecosystem services included of the information function for the city of Gainesville

Statistic	REC	AES	Information Function
Mean	2.3	2	2.1
Variance	0.33	0.25	0.16
Min	1	1	1
Max	3	3	3
p-value	<0.0001	<0.0001	<0.0001

REC, forest recreation, institutional recreation or residential recreation; AES, Aesthetics

Table 3-13. Mean for ecosystem services included in information function and p-values ANOVA (α=0.05)

		REC	AES	Mean INF	St. dev. INF
YUR	0-20	2.3	1.8	1.9	0.31
	20-40	2.4	2.2	2.2	0.39
	40-60	2.3	2.2	2.2	0.48
	>60	1.8	2	1.9	0.12
	p-value	NS	NS	NS	
LU	Forested	2.3	1.8	2	0.39
	Residential	2.5	2.3	2.4	0.31
	Institutional	2.4	1.9	2.1	0.34
	Commercial	1.7	2.1	1.9	0.42
	Vacant	2.5	2	2.2	0
	p-value	0.02	0.002	0.002	
PVAL (US$/acre)	<12,500	2.3	1.5	1.8	0.25
	12,501-210,000	2.2	1.9	2	0.27
	>210,000	2.4	2.5	2.4	0.29
	p-value	NS	<0.0001	<0.0001	
POP (hab./census block)	<953	2.4	2	2.1	0.42
	954-1,698	2.4	2.2	2.3	0.30
	1,699-3,503	2.4	2	2.1	0.34
	>3,503	2.1	2	2	0.46
	p-value	NS	NS	NS	
HI (US$)	<21,000	2.5	1.9	2.2	0.33
	21,001-32,700	2.4	2.1	2.2	0.36
	32,701-44,000	2.3	1.8	2	0.42
	>44,000	2.1	2.2	2.1	0.45
	p-value	NS	NS	NS	

NS, no significant differences (α=0.05). YUR, years since urban development; LU, land use; PVAL, property value; POP, population density; HI, household income. REC, forest recreation, institutional recreation or residential recreation; AES, Aesthetics; INF, Information Function.

Table 3-14. Indicator value, statistics and normality test for ecosystem disservices for the city of Gainesville

Statistic	FF	AL	DI	DAQ	Disservices
Mean	1.5	2	1.8	2.2	1.9
Variance	0.4	0	0.73	0.21	0.09
Min	1	2	1	1	1
Max	3	2	3	2.9	2.6
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

FF, Fruit Fall; AL, Allergenicity; DI, Damage to infrastructure or humans; DAQ, Decrease of air quality.

Table 3-15. Mean for disservices and p-values ANOVA (α=0.05)

		FF	AL	DI	DAQ	Mean DIS	St. dev. DIS
YUR	0-20	1.3	2	1.9	2.3	1.9	0.29
	20-40	1.6	2	1.6	2.2	1.8	0.29
	40-60	1.6	2	1.7	2	1.8	0.30
	>60	1.5	2	2.5	2.7	2.2	0.02
	p-value	NS	na	NS	NS	NS	
LU	Forested	1.4	2	2	2	1.8	0.33
	Residential	1.7	2	1.6	2.3	1.9	0.27
	Institutional	1.2	2	1.4	2.1	1.7	0.33
	Commercial	1.5	2	2.1	2.2	1.9	0.31
	Vacant	1.5	2	2.5	2.3	2.1	0.04
	p-value	NS	na	NS	NS	NS	
PVAL (US$/acre)	<12,500	1.3	2	2.2	2.3	1.9	0.24
	12,501-210,000	1.5	2	2.2	2	1.9	0.24
	>210,000	1.7	2	1.4	1.9	1.8	0.32
	p-value	NS	na	0.002	NS	NS	
POP (hab./census block)	<953	1.4	2	1.7	2.3	1.8	0.26
	954-1,698	1.6	2	2	2.3	2	0.28
	1,699-3,503	1.6	2	1.8	2.1	1.9	0.27
	>3,503	1.4	2	1.7	2	1.8	0.33
	p-value	NS	na	NS	NS	NS	
HI (US$)	<21,000	1.5	2	1.9	2.2	1.9	0.24
	21,001-32,700	1.5	2	1.9	2.3	1.9	0.25
	32,701-44,000	1.7	2	1.6	2.2	1.9	0.28
	>44,000	1.5	2	1.7	2.1	1.8	0.37
	p-value	NS	na	NS	NS	NS	

NS, no significant differences (α=0.05). na not applicable. YUR, years since urban development; LU, land use; PVAL, property value; POP, population density; HI, household income. FF, Fruit Fall; AL, Allergenicity; DI, Damage to infrastructure or humans; DAQ, Decrease of air quality; DIS, Dis-service.

Table 3-16. Mean values and standard errors for the 4 ecosystem functions

Function	Indicator value	Category
Regulation	2.2±0.03	Medium
Habitat	1.6±0.04	Medium-Low
Production	2.1±0.03	Medium
Information	2.1±0.04	Medium-Low
Total	2.0±0.02	Medium-Low
Dis-service	1.9±0.03	Medium-Low

Low [1-1.5], Medium-Low [1.51-2.0], Medium [2.01-2.5], High [2.51-3]

CHAPTER 4
SPATIAL DISTRIBUTION OFGAINESVILLE'S URBAN FOREST ECOSYSTEM SERVICES INDEX

Introduction

Human well-being depends on natural resources and health of the ecosystem. The current trends associated with population expansion could threaten the sustainability and services provided from ecosystems (Zurlini and Girardin, 2008). Assessing ecosystem health is determinant to provide environmental security (Petrosillo et al., 2007). Environmental indices can be useful for assessing ecosystem health and quality, since they describe the socio-ecological systems in a simple way that can be understood by scientists, managers, and policy makers (Zurlini and Girardin, 2008). Indices of an urban area's ecological condition can also help in evaluating the state of the urban ecosystem by comparing differences across space and the results of past policies can be evaluated (Banzhaf and Boyd, 2005).

An index is a scalar form that aggregates two or more values (MFE, 2004) and helps simplify a problem (Atkinson et al., 1997) by summarizing complex and multi-dimensional issues (Saisana et al., 2005). If two or more indicators are combined an index is created (Segnestam, 2002). Composite indicators (i.e. indices) may have the advantage of giving an overall picture of a system's performance in a simple but compelling way that can attract people's interest through a summary figure that makes the comparison across analysis units easier (Saisana et al., 2005). They can also include a weighting scheme to even out the relationships among indicators (UNEP, 2006) and to show the importance of certain variables (Esty et al., 2005). The index should take into account variable spatial and temporal scales so standardization is accounted for, thus making it comparable (Esty et al., 2005). Although aggregate indices are often subjective; due to choice of weights or the aggregation of the system, sensitivity analysis can help strengthen the index (Singh et al., 2007).

System State Indices

Several indices had been developed to compare and evaluate the state of a system. Indices such as Composite Leading Indicators, Environmental Sustainability Index, the Human Development Index, Environmental Policy Performance Indicator, Index of Sustainable Economy and Welfare and The Technology Achieved Index use an arithmetic average of normalized indicators. The Business Climate Indicator, the General Indicator of Science and Technology and the Success of Software Process Improvement use principal component analysis (PCA) to assign weights to each indicator. Technology performance is more related with PCA analysis (Esty et al., 2005).

Other indicators are weighed based on user needs or weights derived from surveys such as Eco-Indicator 99 and the Index of Environmental Friendliness. Environmental issues are assigned equal weights, where no more importance is given to any specific variable or public opinion. Analytical hierarchical process is occasionally used to assign weights to the indicators. This is a weighting method that enables decision-makers to assign weights non arbitrarily (Saisana and Tarantola, 2002).

An index of ecosystem services should be able to describe the phenomena at multi-scales along space and time, as long as it is constantly re-evaluated and re-interpreted according to the increased understanding of the socio-ecological system (Zurlini and Girardin, 2008). Similar to sustainable development indices, ecosystem services indices are also related to human well being (Singh et al., 2007).

Remote Sensing Indices

Urban morphology (e.g. ecosystem structure) has been mapped and modeled in several different ways using a land use and land cover classifications, or vegetation indices. Specifically, the normalized difference vegetation index (NDVI), modified soil vegetation index (MSAVI) and normalized difference building index (NDBI) have been widely used. The NDVI has shown consistent correlation with vegetation in several ecosystems (Sellers et al., 1992). NDVI has been correlated with soil properties such as content of soil, clay and silt, the distribution of carbon and nitrogen, drainage and topographical variables (Lozano-Garcia et al., 1991; Sumfleth and Duttman, 2008). NDVI also has been used to build models to estimate characteristics of urban forests and its environment such as carbon storage or biomass (Myeong et al., 2005; Aznim and Haslim, 2007), leaf area (Jensen and Hardin, 2007) and bird species richness (Bino et al., 2008). Models for estimation of housing prices based on greenness have been built (Mansfield et al., 2005). Zha et al. (2003) found that built up areas increase their reflectance for bands 4 and 5 in comparison to vegetation that slightly decreases its reflectance, building up a relationship between the mid-infrared band and the near infrared band.

The MSAVI was designed to reduce the soil radiance from the vegetation indices, and therefore uses the modified version for improved vegetation detection sensitivity since it increases the vegetation to soil ratio signal (Qi et al., 1994). This index has been used to map and analyze patterns of urban green space (Huapeng et al., 2007) and as a component in the delineation of built-up land features (Xu, 2008). A combination of some of these remotely sensor derived indices have been used before for mapping urban areas in the city of Nanjing, China to produce more accurate results than supervised classification methods (Zha et al., 2003).

This chapter will aggregate the urban forest ecosystem services and goods (ESG) indicators into an index. Secondly, it will assess if the spatial distribution of the ESG index is related to socioeconomic patterns at the city level. Finally, it will determine if remote sensing vegetation indices (RS index) can be used to estimate the ESG index and evaluate the effects of urbanization. To accomplish this, the following specific objectives are pursued:

- The ESG index will be developed using three common weighting schemes, equal weight, double weight and eigenvalue based weights. Sensitivity analysis will be used to select the index(ices) for subsequent analysis.
- Spatial distribution relationships between the ESG index and socioeconomic variables will be analyzed at the city level. Values for the ESG index will be obtained by interpolating the ESG index from plot level to city level using an ordinary kriging technique. Kriging estimate accuracy will be assessed by comparing plot and the city-level ESG index values.
- To analyze the effects of urban morphology on the ESG index, a normalized difference vegetation index, a modified vegetation index that accounts for soil presence and a normalized building index will be used. Statistical relationships between the ESG index and RS indices will be tested at the plot level to determine if spatially explicit remote sensing estimation models can be developed.

