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Modeling air pollutant removal, carbon storage, and CO_2 sequestration potential of urban forests in Scotlandville, Louisiana, USA

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Understanding an urban forest's structure, function, and value can promote management decisions that will improve environmental quality and human health. Using i-Tree Eco software and its sampling and data collection protocol, an assessment of the baseline condition, ecological function, and value of the urban forests in Scotlandville (Louisiana, USA) was conducted during 2014. A stratified (by land use type) random sample plot map of the town was generated. Data from 170 field plots located throughout Scotlandville were collected, including tree species, diameter at breast height, total tree height, height to live top, height to crown base, crown width, crown dieback, crown light exposure, percent impervious surface under the tree, and direction and distance to building. Data were then entered into i-Tree Eco v5.0 and analyzed. Modeling results indicated that there are a total of 31 species and an estimated 239,000 trees in Scotlandville with a tree canopy cover of 23.7 percent; the three most common species are Black willow (*Salix nigra*), Water oak (*Quercus nigra*), and American elm (*Ulmus americana*); the overall tree density is 77 trees per hectare and trees with diameters of more than 15 cm (6 inches) constitute 56.5% of the population. The model estimated that annually, the urban forests in Scotlandville remove 96 tons of air pollutants; gross sequestration is about 3,880 tons of carbon and net carbon sequestration is about 3,650 tons. Each year, trees in Scotlandville are estimated to store 88,700 tons of carbon, produce 9,720 tons of oxygen, reduce runoff by 121,200 m^3, reduce energy-related costs by $324,000 USD, and provide an additional $52,595 in value by reducing the amount of carbon released by power plants (a reduction of 739 tons of carbon emissions). The structural value for Scotlandville community forest is estimated at $185 million and the annual ecological functional value is estimated at 9 million USD. These results provide baseline information for management recommendations to maximize the ecological benefits provided by trees.

Keywords: Urban Forest, Pollution Removal, Carbon Sequestration, Carbon Storage, Runoff Reduction, Energy Saving, Climate Change

Introduction

Urban forests are integral components of land use planning because they add both ecological and economic values to local communities by improving air quality, sequestrating and storing carbon, saving energy, preventing runoff, and increasing land values (Broecker 1970, Dwyer et al. 1992, Meza 1992, Beckett et al. 1998, Kuchelmeister 1998, Bolund & Hunhammar 1999, Konijendijk 1999, Abdollahi et al. 2000, Dwyer et al. 2003, West et al. 2009, Pandit & Laband 2010). Air pollution is a persistent environmental problem in most major cities across the world. An important focus of research has been the role of urban vegetation in mitigating air pollutants (Nowak et al. 2006, Davidson et al. 2007, Paoletti Bardelli et al. 2011). Studying the ecological function of urban forests is important because of their geographic extent, their impact on local economies, and their proximity to people (Rowntree & Nowak 1991, Nowak & Walton 2005, McPherson 2006, Wolf 2009, Nowak et al. 2010a). A great deal of attention has been given to the sustainability of urban forests worldwide due to present global climatic changes. The ecological function that contribute to the quality of urban life should

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be assessed in quantitative and monetary terms because, to achieve a sustainable urban forest, the forest has to be founded upon community cooperation, quality care, continued funding, and personal involvement (Clark et al. 1997, Tyrväinen & Väänänen 1998).

i-Tree is a software suite created by the research scientists of the United States Department of Agriculture Forest Service and their partners (USDA 2015). The i-Tree suite consists of seven analysis models that provide urban and community forestry analysis and benefits assessment tools. Among them, i-Tree Eco, formerly known as the Urban Forests Effects (UFORE) model (Nowak & Crane 2000), was designed to use standardized field data from randomly located plots, as well as local hourly air pollution and meteorological data, to quantify urban forest structure, ecological function, and the associated value (Maco & McPherson 2003, Nowak et al. 2008a, McPherson 2010b). Some of the attributes that i-Tree Eco can quantify are: species composition, tree health, and leaf area; amount of pollution removed annually by the urban forest, including ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, and particulate matter (<2.5 microns and <10 microns), and its associated percent air quality improvement; total carbon stored and net carbon annually sequestered by the urban forest; effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants; storm water runoff reduction; structural value of the forest, as well as monetary value for its ecological function (Nowak et al. 2008b, 2010b, 2013, Abd-Elrahman et al. 2010, Mc Pherson 2010a, Hirabayashi et al. 2011, Martin 2013).