I hypothesized that the ESG index will reflect the state of ecosystem services currently being provided by Gainesville’s urban forests based on the premise that urban ecosystem composition and structure influences function and therefore the provision of ecosystem services and goods. The equal weight method will provide a robust method to assess ecosystem services and goods in urban areas.

Kriged spatial estimates of the ESG index are expected to resemble plot-level results obtained for the index, therefore allowing for an assessment of the state of ecosystem services in Gainesville, FL. Household income and population density are related with the value of the ESG index so that, the higher income areas will have the highest ESG index. Conversely population density has an inverse relationship where the ESG index decreases with an increasing density.

Highly forested areas, represented by high NDVI will have high ESG index values, while areas dominated by impervious cover and a high NDBI will show low values for the ESG index. The NDVI will most effectively represent the spatial distribution of the ESG index, thus allowing the development of an ESG index prediction model.

Methods

Study Area

A description of the study area is provided in detail in Chapter 2.

Ecosystem Services and Goods Index

The ESG index was developed based on a series of indicators of ecosystem functions representing groups of ecosystem services and goods. The indicators that are aggregated in the ESG index consisted of specific values for each ecosystem function defined by De Groot et al. (2002). Ecosystem functions were previously defined in Chapter 3 as regulation function (RF), habitat function (HF), production function (PF) and information function (IF), plus disservices (DIS) that were also included in the calculation. These functions combined 3 to 26 variables derived from urban forests structure and composition values, urban soils and social values of the urban forest from the literature and available data. To make variables comparables, categories were used to standardize indicators. No weight was assigned to build the indicators, because no information of the preferences of people towards any ecosystem service was obtained.

To deal with different measurement units and scales, all services were standardized by assigning a unique value related to the state of each ecosystem service in each plot (See Chapter 3). A difficulty in developing an index is assigning the appropriate weight to each indicator (Saisana and Tarantola, 2002). Three methods for assigning weights to indicators were used in developing the ESG index. The first method (hereafter referred to as EWI) assigned equal weight to all the individual indicators and the value of the ESG index is based on ordinal levels (1^{st}, 2^{nd}, 3^{rd},….). This has the advantage of being simple and independent of outliers. However, it has the disadvantage of losing the absolute level of information, since it does not inform about the real value by which the ordinal scale is built. EWI works well when indicators are properly scaled, as described in Chapter 3. (Saisana and Tarantola, 2002).

$$\text{EWI} = (\Sigma^{4}_{n=1}\text{Ecosystem Functions}_{n})\text{-DIS; interval [1-11]} \qquad (1)$$

The second weighting method (hereafter refer to as DWI) subjectively assigns double weight to the information function since its service of recreation has been valued as one of the highest in urban ecosystems (Costanza et al., 1997). Assigning greater weights to the information function is related to how the ecosystem function directly affects human well being (Costanza et al., 1997). This method has the advantage of representing one of the main perceptions of city inhabitants towards trees, the benefit of recreation, increase of property value and bonds with nature (Anderson and Cordell, 1988; Dwyer et al., 1991; Tyrväinen and Miettinen, 2000; Jim and Chen, 2006).

$$\text{DWI} = (\Sigma^{3}_{n=1}\text{Ecosystem Functions}_{n}) + 2\text{*IF-DIS; interval [2-14]} \qquad (2)$$

Finally, the third method (hereafter referred as to PCAI) assigned weights according to the eigenvalues obtained from a PCA, by the average of the first three principal components. The use of a PCA justifies the statement that weights are applied in a neutral and data-reliable way, based merely on the behavior of the data (Esty el al., 2005).

PCAI = -0.15RF-0.65HF+0.67PF+0.13IF+0.29DIS; Interval [-0.2-2.0] (3)

The PCA is a technique that defines the weight of the indicator of an index, by showing the correlation between the indicators and not the causality. This method has been widely used to develop indices with the objective of giving more importance to the variables that explain the highest amount of variability of the data (Saisana and Tarantola, 2002). The disadvantage of using a PCA is that correlations do not necessarily represent the real influence of the indicators in the index and do not express the priorities of decision makers nor budget constraints (Esty et al., 2005).

Statistical analyses

The ESG index analysis included the calculation of the average, maximum, and minimum values. A ranking was calculated for the ESG index and for the functions used to develop the ESG index. The ranking shows the relative position of a certain plot in relation to the delivery of ecosystem services and goods, where 1 implies the lowest delivery and 70 the highest delivery. An average ESG index for the city of Gainesville was calculated, and analyses of variance (ANOVA’s) were performed to explore significant differences (p-value<0.05) between the rankings obtained by the different ESG index methods. To classify the ESG index as high, medium and low, the interval of the possible values obtained was divided into three equi-distant categories.

Sensitivity analyses were performed to assess the robustness of the indices by looking at the variation of the output and measuring how the ESG index was dependent on the collected data (Singh et al., 2007), (e.g. how much the individual source of uncertainty is contributing to the variance of the output) (Saisana et al., 2005).

Comparison of the rankings between the plots was done. Pearson correlation analysis looked for associations in the components of the ESG index. Sensitivity analysis was done by systematically removing each function indicator individually for each ESG index scheme to see which influenced the most the ranking positions, this will determine which index(ices) will be used for the rest of the analysis.

The ESG indices were explored for spatial patterns and the Moran's Index was calculated using the spatial statistics tool in ArgGis 9.2 (ESRI, 2008). Moran's index will look for clustering of the ESG index, showing if there is any trend in spatial distribution. Moran's index is a tool for measuring spatial autocorrelation based on feature location and the respective attribute, where values closer to -1 indicates high dispersion of the data and values near 1 will indicate that the data is clustered (Griffith and Peres-Neto, 2006). This will analyze the relationships between the ESG indices and the socioeconomic variables (ESRI, 2008).

Spatial Analysis of ESG Indices at the City Level

The units used to explore distribution patterns of the ESG index were land use, city quadrants and US Census blocks. See Chapters 2 and Chapter 3 for a description of these units. For spatial analysis of the ESG index among units an ordinary kriging technique which is an interpolation method to estimate the value of unobserved locations. Estimates are obtained using the least squares method. The ordinary kriging was applied using the ArcGis 9.2 tool (ESRI, 2008) to estimate the value of the ESG index in a continuous surface to better visualize the pattern of it .To determine ESG index sensitivity to the different estimation techniques, mean and standard error were compared between the results estimated by the ordinary kriging and those obtained using the plot-level sampling. With this comparison the differences between the observed and the estimated values of each ESG index method were obtained. Mean values of the ESG index by unit for all the analyzed indices, obtained from the plot sampling and those estimated by kriging, were tested for statistical differences using a student t-test PROC TTEST for dependent samples (SAS Institute, 2007).

Remote Sensing Analysis of ESG Indices at the Plot Level.

I explored the use of a model to estimate the value of the ESG index based on easily obtainable data, such satellite images. This analysis of biophysical variables used three indices derived from remote sensing data (RS Index). To explore spatial patterns, variables were plotted in a 3-Dimensional graph. To see similarities in trends between the ESG index and the RS indices, a surface linear trend was added to each one of the indices. The linear trend is calculated as a linear regression that relates the value of the ESG index with the value of the RS index by plot, r^2-adjusted is recorded.

Three RS indices were used for the analysis: NDVI, MSAVI and NDBI (Table 4-1). These RS indices have been proved to be highly correlated to urban features and have been used for mapping urban areas or to show trends of the environmental behavior of urban ecosystems (Zha et al., 2003, Myeong et al., 2006, Delm and Gulink, 2009). The remote sensing information was extracted from the Landsat Thematic Mapper (TM) image taken in April 2006. This was the same date urban forest sampling in Gainesville occurred and when the vegetation is starting its growing season. Images for the summer period (June-August) were not used since more than 50% of the image was covered by clouds, delivering an insufficient reflectance value for the pixels.

The NDVI and MSAVI linked the vegetation performance with the near-infrared (NIR) and red (RED) reflectance ratio, and the NDBI linked the mid-infrared (MIR) and the near infrared reflectance wavelength. The value of the NDVI ranges from 0 to 1, where values close to 0 correspond to absence of vegetation. Values close to 0.5 correspond to vegetated areas with limited photosynthetic activity and values close to 1 indicate high density leaf concentration (i.e. appropriate nutrient and water availability) (Myeong et al., 2001; Pettorelli et al., 2005, Sumfleth and Duttmann, 2008).

The NDBI was used to highlight urban morphology features such as buildings and impervious surfaces, both of importance for some of the ecosystem services that composed the index. Negative values or values close to zero show the presence of vegetation, while positive values are showing the presence of built up infrastructure, and the highest the NDBI the highest the building cover. The MSAVI has values between 0 and 1, values close to 1 show the presence of vegetation, and similarly, the highest index represents the highest amount of vegetative biomass (Qi et al., 1994).

Results

ESG Indices

The calculation of the ESG indices shows differences in the ranking of each plot. The PCAI was removed from the analyses since it assigned a positive weight for disservices, contrary to the effect of a dis-service, which is negative. The Moran's index showed no spatial correlation for any of the ESG indices. The EWI and DWI are randomly distributed and do not appear clustered or dispersed (Moran's value -0.1 and -0.08 respectively).

In the EWI, the highest significant correlation is with the information function (0.66), while the lowest is the productivity function. The differences between the ranking of EWI and the change in ranking when the regulation function, information function and disservices were removed from the analysis were significant (α=0.05). The average of the EWI for the city of Gainesville is 6.14 therefore the urban forest is delivering ecosystem services and goods of a medium value. Most of the plots range between 4 and 7 (Figure 4-1).

The DWI shows the highest significant correlation with the information function (0.66) and the regulation function (0.33), while the lowest association appears again for the productivity function. The differences between the ranking of DWI and the ranking when the information function and disservices were extracted are significant at $\alpha=0.05$. The average for this index is 8.2, with plots ranging from 4.8 to 10.1. Analyses resulted in one plot with a high DWI for services and goods, while most of the plots are found in a medium category. The maximum value changes between both ESG indices, shifting from a densely forested plot with small trees to a sparse tree area with bigger individuals. The maximum DWI values are found in areas suitable for recreation (Figure 4-2).

Differences between the two ESG index's methods selected are shown in Figure 4-3. The EWI has an average difference with the DWI of five positions, with 59% of the differences between rankings below this average, and 94% of the plots below 10 positions of difference. This indicates that the EWI or DWI forms a robust index, where the major source of variation is the information function and disservices for the EWI and the productivity and information function for DWI.

For EWI the most influential functions are the information and disservices. When the information function is removed, the ranking of the EWI minimum value changes, while the ranking stays the same when other functions are removed. The EWI mean value has the highest increment in positions, being rank as delivering more ecosystem services and goods. Eliminating disservices from the EWI modified the medium ranking positions. The DWI ranking changes when the productivity and information functions were removed and no change occurred in maximum DWI values (Table 4-2). Both ESG indices are highly sensitive to changes in the information function, showing the EWI to be more robust than the DWI. The EWI appears to be more sensitive and more appropriate for showing changes in the delivery of ecosystem services and goods.

Spatial Analysis of ESG Indices at the City Level

City quadrants analysis

In EWI the highest values are located in the core of Gainesville (Figure 4-4). Towards the limits of the city the EWI decreases, especially towards the Northeast (NE).The Southeast (SE) of the city has the highest value for the EWI, with no areas less than 6. In the NE almost all the quadrant has low values for the EWI, especially towards the North. To the East the EWI improves. The Northwest (NW) has higher values on the oldest part of the quadrant, while new urbanization areas show lower values for the EWI. Towards the North of the quadrant the value of the EWI decreases. The Southwest (SW) has low EWI values.

Opposite to the EWI ordinary kriging estimate, the highest values using plot-level EWI values are found in the NE, while the lowest are located in the SE. Low values for EWI, contrary to the ordinary kriging estimate, are located in the SE quadrant. Values estimated from the ordinary kriging are less accurate towards the East side of the city (Table 4-3).

The DWI has similar values to EWI, where the overall trend for the city shows an increase of the DWI values towards the core of Gainesville. The DWI decreases towards the city limits and is the highest in SE. The NE has lower DWI values than the EWI for the same area, and differences with the other quadrants become sharper. The

NW shows a clear trend where DWI higher values are located in the quadrant's corner heading to the core of the city and decreasing when moving to the North (Figure 4-5).

The DWI differences become more extreme between the ordinary kriging estimates and the plot values. While the plots results exhibit the highest values in the NE, the ordinary kriging estimate shows higher DWI values in the SE. The same happens with the lowest DWI values, which are located in SW for the plots calculations and in NW for the ordinary kriging estimates.

Land use analysis

The spatial distribution of EWI shows that vacant areas have the highest value and commercial areas the lowest. The greatest variability is also found in vacant areas since the krigging estimation used included bare soil and forested areas classified as vacant. DWI shows slight differences, where vacant areas are still classified as the highest but the lowest values were found in forested areas.Land use analyses show no clear patterns with the exception that forested areas tend to concentrate the lowest ESG index values for the two indices (Figure 4-6, Figure 4-7). The overall ESG index magnitude show that the highest and the lowest value for EWI and DWI are the same (Table 4-4). No significant differences appear at α=0.05 level.

Population density analysis

No clear spatial patterns appeared when contrasting the ESG index and population density for neither of the EWI and DWI methods (Figure 4-8, Figure 4-9). Additionally no significant differences appeared between the mean ESG index obtained from the plots value and the kriging estimates; however differences in the rank position did occur (Table 4-5).

Household income analysis

Spatial analyses for EWI indicated that high income areas tend to have higher values for this ESG index and the remaining household categories do not show any particular pattern (Figure 4-10). The DWI does not show a clear trend, even though high and low income areas located towards the center of the city have high values (Figure 4-11). This same situation does not occur for the rest of the city. No significant differences appeared between plot-level and kriged ESG indices (α=0.05), but the mean ranking position of the different household classes varied (Table 4-6).

Remote Sensing Analysis of ESG Indices at the Plot Level

The 3-D trend line graphs show that, in general, EWI decreases towards the SE and increases in the opposite direction where higher values can be found in the northern part of the city. DWI showed variation from East to West, decreasing its value towards the East. EWI shows a spatial trend similar to MSAVI (R^2=0.15), where for both the ESG indices decrease towards the SW and increase towards the East, while increasing to the North (Figure 4-12). The DWI shows a linear trend with the NDBI (R^2=0.25), where highest values NDBI correspond to the lowest DWI value, particularly in the NW quadrant (Figure 4-13). Linear model construction do not show ESG indices and the RS indices to be correlated (R^2<0.25). The NDVI did not showed similar trends with neither index.

Discussion

Gainesville's urban morphology is unique in that it is a college town and several of the trends observed here are not applicable to other urban areas. Demographics are different, several university students are concentrated in certain areas of the city indicating high education levels and low income which are related with high tree cover opposite situations existing in other studies (Escobedo et al., 2006; Szantoi et al., 2009). Gainesville has also large areas covered by dense forests in the middle of the city. These situations could lead to different results and robustness of the ESG index if applied to other cities.

The application of the index in different cities, different ecoregions or biogeographic provinces, and countries with different levels of development will require changes to the index. In particular, the regulation function indicators should be rescaled since several of the categories assigned in Chapter 3 were derived from the distribution of the measured data. Rescaling could be done using equation (4):

$$\text{Indicator}=\frac{x_{q,c}-\text{mean}(x_q)}{\text{range}(x_q)} \quad (4)$$

Where $x_{q,c}$ is the value of the indicator x_q for the city c (Saisana and Tarantola, 2002).

The ESG indices developed in this study included many easily measured social, economical, and environmental variables drivers of the urban environment (Grimm et al., 2000; Pickett and Cadenasso, 2002; Alberti et al., 2003). To improve the robustness of the ESG index a participatory approach might be warranted, such as an analytic hierarchy process (Cox et al., 1992; Saisana and Tarantola, 2002). The weighting issue is crucial to assess the robustness of an index (Saisana and Satelli, 2008). The use of the PCA to assign weights to the composite index makes the least sense, since it assigned a positive value to the disservices which imply that these are increasing the delivery of ecosystem services and goods and not decreasing it as expected. The EWI or DWI provides a more robust valuation for the assessment of ecosystem services and goods in urban areas. Moreover the EWI is the least subjective, providing more robust results when no participatory information has been collected.

The lowest value for the provision of ecosystem services and goods for the EWI corresponded to a dense forested area, with only 5 tree species and more than 10% of this in poor condition or already dead. Its soil is sandy with bulk density values within the range recommended for tree growth in urban areas (Craul, 1999), surface soil cover is scarce and nutrients are low (Heckman, 2006; Roa et al., 2008) and the structure of the forest does not provide a suitable area for any type of recreation. Only one plot has the highest value for the EWI index, which corresponded to a residential property with few large, good condition trees, where carbon storage and sequestration is high. Soil bulk density levels are low, showing no signs of compaction, and the concentration of nutrients is suitable for the growth of a yard or ornamental trees. The plot provides a good area for recreation and the existence of the trees increased its value.

City level analysis of spatial variables illustrate that the distribution of the ESG index by quadrants has evident trends. In general, the center of the city has higher values than areas along the city limits which coincide with older areas and younger areas in the city, respectively. This might indicate that the urban ecosystem is resilient, and that after years since the system was disturbed it returns to a point of equilibrium where the system can maintain ecosystem functions similar to those of natural areas (Alberti, 2009). The calculation of a time series of the ESG index could lead to a better understanding of which type of urbanization allows a more rapidly return to the equilibrium point of the ecosystem, thereby a more sustainable development process for cities (McDonald, 2008). This information could also help in defining what is more appropriate: urban areas located in smaller but denser areas or less dense and more widely spread areas. Also the ESG index could help evaluating which type of development is more appropriate for the maximization of ecosystem services and goods. Tratalos et al. (2007) observed some of these relationships in the United Kingdom finding that the type of development is more important in residential areas in terms of some ecosystem services delivery.

Land use analyses shows that forested areas have lower ESG index values, even though they are natural systems. High index values for low income areas could be related to the existence of older parts of the city and conservation areas and natural parks. However Liu et al. (2009) found this same inverse relationship between environmental quality and economic wealth. This trend could also be related to the existence of areas with well educated population made up by the students of University of Florida (Margai, 1995; Farzin and Bond, 2009).

Results indicate that the use of geostatistics as a method to interpolate environmental variables across urban areas could deliver appropriate results using a low intensity sampling (Table 4-3, 4-4, 4-5 and 4-6). Increases in the sampling density could however raise other patterns that were overlooked due to the sampling size used in this study. This study's sampling design resulted in a higher sampling intensity in the western part of the city which could be leading to less accurate results in the estimation of the ESG index obtained by kriging. Increases in the intensity of the sampling and the use of a systematic sampling method could also lead to more accurate results for the kriging, since the interpolation would have more information about the spatial variability existing in the urban area (Webster and Oliver, 1990; Brus and Heuvelink, 2007).

The Landsat TM resulted in the calculation of the NDVI, MSAVI and NDBI at a 30x30 meter resolution; an area higher than the area covered by the sampling unit used. The value of the RS index could be influenced by the type of cover outside the sampled plot. Previous studies found strong relationships between vegetation indices derive from satellite images and urban forest plot-level variables (Myeong et al., 2006; Huang et al., 2007) however no reliable relationship between the ESG index and the RS index could be established. The use of an image with better resolution could be used to find a stronger relationship between the ESG index and RS indices derived from a satellite image. Moreover if a high resolution image is used, a RS index could be created using plot-level spectral mixture by the combination of impervious surface, the grass surface, the tree cover and the bare soil (Rashed et al., 2007; Zoran et al., 2008) allowing the construction of a model for the rapid assessment of the ESG index in an urban area.

The development of an urban forest ecosystem services and goods index therefore could have implications on urban planning decisions if maximization of the services and goods is the main objective. The implications on public policies are that the index could provide a comprehensive method for valuing the delivery of ecosystem services and goods from a non-economical point of view. It could provide a way to assess how public policies and private sector activities might affect human well-being (Banzhaf and Boyd, 2005)

Conclusion

Quantification of ecosystem services and goods is a difficult task, especially in urban areas, since this implies complex ecological patterns, processes and disturbances, involving altered climate, hydrology, vegetation, fauna, population dynamics and different flows of energy and matter (Rebele, 1994; Pickett et al., 2001). Urban areas are highly dynamic, changing at different scales in time and space. The construction of an ESG index in urban areas will provide a static state of the city at time t, if we moved to time t+1 the value of the ESG index will change since the urban ecosystem is constantly subjected to disturbances. Changes in socioeconomic, population, economic growth and policies will affect human and ecosystem dynamics (Alberti, 2009), thus changing the ecosystem services and the value of the ESG index.

Variations of the ESG indices show that urbanization has an effect on the services and goods, and this effect is not necessarily negative. ESG Index values increased with indicators existing in urban spaces such as areas associated with recreation, better soil quality and aesthetics provided by trees. Continuing calculation of the index could provide information for urban planning. Also the EWI could provide information about the resiliency of urban ecosystems. Information about how the ESG index varies with the different socioeconomics could be used to identify specific areas in the city for improvements to human well-being by making cities more comfortable to live in.

The EWI should be under constant improvement, the addition of other services to the indicators will change the value of the index, in doing so, improving its accuracy in estimating state of the ecosystem services in an urban area at a given certain time and urban morphology. The data required to build the ESG index is not difficult to compile, census data and urban forest data is available in several cities, the UFORE model can be used for free, soil sampling is probably more expensive but the index could use just a few easily measured variables such as bulk density, pH and depth of litter. Further analysis is necessary to increase the robustness of the index by its application in different cities and the comparison of its results.