To preserve, manage, and sustain the urban forests in Scotlandville, Louisiana (USA), an assessment of the city's urban forests is needed to make the policy makers, city managers, and the general public aware of the ecological benefits that their city trees provide. Communicating the benefits only with intangible values would not be convincing unless these values are expressed in monetary terms. The application of i-Tree Eco in Scotlandville can better demonstrate the need for investment in the city's urban forests.

There is no baseline information available on the structure, ecological function, and value of the urban forests in Scotlandville. Our research objectives were: (1) to assess the urban forest structure in Scotlandville; and (2) to estimate the urban forest ecosystem services and associated values. The results can be used to provide recommendations to Scotlandville's authorities for better management of its urban forests so as to maximize the ecological benefits they provide. The study area is important because of its association with the Mississippi river, the oil refinery, and the Baton Rouge Metropolitan Airport (Fig. 1). Baseline data can be used for making effective resource management decisions, developing policies, and setting priorities for Scotlandville. Better-managed urban forests in this area can contribute to watershed protection along the river and the removal of air pollutants emitted by the oil refinery and air traffic.

Material and methods

Study area

Scotlandville is a community located in East Baton Rouge Parish of the state of Louisiana, USA (latitude 30.5204668 N, longitude 91.1787186 W). Situated in a temperate climate zone, its elevation is 17.70 m a.s.l. Consisting of twenty-one distinct subcommunities as identified by the Scotlandville Comprehensive Community Development Plan, and according to the US Census Bureau data, Scotlandville is divided into six different census tracts, with a combined population of 27,230 on a total of 3060.31 hectares of land.

Establishment of sample plots

Utilizing ESRI ArcGIS ® software with the spatial analysis extension, a stratified (by land use/cover type) random sample plot map was generated (Fig. 1). The following land use strata were deployed for the study area:

1. *Commercial* : factories, airports, other industrial areas, warehouses, and large