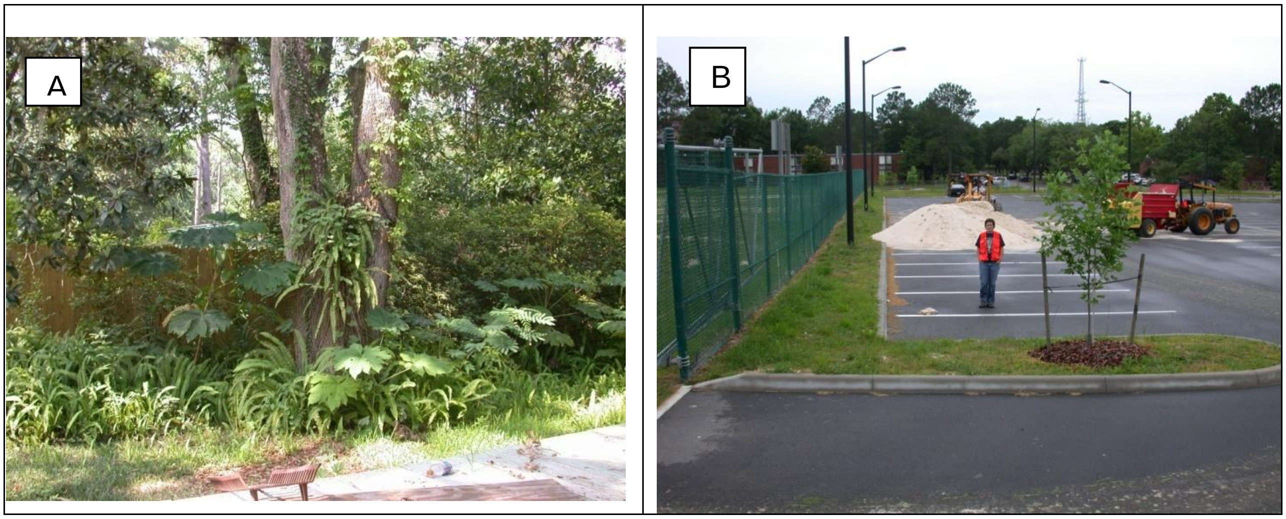

Figure 4-1. Plots with the best (A) and worst (B) value for the Equal Weight Index.

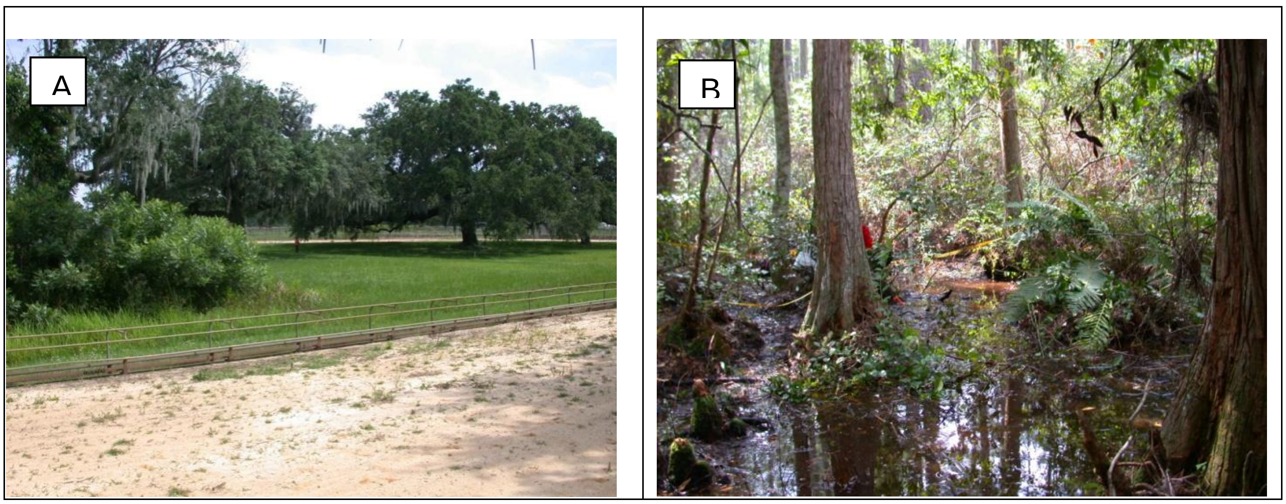

Figure 4-2. Plots with the best (A) and worst (B) value for the Double Weight Information Function Index.

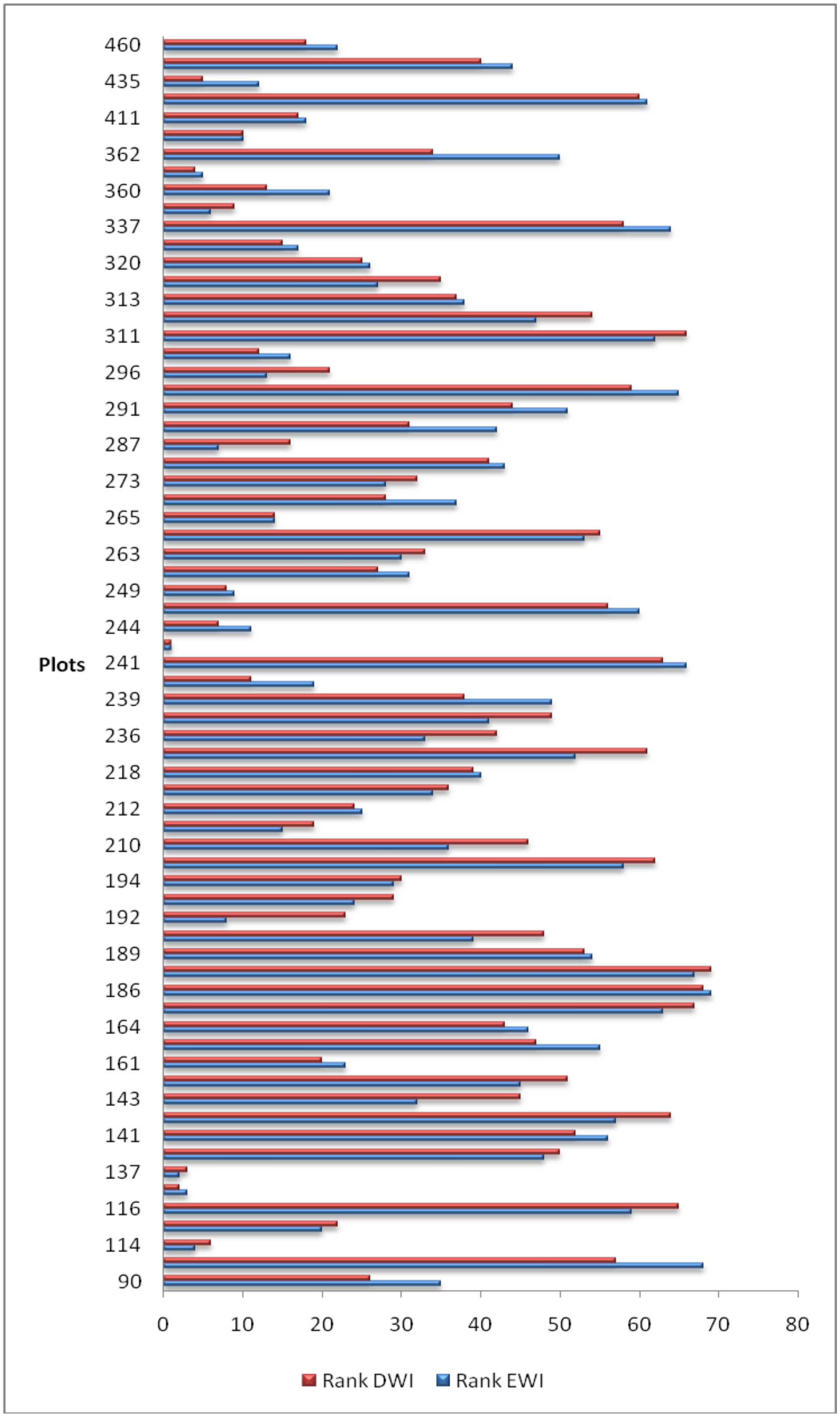

Figure 4-3. Ranking of plots according to Equal Weight Index and Double Weight Information Function Index

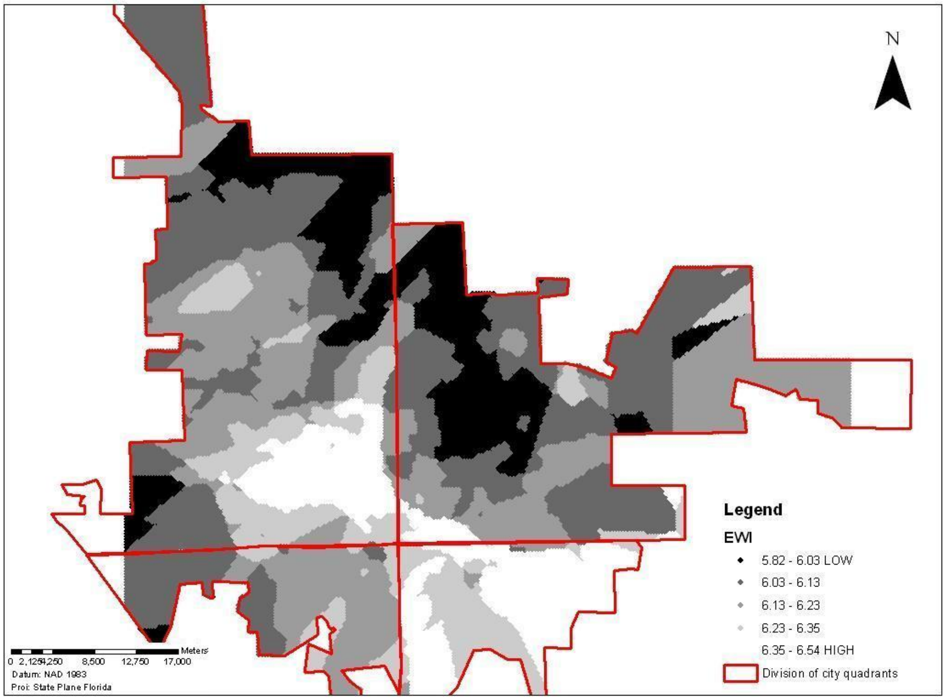

Figure 4-4. Analysis of the Equal Weight Index using ordinary kriging and classification of city quadrants.

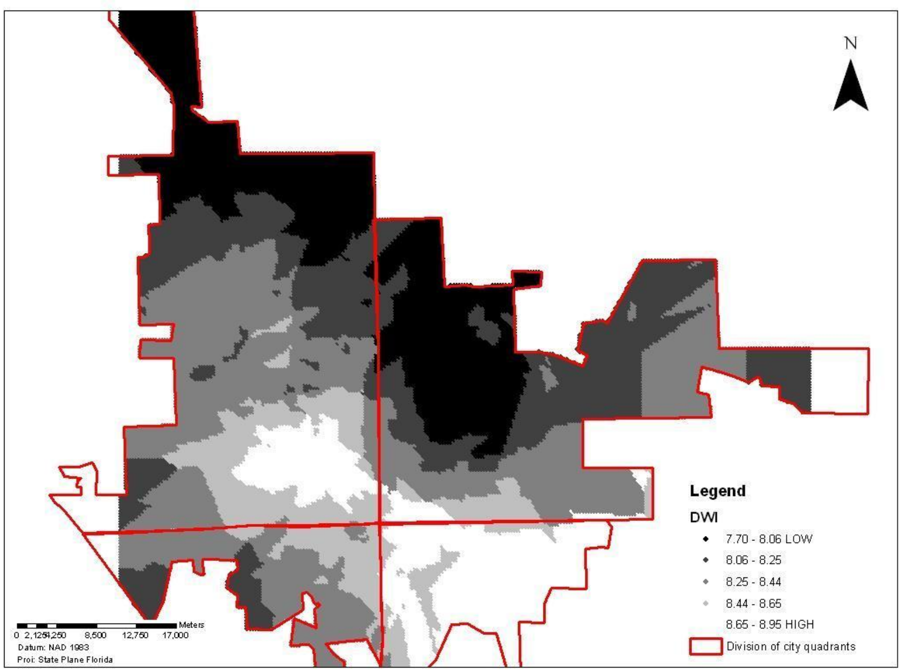

Figure 4-5. Analysis of the Double Weight Information Function Index using ordinary kriging and classification of city quadrants.

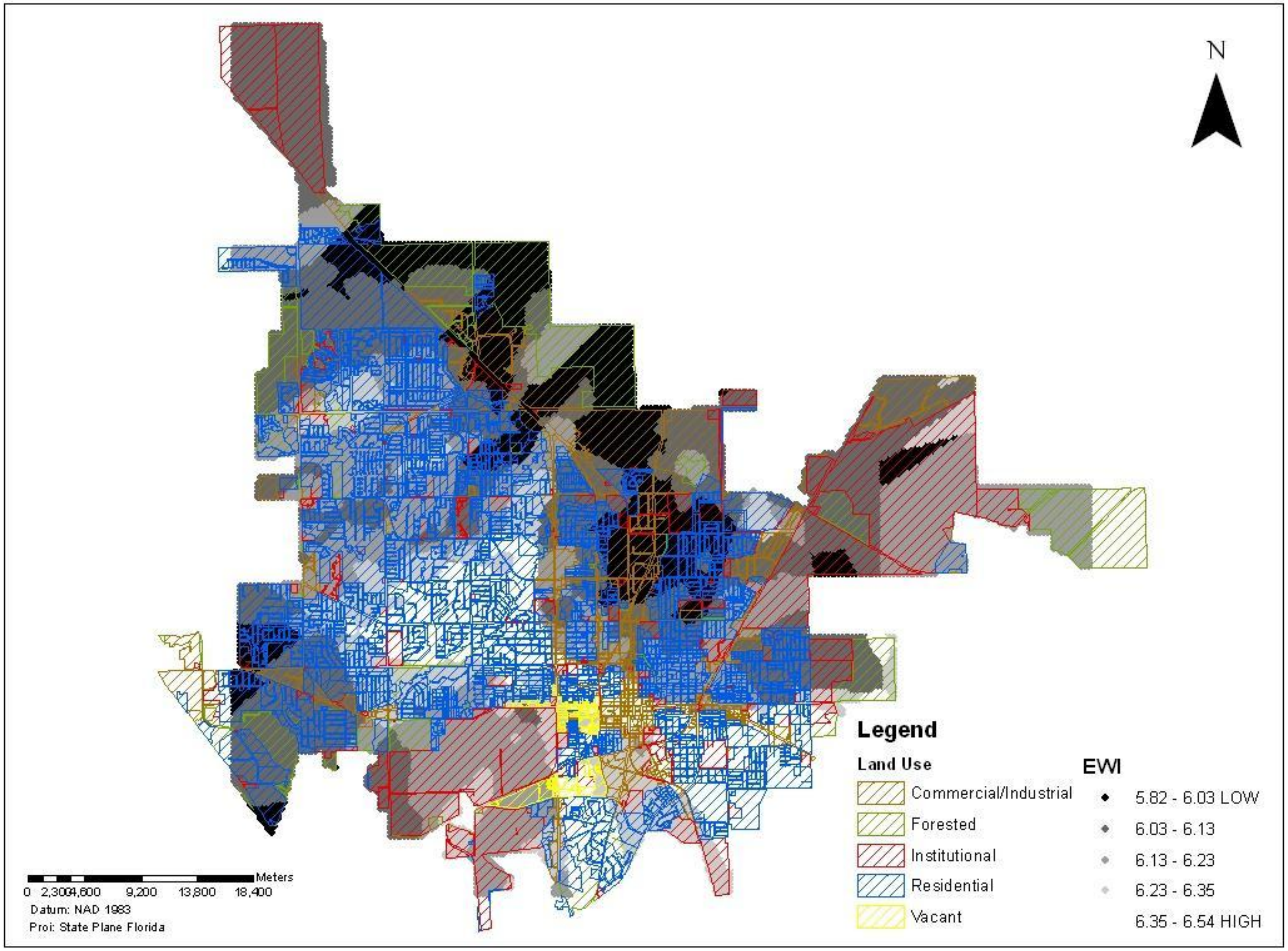

Figure 4-6. Analysis of the Equal Weight Index using ordinary kriging and land use classification.

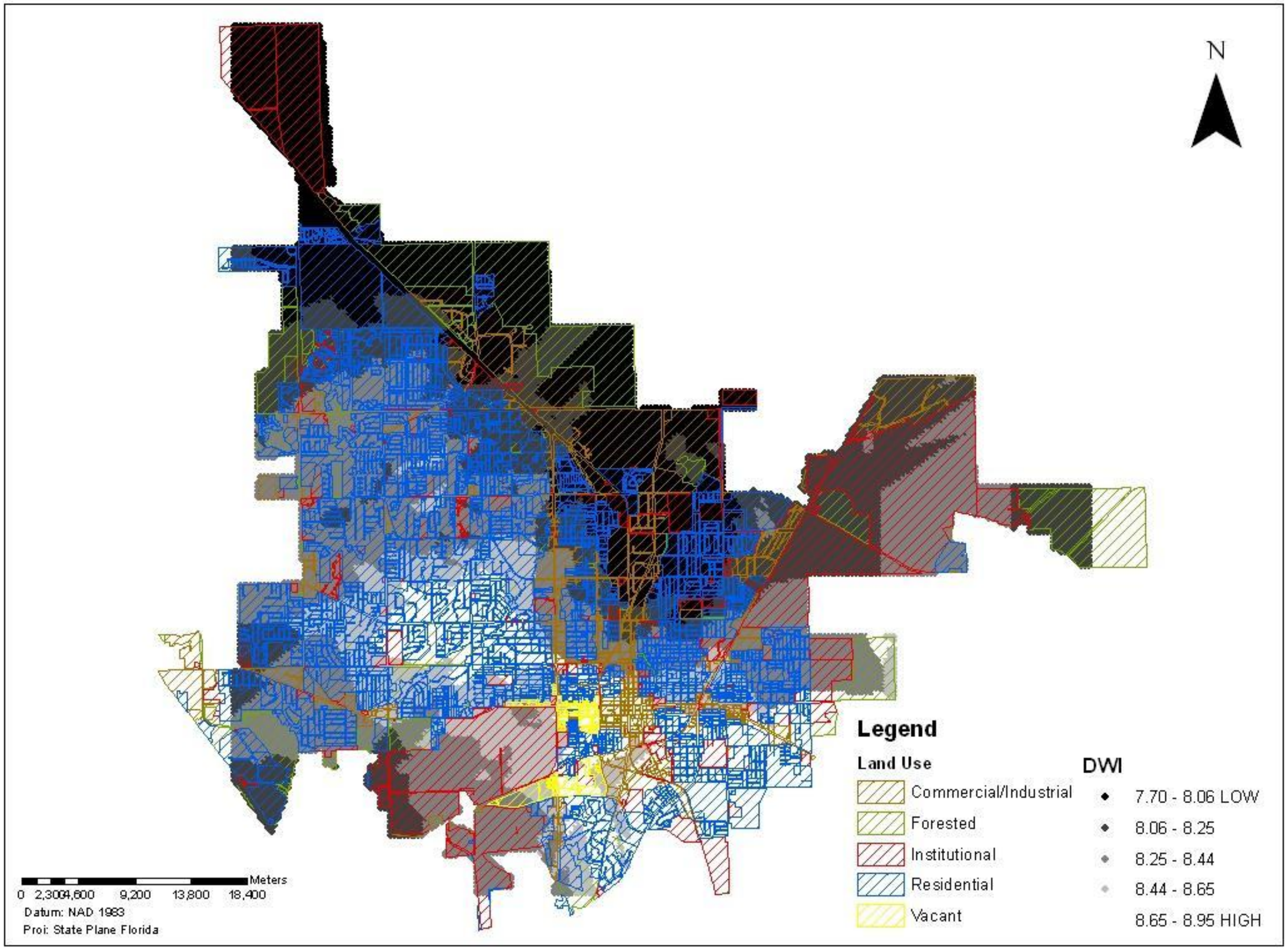

Figure 4-7. Analysis of the Double Weight Information Function Index using ordinary kriging and land use classification.