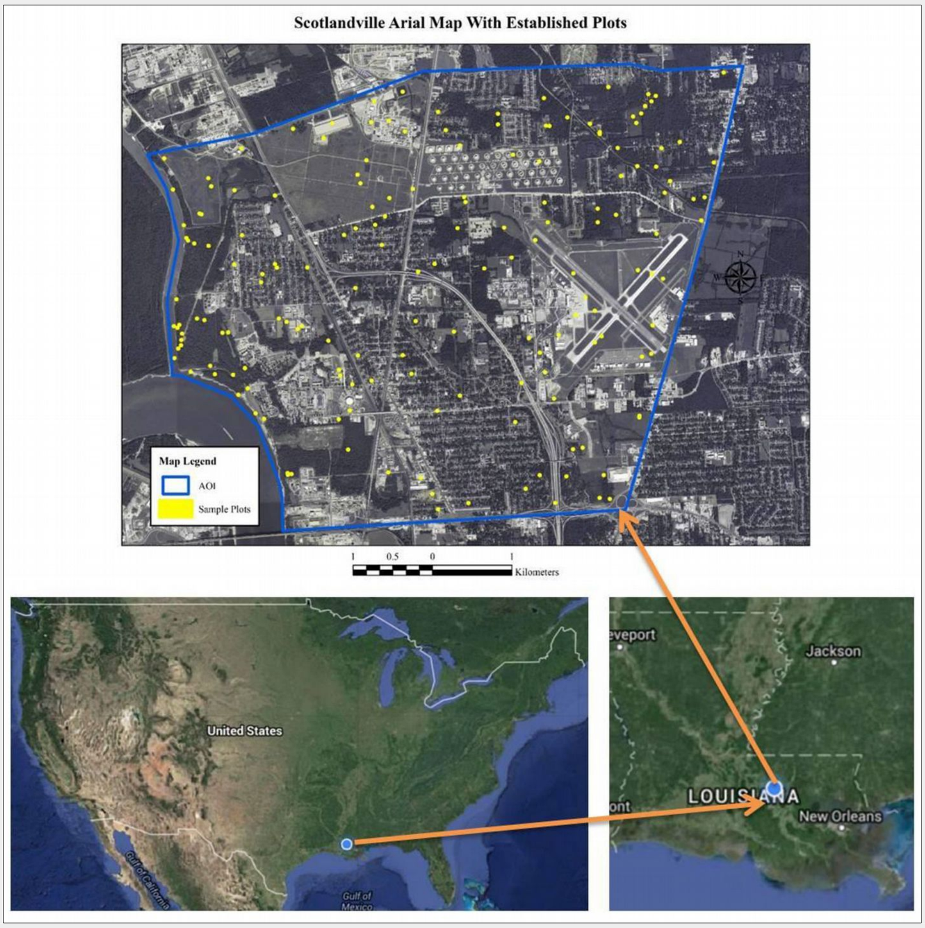

Fig. 1 – Map of the study area with indication of sample plots (yellow circles).

shopping centers. In addition to standard commercial and industrial land uses, this category includes outdoor storage/staging areas as well as parking lots that are not connected with a residential use.

2. *Residential*: including freestanding structures serving one to four families each, multi-family residential, and structures containing more than four residential units. Residential complexes consisting of many separate one- to four-family structures and related green space are also considered multi-family residential.
3. *Wetland*: consisting of swamps and saturated lands.
4. *Water*: streams, rivers, lakes, and other water bodies (natural or man-made).
5. *Grassland*: lands covered mainly with grass.
6. *Forest*: lands covered with forests.

The 2006 USGS National Land Cover Database (NLCD) data was employed for these strata. A GIS map layer representing the study area polygon(s) for Scotlandville was obtained from http://www.esri.com/data. A total of 170 circular plots were randomly plotted with 404.69 m^2 per plot.

Data collection and analysis

Following the i-Tree Eco data collection protocol (http://www.itreetools.org/) developed by the US Forest Service, Northern Research Station, field data were collected from the 170 plots during the leaf-on season in 2014 to properly assess tree canopies. Data collected included land use, ground and tree cover, tree species, diameter at breast height (dbh), total tree height, height to live top, height to crown base, crown width, crown dieback, crown light exposure, percent impervious surface under the tree, and direction and distance to building. Data were then entered into i-Tree Eco v5.0 for analysis.

Calculation of ecological function and associated economic value using i-Tree Eco

Air pollution removal

Air pollution removal estimates were derived from calculated hourly tree-canopy resistances for ozone, sulfur dioxide, and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi et al. 1987, Baldocchi 1988). Canopy resistances mainly refer to the result of stomatal regulation. Canopy resistances have three components: stomatal resistance, mesophyll resistance, and cuticular resistance (Nowak et al. 2006). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell & Fraser 1972, Lovett 1994) and were adjusted depending on leaf phenology and leaf area. Recent updates to air quality modeling are based on improved leaf area index simulations, weather, pollution processing and interpolation, and updated pollutant monetary values (Hirabayashi et al. 2011, Hirabayashi 2013).

The air pollution removal value was calculated based on local incidence of adverse health effects and national median externality costs (Nowak et al. 2014). The number of adverse health effects and associated economic value was calculated for ozone, sulfur dioxide, nitrogen dioxide, and particulate matter using the US Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP) model. The model uses a damage-function approach that is based on the local change in pollution concentration and population (Davidson et al. 2007). The monetary value of pollution removal by trees was estimated using the median externality values for the United States for each pollutant (Murray et al. 1994). These values were adjusted to 2007 values based on the producer's price index by the Capital District Planning Commission. Pollution removal value was calculated based on the prices of $1,136 per ton of carbon monoxide, $3,496 per ton of ozone, $622 per ton of nitrogen dioxide, $208 per ton of sulfur dioxide, $14,749 per ton of particulate matter less than 10 microns and greater than 2.5 microns, and $148,412 per ton of particulate matter less than 2.5 microns.

Carbon sequestration and storage

To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data (Nowak 1994). Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations. To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5. To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1. To estimate monetary value associated with urban tree carbon storage and sequestration (Nowak et al. 2008a), carbon values were based on the estimated marginal social costs of carbon dioxide emissions for 2001 to 2010 (Fankhauser 1994).

Oxygen production

The amount of oxygen produced was estimated from carbon sequestration based on atomic weights: net O_2 release ($kg\ yr^{-1}$) = net C sequestration ($kg\ yr^{-1}$) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth was reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition after tree death (Nowak et al. 2007).

Runoff prevention

Annual avoided surface runoff was calculated based on rainfall interception by vegetation. Specifically, it is the difference between annual runoff with and without vegetation. Although tree leaves, branches and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves was accounted for in this analysis (Hirabayashi 2013). The value of avoided runoff was based on estimated or user-defined local values indicated on the US Forest Service's Community Tree Guide Series (US Forest Service).

Energy saving

Seasonal effects of trees on residential building energy use were calculated based on procedures described in the literature by McPherson & Simpson (1999), using data for distance and direction of trees from residential structures, tree height, and tree condition. To determine the estimated economic impact of the change in building energy use (Nowak et al. 2008a), state average price per kWh between 1970 and 2002 by the Energy Information Administration and per MBtu for natural gas, residential fuel, and wood between 1990 and 2002 were used. All prices were adjusted to 2002 US dollars using the consumer price index of the US Department of Labor and Statistics. State prices were used to determine the value of energy effects. Average price for heating change resulting from trees is based on the average distribution of buildings in the region that heat by natural gas, fuel oil, and other means (including wood – McPherson & Simpson 1999).

Structural values

The structural value of the trees (Nowak et al. 2002, 2008a) was estimated by methods from the Council of Tree and Landscape Appraisers (Gooding et al. 2000). Compensatory value was based on four tree/site characteristics: trunk area (cross-sectional area at dbh), species, condition, and location. Trunk area and species were used to determine the basic value, which was then multiplied by condition and location ratings (0 to 1) to determine the final tree compensatory value. Local species factors, average replacement cost, and transplantable size and replacement prices were obtained from ISA publication (Neely 1988). Condition factors were based on percent crown dieback.

Results

Tree species composition, size, and distribution

i-Tree Eco estimated that Scotlandville

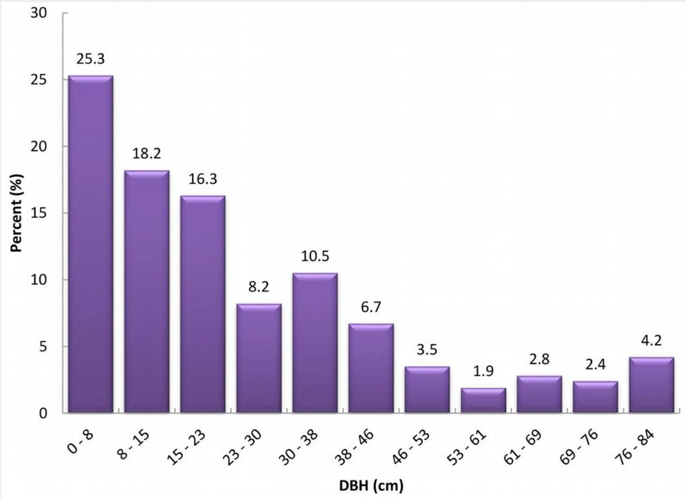

Fig. 2 - Tree population by diameter class (DBH): stem diameter at 1.4 m.