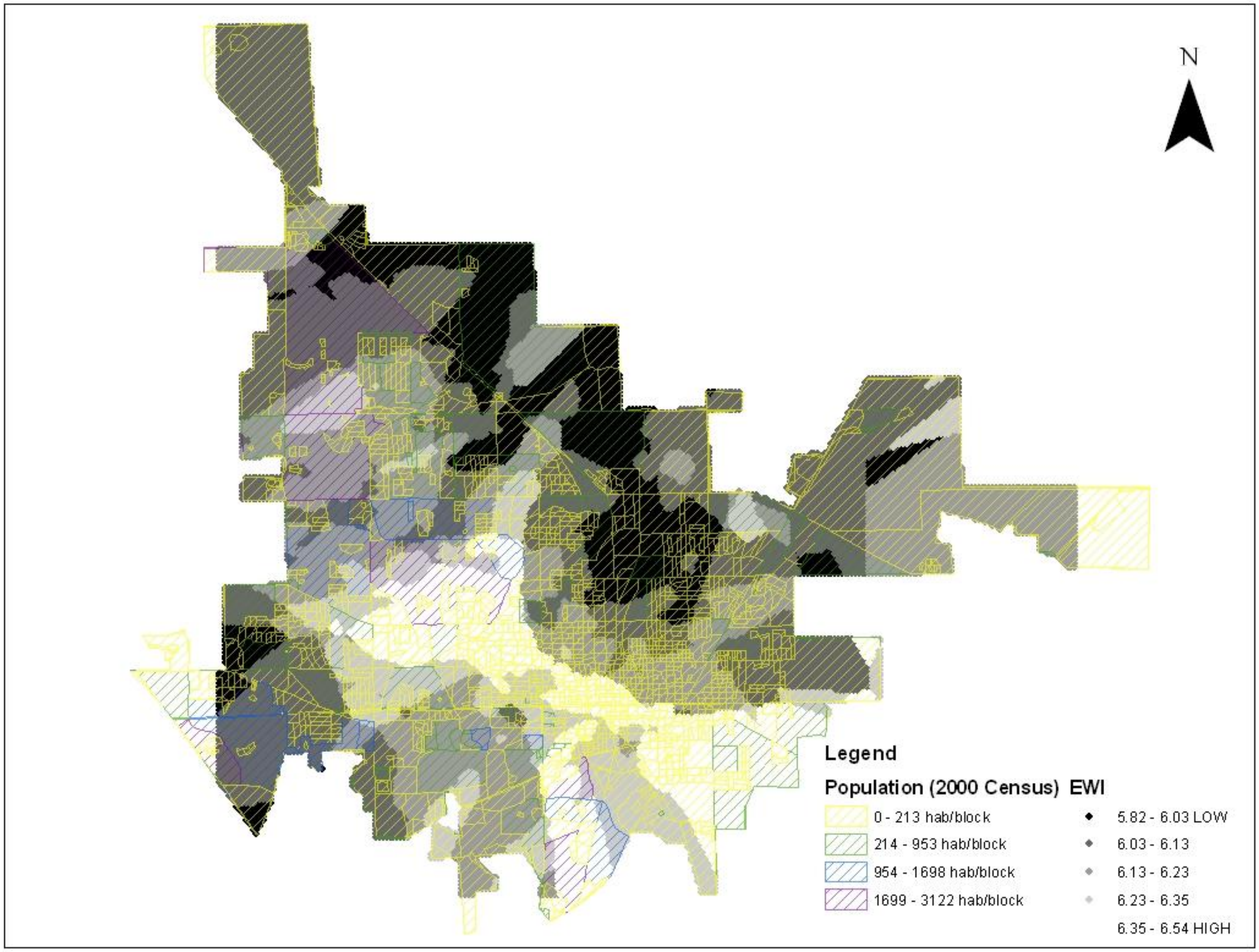

Figure 4-8. Analysis of the Equal Weight Index using ordinary kriging and population classification by 2000 Census Block.

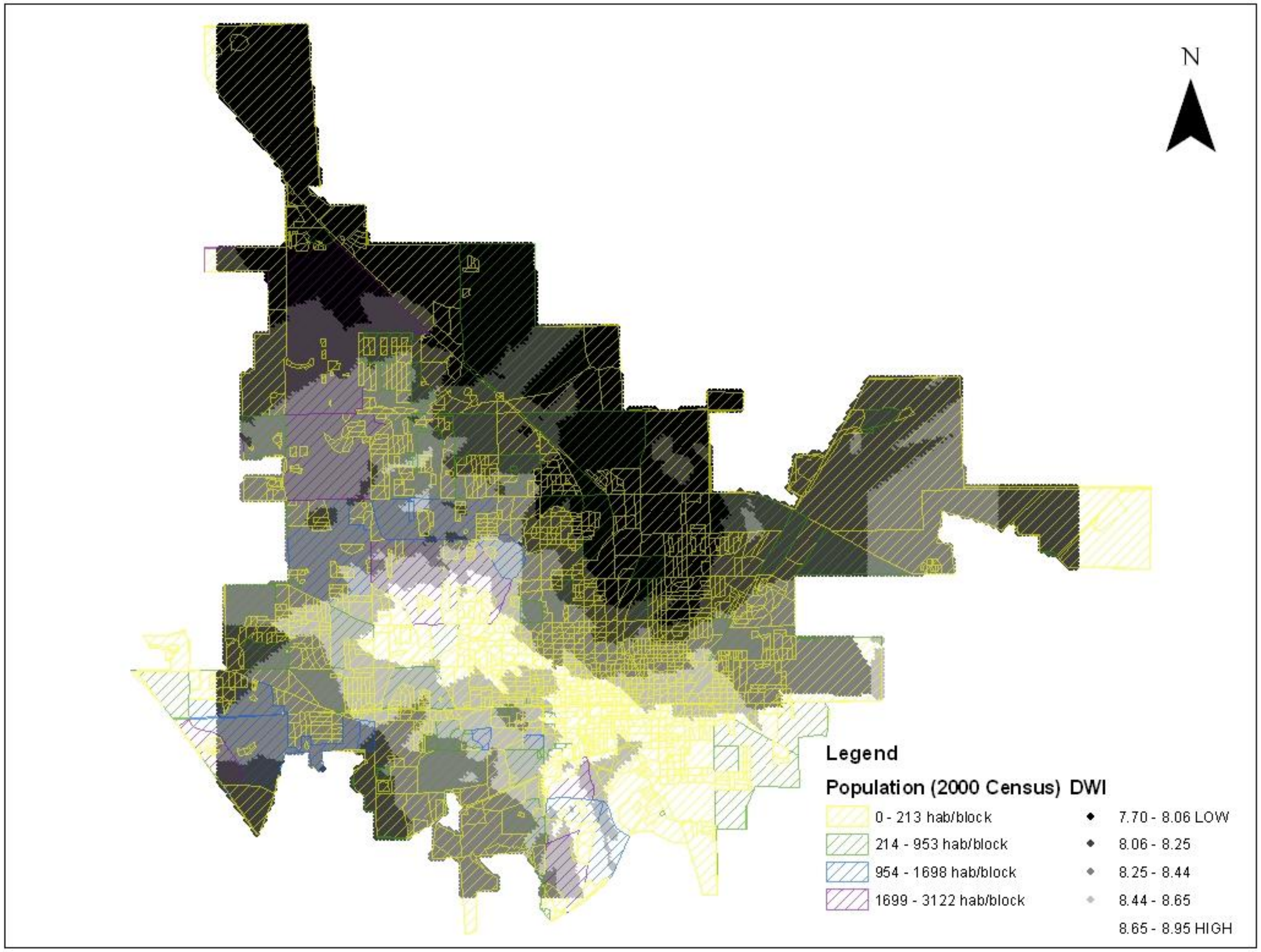

Figure 4-9. Analysis of the Double Weight Information Function Index using ordinary kriging and population classification by 2000 Census Block.

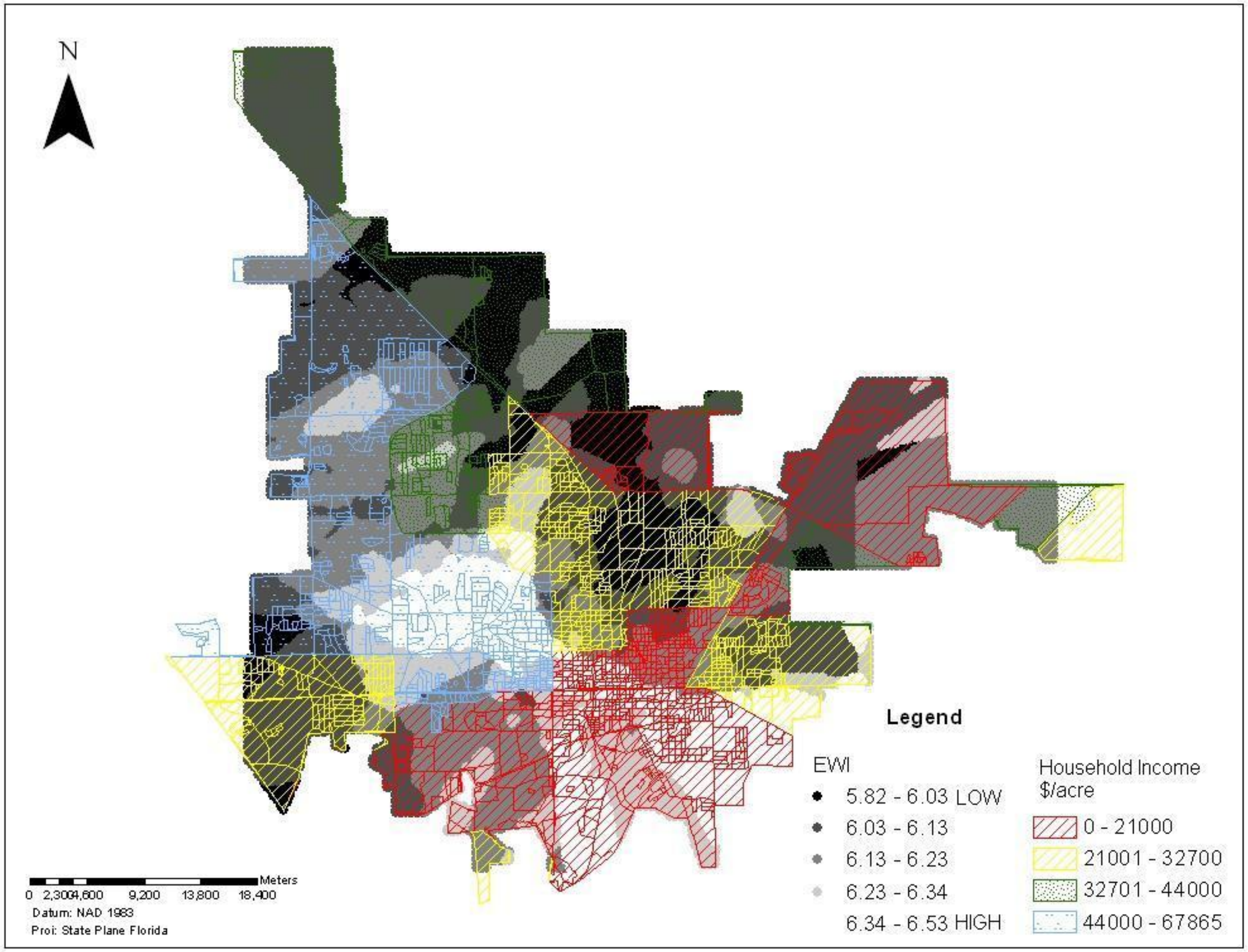

Figure 4-10. Analysis of Equal Weight Index using ordinary kriging and household income classification by 2000 Census Block.