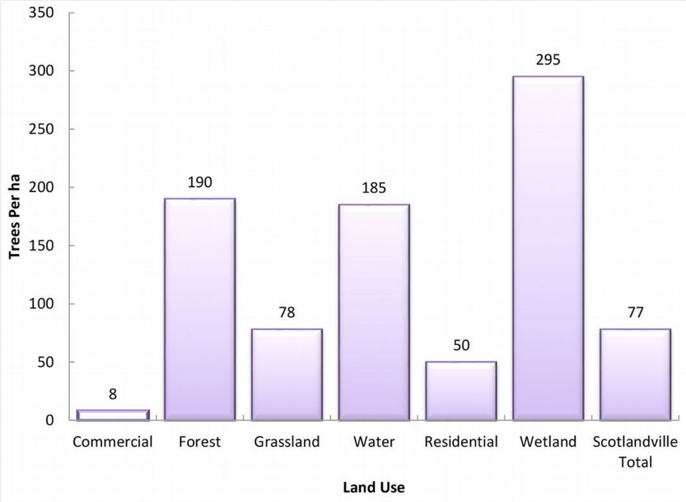

Fig. 3 - Tree density (number of trees per ha) on different land use type.

has 239,000 trees and the estimated tree cover is 23.7%. Small trees with diameter < 15 cm constitute 43.5% of the population (Fig. 2), whereas mid-size trees with DBH between 15 and 46 cm account for a 41.7%. Only 14.8% of the populations are trees with DBH larger than 46cm. A total of 31 different tree species were detected in Scotlandville, with the top three most common species (Tab. 1) being Black willow (*Salix nigra* – 16.9%), Water oak (*Quercus nigra* – 11.6%), and American elm (*Ulmus americana* – 11.1%). About 63% of the trees are species native to North America, and 57% are native to the state. Species exotic to North America make up 37% of the population, with 6.6% from South America, 5.9% from Asia, and 0.8% from elsewhere.

The tree density in Scotlandville is 77 trees per hectare, and the highest tree density occurred in the wetland land cover/use type (295 trees ha^{-1}), followed by forest (190 trees ha^{-1}) and water (185 trees ha^{-1}) land use types (Fig. 3). The tree density is higher in the wetland and water land-cover/use types because these cover types are mostly located on the west side of Scotlandville along the Mississippi River, where a large extension of undisturbed forest patches occur.

Tree leaf area

Among species in Scotlandville, Water oak, Black willow, Sugar maple (*Acer saccharum*), Willow Oak (*Quercus phellos*), and American elm ranked as the top five species in leaf area, with 9.63, 4.95, 4.45, 3.13, and 2.85 per km^2, respectively (Tab. 1). Leaf area is what provides the environmental services (Gower et al. 1999, Marshall & Waring 1986, Reich et al. 1992). Many ecological benefits provided by a tree equate directly to the amount of healthy leaf surface area of the tree. The greater the leaf area of a tree, the greater the shade it is provided, the carbon that is sequestered, the amount air pollution removed, and the amount of storm-water intercepted (Bidwell & Fraser 1972, Baldocchi et al. 1987, Baldocchi 1988).

Tree health condition

Of all the trees inventoried within the 170 sample plots, 92% showed excelled health conditions as determined by the i-Tree model. Seven percent (7%) were in good

Tab. 1 - Top ten ranked tree species by population in Scotlandville. (a): Percent of total tree population in Scotlandville; (b): Percent of total tree leaf area in Scotlandville; (c): Percent of population plus percent of leaf area.

Species	Number of trees	Percent of Population (%)[a]	Leaf area per km^2	Percent of Leaf Area (%)[b]	Importance Value[c]
Water Oak (*Quercus nigra*)	27,860	11.6	9.63	24.0	35.7
Black Willow (*Salix nigra*)	40,423	16.9	4.95	12.3	29.2
American Elm (*Ulmus americana*)	26,592	11.1	2.85	7.1	18.2
Sugar Maple (*Acer saccharum*)	14,537	6.1	4.45	11.1	17.2
Willow Oak (*Quercus phellos*)	12,943	5.4	3.13	7.8	13.2
Sweetgum (*Liquidambar styraciflua*)	17,124	7.2	1.92	4.8	11.9
Southern Red Oak (*Quercus falcata*)	18,783	7.9	0.65	1.6	9.5
Tallowtree (*Triadica sebifera*)	15,219	6.4	1.19	3.0	9.3
Red Maple (*Acer rubrum*)	10,255	4.3	1.45	3.6	7.9
Lagerstroemia spp.	9,968	4.2	0.98	2.5	6.7

condition and 1% was fair. None of the trees were determined to be in poor health condition, 0% were dying, and 0% were dead.

Air pollution removal

We estimated that each year, trees and shrubs in Scotlandville remove 96 tons of air pollutants (Tab. 2), including ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter < 10 microns and > 2.5 microns (PM_{10}), particulate matter < 2.5 microns ($PM_{2.5}$), and sulfur dioxide (SO_2). Pollution removal was greatest for ozone (39.54 ton year^{-1}) and PM_{10} (38.07), and lowest for CO (1.76) and $PM_{2.5}$ (2.68). The tree ecological functional value (avoided costs) associated with the pollution removal is $1.1 million.

Carbon storage and sequestration

It was estimated that the urban forests in Scotlandville store 88,700 tons of carbon. The gross carbon sequestration was about 3,880 tons of carbon per year, its associated ecological functional value (avoided cost) was $276,000, and its net carbon sequestration was about 3,650 tons. The ten species mostly contributing to carbon sequestration (in descending order of importance) were: Water oak, Black willow, Sugar maple, Willow oak, Live oak (*Quercus virginiana*), Pecan (*Carya illinoinensis*), American elm, Red maple (*Acer rubrum*), Sweetgum (*Liquidambar styraciflua*), and *Lagerstroemia* spp. (Tab. 3). The land use type showing the largest amount of estimated elemental carbon being stored by trees is wetland (46.5%), followed by residential (45.8%), grassland (3.3%), water (1.9%), forest (1.5%), and commercial (1%).

Tab. 2 - Annual pollution removal by trees in Scotlandville and the associated value (avoided costs).

Pollutants	Removal (Ton)	Value (US$ × 1000)
CO	1.76	2.00
NO_2	8.65	5.38
O_3	39.54	138.24
PM10	38.07	561.46
PM2.5	2.68	397.62
SO_2	5.69	1.18
Total	96.39	1101.88

Oxygen production

Oxygen production is one of the most commonly cited benefits of urban trees. The net annual oxygen production of a tree is directly related to the amount of carbon sequestered by the tree, which is tied to the accumulation of tree biomass. Trees in Scotlandville were estimated to produce 9,720 tons of oxygen per year. Water oak, Black willow, Sugar maple, Willow oak, and Live oak are the top 5 oxygen producers (Tab. 3).

Runoff reduction

The trees of Scotlandville helped to reduce runoff by an estimated 121,200 m^3 per year. Their associated ecological functional value (avoided costs) was $269,000. The five species (Tab. 3) with greatest overall impact on runoff reduction are Water oak, Black willow, Sugar maple, Willow oak, and American elm.

Energy saving

Trees in Scotlandville were estimated to reduce energy-related costs from residential buildings by $324,000 annually. Trees also provide an additional $52,595 in value by reducing the amount of carbon released by power plants (a reduction of 739 tons of carbon emissions).

Ecological functional values and structural value

The annual total ecological functional value of urban forests around Scotlandville was estimated at 9 million US$, including values for an estimate carbon sequestration at $276,000, carbon storage at $6.97 million, pollution removal at $1.10 million, reducing runoff at $269,000, and lower energy costs and carbon emission reductions at $376,595. In addition to the ecological functional values, the urban forests have a structural value based on the trees themselves (*e.g.*, the cost of replacing a tree with a similar tree). The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees (Nowak et al. 2002). The structural value for Scotlandville community forest was estimated at $185 million, with Live oak, Water oak, Sweetgum, Willow oak, and Black oak (*Quercus nigra*) ranked as the top five species (Tab. 3).

Discussion

The standard i-Tree Eco sampling approach establishes approximately 150 to 200 field plots (i-Tree Manual). Based on the analysis of the results of the 14 cities

Tab. 3 - Top ten ranked tree species by ecological functions and values in Scotlandville. (na): species not ranked among top ten for a particular function or value.