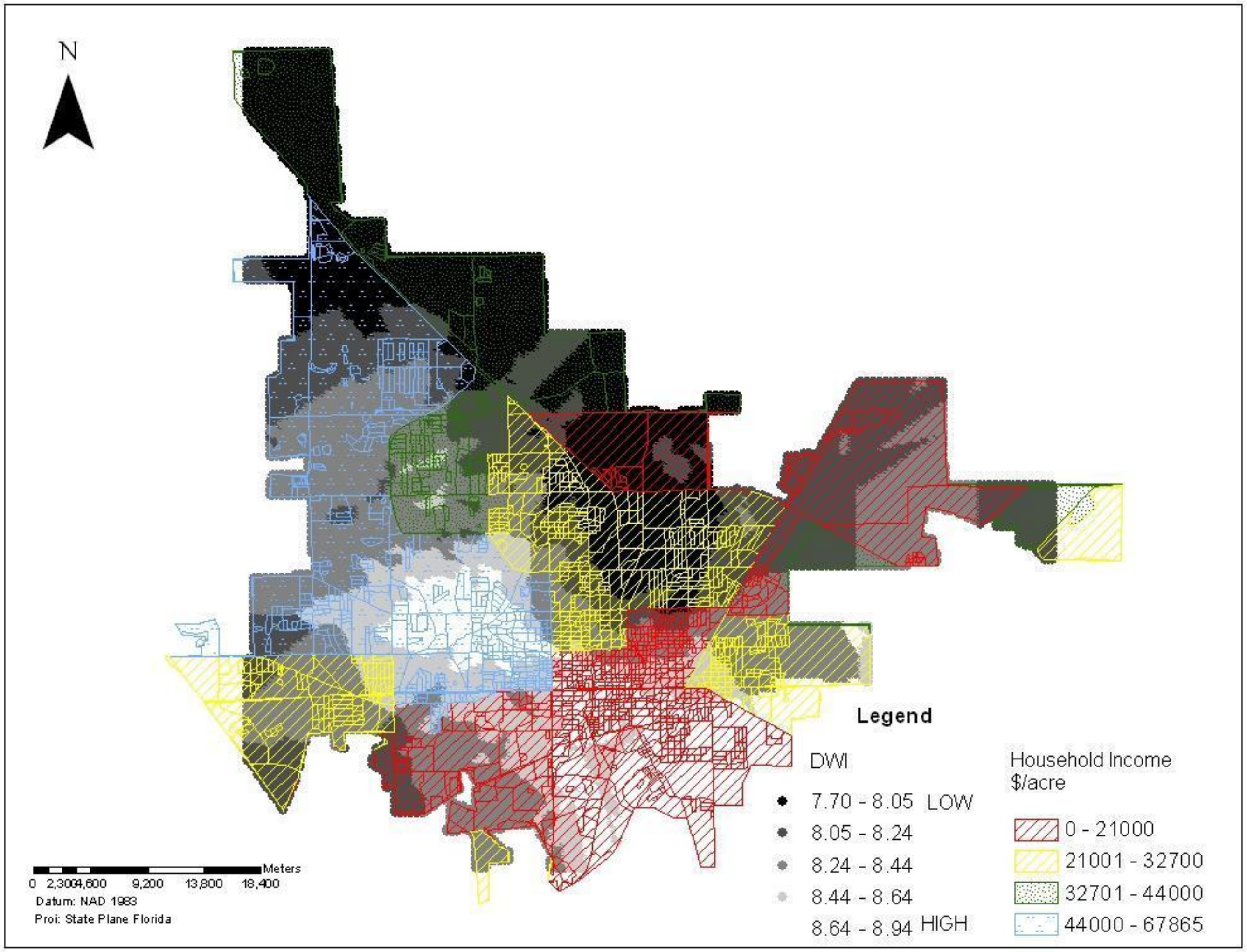

Figure 4-11. Analysis of the Double Weight Information Function Index using ordinary kriging and household income classification by 2000 Census Block.

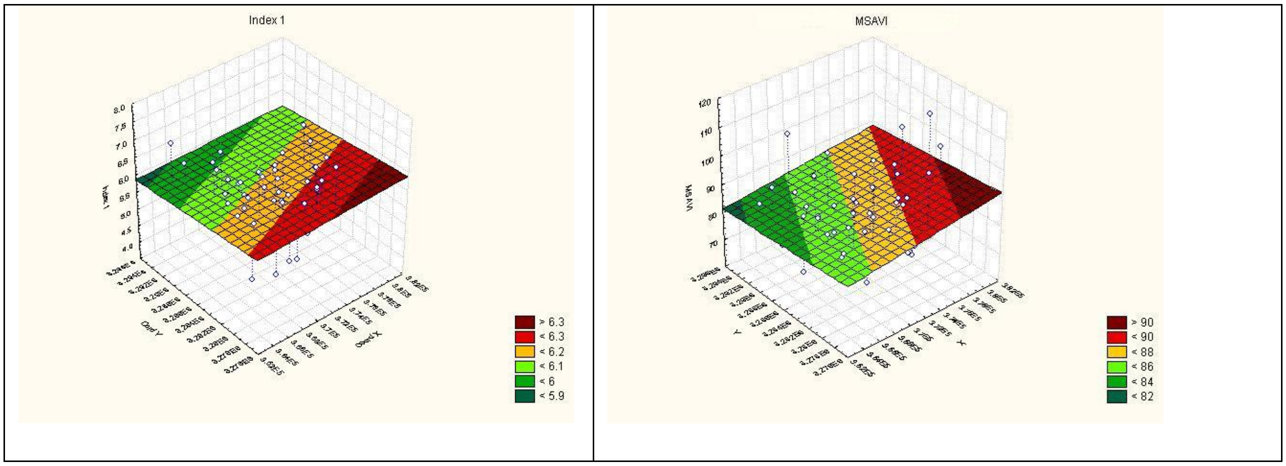

Figure 4-12 Linear trend 3-Dimensional graphs for the Equal Weight Index and Modified Soil Adjusted Vegetation Index. Scales represent the range of value for each ecosystem services and goods and remote sensing index.

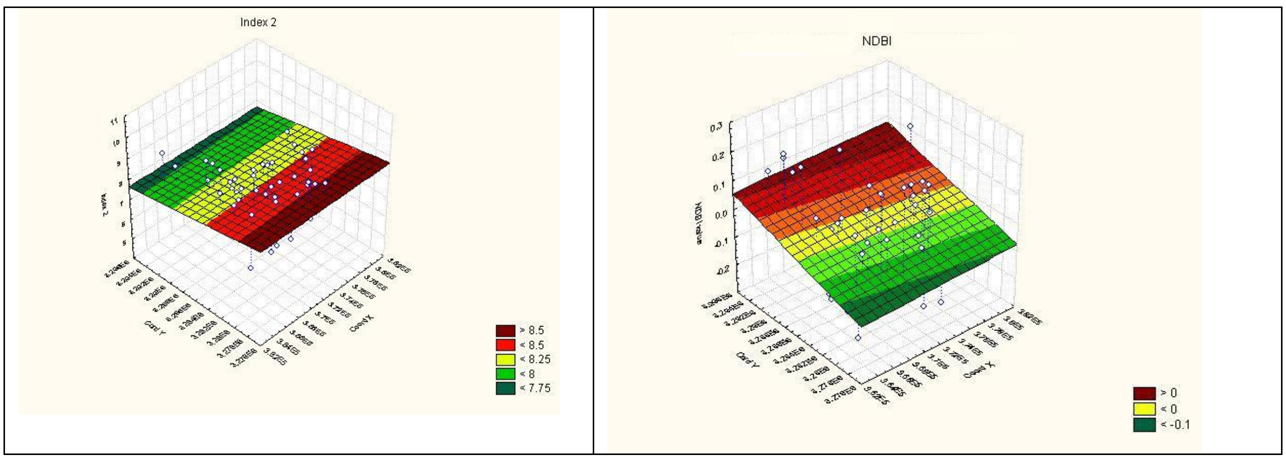

Figure 4-13. Linear trend 3-Dimensional graphs for the Double Weight Information Function Index and Normalized Difference Building Index. Scales represent the range of value for each ecosystem services and goods and remote sensing index.

Table 4-1. Indices based on remotely sensed data

Index	Algorithm
NDVI	(NIR-RED)/(NIR+RED)
MSAVI	$(2*NIR+1-\sqrt{((2*NIR+1))^2-8*(NIR-RED)})/2$
NDBI	NDBI=(MIR-NIR)/(MIR+NIR)

NIR: Near infrared Band; RED: red band; MIR: Mid-infrared band; NDVI, normalized difference vegetation index; MSAVI, modified soil adjusted vegetation index; NDBI, normalized difference build-up index.

Table 4-2. Mean, maximum, and minimum rank for the three index methods and values for sensitivity analysis of ecosystem services and goods functions.

	Stats.	All included	Reg. function eliminated	Hab. function eliminated	Prod. function eliminated	Inf. Function eliminated	Disservices eliminated
EWI	Mean	Plot 90	Plot 90	Plot 90	Plot 90	Plot 90	Plot 90
		Rank #35	Rank #44	Rank #32	Rank #39	Rank #53	Rank #16
	Min.	Plot 242	Plot 242	Plot 242	Plot 242	Plot 242	Plot 242
		Rank #1	Rank #1	Rank #1	Rank #1	Rank #2	Rank #1
	Max.	Plot 186	Plot 186	Plot 186	Plot 186	Plot 186	Plot 186
		Rank #69	Rank #68	Rank #67	Rank #63	Rank #64	Rank #68
DWI	Mean	Plot 314	Plot 314	Plot 314	Plot 314	Plot 314	Plot 314
		Rank #35	Rank #33	Rank #34	Rank #46	Rank #12	Rank #39
	Min.	Plot 242	Plot 242	Plot 242	Plot 242	Plot 242	Plot 242
		Rank #1	Rank #1	Rank #1	Rank #1	Rank #2	Rank #1
	Max.	Plot 188	Plot 188	Plot 188	Plot 188	Plot 188	Plot 188
		Rank #69	Rank #65	Rank #68	Rank #69	Rank #57	Rank #69
PCAI	Mean	Plot 361	Plot 361	Plot 361	Plot 361	Plot 361	Plot 361
		Rank #35	Rank #34	Rank #41	Rank #41	Rank #44	Rank #29
	Min.	Plot 336	Plot 336	Plot 336	Plot 336	Plot 336	Plot 336
		Rank #1	Rank #1	Rank #2	Rank #3	Rank #1	Rank #1
	Max.	Plot 114	Plot 114	Plot 114	Plot 114	Plot 114	Plot 114
		Rank #69	Rank #69	Rank #69	Rank #68	Rank #69	Rank #69

Reg, Regulation; Hab, Habitat; Prod, Productivity; Inf, Information; EWI, Equal Weight Index; DWI, Double Weight Information Function Index; PCAI, Eigenvalue-based Weight Index.