Species	Oxygen (tons)	Net Carbon Sequestration (tons yr^{-1})	Runoff Reduction (m^3 yr^{-1})	Carbon sequestration value (US$ × 1000)	Runoff reduction value (US$ × 1000)	Structural value (US$ × 1000)
Water Oak *(Quercus nigra)*	2,243.16	841.18	27,475	59.72	64.60	28.24
Black Willow *(Salix nigra)*	1,247.90	467.96	14,110	33.23	33.17	11.60
Sugar Maple *(Acer saccharum)*	961.72	360.64	12,716	25.61	29.90	10.82
Willow Oak *(Quercus phellos)*	676.08	253.53	8,932	18.00	21.00	11.69
Live Oak *(Quercus virginiana)*	642.46	240.92	3,353	17.11	7.88	42.02
Pecan *(Carya illinoinensis)*	492.04	184.52	3,550	13.10	8.35	8.85
American Elm *(Ulmus americana)*	462.82	173.56	8,105	12.32	19.06	9.51
Red Maple *(Acer rubrum)*	400.83	150.31	4,100	10.67	9.64	na
Sweetgum *(Liquidambar styraciflua)*	394.51	147.94	5,434	10.50	12.78	16.97
Lagerstroemia spp.	388.45	145.67	na	10.34	na	7.27
Tallowtree *(Triadica sebifera)*	na	na	3,404	na	8.00	5.41

Tab. 4 - Values (per ha) of tree effects on carbon storage, carbon sequestration, and pollution removal in 21 cities. Data for thirteen US and two Canadian cities are from the I-tree Eco analysis results posted on http://www.i-tree.org. (a): Saunders et al. 2011; (b): Baró et al. 2014, Chaparro & Terradas 2009; (c): Rogers et al. 2015; (d): Yang et al. 2005; (e): The sum of CO, NO_2, O_3, SO_2, PM_{10} and $PM_{2.5}$.

City	Tree Density (trees ha^{-1})	Carbon Storage (tons ha^{-1} yr^{-1})	Carbon Sequestration (tons ha^{-1} yr^{-1})	Pollution Removal (tons ha^{-1} yr^{-1})^e
Calgary, Canada	165	2.5	0.120	3.6
Atlanta, GA	276	15.9	0.550	39.4
Toronto, Canada	154	6.4	0.258	15.6
New York, NY	65	6.8	0.214	17.0
Baltimore, MD	123	11.5	0.312	16.6
Philadelphia, PA	62	6.3	0.190	13.6
Washington, DC	121	13.3	0.410	21.2
Boston, MA	83	9.0	0.297	16.0
Woodbridge, NJ	164	10.8	0.375	28.4
Minneapolis, MN	65	6.7	0.238	16.4
Syracuse, NY	135	10.8	0.338	13.6
Morgantown, WV	296	17.0	0.532	23.8
Moorestown, NJ	153	12.5	0.400	25.2
Jersey City, NJ	36	2.2	0.094	8.6
Freehold, NJ	95	16.0	0.437	33.6
Scotlandville, LA	77	29.0	0.452	0.1
Perth, Australia^a	83	15.0	0.300	0.2
Barcelona, Spain^b	141	11.2	0.537	0.1
London, UK^c	53	15.0	0.490	0.1
Beijing, China^d	79	7.4	0.378	0.3
Houston, TX	337	20.0	0.815	30.0
Average	132	10.9	0.386	16.3

assessed using i-Tree Eco, a sampling of 150 to 200 plots is statistically representative for the area (Nowak et al. 2008b), with an average relative standard error (RSE) of 14.4% and 12.1%, respectively. When the sampling plot number is 170, it yields an average RSE of 13.1%. As Scotlandville is relatively small in size (3060.31 ha) compared to other cities studied, 170 plots resulted in a sample plot every 18 ha. This provided a relevant sample size compared to the 14 US cities that are cited by Nowak et al. (2008b) and the studies done in other large cities, such as London – a sample plot every 220 ha (Rogers et al. 2015); Barcelona – a sample plot every 17 ha (Baró et al. 2014); and Toronto – a sample plot every 163 ha (City of Toronto 2011).