Table 4-3. Mean, minimum, and maximum values for ecosystem services and goods indices.

		Plots				Ordinary Kriging				p-values
	Quadrant	Mean	Std. Error	Min	Max	Mean	Std. Error	Min	Max	
EWI	NE	6.32	0.170	5.95	6.68	6.11	0.009	6.08	6.13	NS
	NW	6.10	0.110	5.87	6.33	6.18	0.006	6.17	6.19	NS
	SE	5.95	0.190	5.49	6.41	6.36	0.009	6.34	6.38	NS
	SW	6.06	0.210	5.53	6.58	6.17	0.011	6.15	6.19	NS
DWI	NE	8.62	0.230	8.13	9.11	8.18	0.002	8.18	8.19	NS
	NW	8.19	0.160	7.86	8.53	8.26	0.001	8.26	8.27	NS
	SE	7.97	0.290	7.29	8.65	8.72	0.002	8.72	8.73	0.03
	SW	7.91	0.320	7.11	8.70	8.35	0.002	8.35	8.36	0.05

NS, no significant differences. NE, NorthEast; NW, NorthWest; SE, SouthEast; SW, SouthWest; EWI, Equal Weight Index; DWI, Double Weight Information Function Index.

Table 4-4. Mean, minimum, and maximum values for ecosystem services and goods indices by land use

		Plots				Ordinary Kriging				p-value
	Land Use	Mean	Std. Error	Min	Max	Mean	Std. Error	Min	Max	
EWI	C	6.00	0.240	5.43	6.57	6.145	0.009	6.13	6.16	NS
	F	6.02	0.150	5.71	6.33	6.186	0.014	6.16	6.21	NS
	I	5.89	0.250	5.31	6.47	6.183	0.010	6.16	6.25	NS
	R	6.32	0.090	6.11	6.52	6.209	0.008	6.19	6.23	NS
	V	7.08	0.120	5.57	8.59	6.362	0.001	6.14	6.22	NS
DWI	C	7.99	0.380	7.10	8.88	8.180	0.003	8.17	8.19	NS
	F	7.96	0.210	7.54	8.39	8.169	0.005	8.16	8.18	NS
	I	7.97	0.340	7.19	8.76	8.279	0.003	8.27	8.29	NS
	R	8.66	0.140	8.37	8.95	8.371	0.004	8.37	8.38	NS
	V	9.25	0.120	7.74	10.76	8.594	0.008	8.58	8.61	NS

NS, no significant differences C, commercial; F, forested; I, institutional; R, residential; V, vacant; EWI, Equal Weight Index; DWI Double Weight Information Function Index.

Table 4-5. Mean, minimum, and maximum values for indices by population

		Plots				Kriging				P-
	Population (hab/block)	Mean	Std. Error	Min	Max	Mean	Std. Error	Min	Max	value
EWI	0-953	6.38	0.130	6.12	6.65	6.18	0.006	6.16	6.19	NS
	954-1698	5.95	0.120	5.69	6.21	6.22	0.018	6.17	6.26	NS
	1699-3503	6.08	0.290	5.45	6.70	6.19	0.013	6.16	6.22	NS
	>3503	6.11	0.130	5.83	6.39	0	0	0	0	NS
DWI	0-953	8.55	0.180	8.17	8.94	8.29	0.002	8.28	8.29	NS
	954-1698	8.07	0.190	7.66	8.49	8.39	0.003	8.38	8.39	NS
	1699-3503	8.11	0.390	7.26	8.97	8.31	0.005	8.30	8.32	NS
	>3503	8.24	0.210	7.79	8.69	0	0	0	0	NS

NS, no significant differences EWI, Equal Weight Index; DWI Double Weight Information Function Index.

Table 4-6. Mean, minimum, and maximum values for indices by household income

		Plots				Kriging				P-
	Household Income (US$)	Mean	Std. Error	Min	Max	Mean	Std. Error	Min	Max	value
EWI	0-21,000	6.21	0.200	5.78	6.64	6.23	0.009	6.21	6.25	NS
	21,000-32,700	6.06	0.140	5.77	6.34	6.13	0.009	6.11	6.15	NS
	32,701-44,000	6.28	0.150	5.87	6.69	6.08	0.007	6.06	6.09	NS
	>44,000	6.16	0.130	5.89	6.42	6.23	0.008	6.21	6.24	NS
DWI	0-21,000	8.47	0.240	7.96	8.99	8.41	0.003	8.41	8.42	NS
	21,000-32,700	8.09	0.210	7.67	8.52	8.24	0.003	8.23	8.24	NS
	32,701-44,000	8.35	0.290	7.56	9.15	8.07	0.002	8.07	8.07	NS
	>44,000	8.30	0.190	7.89	8.71	8.37	0.003	8.36	8.37	NS

NS, no significant differences EWI, Equal Weight Index; DWI Double Weight Information Function Index.

CHAPTER 5
CONCLUSIONS

Summary

Gainesville's tree cover is higher than other cities of the U.S. Its distribution is not only restricted to the city limits but includes treed areas in the middle of the city. This special characteristic of the city makes that some areas found in the central core of the city have similar characteristics to natural forest existing in surroundings areas. The most influential structure variable on the calculation of ecosystem services and goods indicators is tree cover, which is used for several indicators. Soils properties vary widely according to urban development, but less urbanized areas show values similar to natural areas. The most influential variable on the state of the soils is pH and organic matter.

Gainesville's urban forest is influenced by the complexities existing in urban morphology and site legacy. Its state not only depends on socioeconomics dynamics and on urban planning policies but also on the priorities established by city managers. Indicators are showing the effect of urbanization on the environment through the value of the ecosystem functions that group services and goods at multiple scales. The calculation of the indicator for each service was based on field data, accepted theories, concepts, techniques and scientific standards and principles. The index provides a way to assess the state of the urban forest ecosystem services and goods at a certain moment in time. Once the data is obtained the calculation of the index is repeatable and easy to compute. It results in a simple number that is suitable and understandable for comparison. The index is relevant since it measures the state of the ecosystem and could have implications for human health and well-being. The index could be policy relevant since it could be used to aid decision makers on how a policy or management regime is affecting the ecosystem.

The kriging technique used in this study can provide reliable estimates of the urban forest ecosystem services and goods. On the other hand, remote sensing indices do not correlate well with the ecosystem services and goods index, since it is not capturing all the urban ecosystem components. Better results might be achieve if the remote sensing indices were to be correlated with just the regulation function which is dependent on tree leaf area and biomass and is more easily measured using remotely sensed data.

Limitations, Implications and Future Research

Gainesville's Urban Forest

The use of UFORE model for the estimation of the structure and the functions of the urban forest could be over or underestimating the real values of Gainesville's urban forest. The UFORE model uses equations developed with species from the Northern US. Tree species in the South have different growth rates, therefore the calculations of biomass and leaf area and its respective carbon stored and sequestered and air pollution removal values are misleading. Future work should include the use of biomass models adequate to the area where the UFORE model is being applied. In the case of Gainesville the model should take into account algorithms that correspond to subtropical tree species, thereby increasing the accuracy of the estimates. Studies like these could be greatly benefitted by accounting for the ecosystem functions provided by shrubs and maintained grass. With this a better system-level estimation of the services and goods they are providing to urban areas could be evaluated.

Increasing sampling size could disclose relationships with socioeconomics that were not evident in this study. A better distribution of the plots could also improve the results, giving a better representation of all the urban forest structures existing in the urban area.

Ecosystem Services and Goods Indicators

This study's indicators of urban forest ecosystem services and goods are dependent on local field data. The services and goods chosen for each function depend on data availability and do not include all those found in an urban area. The inclusion of additional services and disservices is necessary to give a more complete state of the urban ecosystem. Categories of the indicators were developed based on available values from the literature and the data ranges found in the city of Gainesville. Several assumptions were made to develop these indicators, however by adjusting for these local differences, this could make them applicable to different urban areas. The categorization of functions in this study facilitates their application to other cities by creating a same scale for different services.

Urban Forest Ecosystem Services and Goods Index

The integration of the indicators into an index aids in determining the best structure and composition arrangements of the urban forest that could be maximizing the delivery of services and goods (e.g. best management practices). It incorporates environmental knowledge to the process of decision making. The construction of the index does not include priorities or perceptions of the people living in the study area. To improve the accuracy of the index, surveys should be done to evaluate which services or goods are seen as more valuable to the population. According to this information the correct weighting could be applied to the indicators thereby facilitating the calculation of the index.

The urban system is dynamic and very complex, therefore the index cannot forecast future trends. Urban ecosystems not only depend on the natural changes of the environment caused by urbanization, but also are dependent on urban planning, policies and trends in the socioeconomics dynamics. Only rough estimates on how the value of the index will change if a certain policy is applied. The index should be in constant re-evaluation, since new ecosystem services could be appearing. It is important that the index be flexible, since ecosystem services and goods are still evolving as understanding of urban ecosystems increases.

Policy-Management Recommendations

Recognizing that urbanization could have positive implications for human well being is determinant for maximizing the benefits in urban areas thereby improving quality of life. As seen in this study, urban forests are not only a source of disservices they also provide valuable service and goods to the community. Moreover with time, certain urban forest ecosystem structure variables reach an equilibrium on the delivery of ecosystem services and goods similar to natural surrounding areas. This could be showing a resilience of the ecosystems when being submitted to the process of urbanization and is directly related to socioeconomic characteristics and morphology of the urban areas. Variables such as the value of the property and the time since the property was urbanized are determining in most cases the delivery of ecosystem services and goods.

The use of an index could help in communicating to the population the state of their urban forest ecosystem services and goods and the management regimes that could be applied to maximize this benefits. The index could also be seen as a tool for comparison among urban areas, but standardization of the categories should be applied.

Several management practices could be implemented to maximize and improve the benefits delivered by urban forests. The key to the success of these management practices is letting the community know the state of their urban forest and possible improvements that they could do. We should teach the community easy and effective management practices that could translate to long term improvements in the quality of the urban forest.

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BIOGRAPHICAL SKETCH

Cynnamon Dobbs Brown was born in Santiago, Chile in 1979. She obtained a B.S degree in Forest Engineer in 2003, during her college years she worked on research related to urban forestry and environment in Santiago, Chile. After that she joined an environmental consulting firm, where she worked during two years developing areas in GIS, vegetation, soils and fauna. The job required field work, reports and maps and included public and private projects. She started her graduate career in 2007 with emphasis in urban ecology, specially working with trees and soils. She plans to continue her education in the Science department of University of Melbourne, Australia.