The national average tree canopy cover in US major cities is 27.1% (Nowak et al. 2001, US Conference of Mayors 2007), whereas the estimated tree cover in Scotlandville is 23.7%, that should be increased to the national average or higher. Integrative studies have revealed that an increase in tree cover leads to reduced ozone formation, increased pollution removal, and enhanced carbon sequestration and storage capacities (Bidwell & Fraser 1972, Baldocchi et al. 1987, Baldocchi 1988, Abdollahi et al. 2000, Yang et al. 2005, Nowak & Dwyer 2007, Paoletti 2009, Baró et al. 2014, Haase et al. 2014a, 2014b, Nowak et al. 2014).

Compared to 21 cities that have been assessed using i-Tree Eco (Smith et al. 2005, Yang et al. 2005, Chaparro & Terradas 2009, Saunders et al. 2011, Baró et al. 2014, Rogers et al. 2015), the density of 77 trees per ha in Scotlandville is below the average of the 21 cities, similar to Beijing (79 trees ha^{-1}), higher than London (53 trees ha^{-1}), but lower than Barcelona (141 trees ha^{-1}). Among the 21 cities, Houston has the highest density (337 trees ha^{-1} – Tab. 4). The tree density on commercial lands in Scotlandville is the lowest, with only 8 trees ha^{-1}. Scotlandville needs to develop greening regulations that will provide guidelines to the commercial landowners to plant more trees and to increase the tree density. However, due to the nature of certain commercial land use (*e.g.*, airport) in Scotlandville, precaution needs to be taken to properly identify the planting spaces. Through tree planting, Scotlandville could establishing a tree buffer zone around the airport, the oil refinery, Exxon chemical storage facility, etc., that could enhance the tree cover and reduce pollution.

Trees have the potential to offset an enormous amount of carbon trapped in the atmosphere. According to a study by Nowak & Crane (2002), urban forests in the southeast regions of the USA store and sequester the most carbon, with the average carbon storage per hectare being greatest in the southeast. Among the 21 cities assessed using i-Tree Eco (Tab. 4), the carbon storage capacity of the urban forests in Houston (southeast USA) is 20 tons ha^{-1}. Our modeling results indicated that the urban forests in Scotlandville, also located in the southeast region of the US, have the carbon storage capacity of 29 tons ha^{-1}, which is 9 tons ha^{-1} higher than Houston, almost four times higher than Beijing (7.4 tons ha^{-1}), two and half times higher than Barcelona (11.2 tons ha^{-1}), and almost two times higher than London (15 tons ha^{-1}). Although London (15 tons ha^{-1}), Perth (15 tons ha^{-1}), and Atlanta (15.9 tons ha^{-1}) are the three cities with similar carbon storage capacity, their tree density is very different, with 53 trees ha^{-1} in London, 83 trees ha^{-1} in Perth, and 276 trees ha^{-1} in Atlanta. Tree density is not the only important factor, however, as cumulative factors, such as tree species, size, growth rate, biomass, and site soil index, also affect carbon storage and carbon sequestration capacity (Nowak 1994). Therefore, comparison among cities should be made with caution as there are many city attributes that affect urban forest structure and function.

Comparison between the gross and net carbon sequestration shows a difference of only 230 tons year^{-1} in Scotlandville. According to i-Tree Eco, to estimate the net amount of carbon sequestered by the urban trees, carbon emissions due to decomposition of dead trees were calculated based on methods detailed in Nowak & Crane (2002). To estimate the net carbon sequestration rate, the amount of carbon sequestered due to tree growth was reduced by the estimated amount of carbon lost due to tree mortality and decay (Nowak et al. 2013). Since 92% of trees in Scotlandville are in excellent health condition, with no poor, dead, or dying trees, it might have resulted in a higher estimate of the net carbon sequestration.

While the removal of air pollutants by the existing trees in Scotlandville was estimated in the amount of 96 tons per year, we also estimated by i-Tree Eco that Scotlandville's trees yearly produce 8.91 tons of monoterpene, 125.53 tons of isoprene, and emit 134.43 tons of volatile organic compounds (VOCs) that may contribute to ozone formation. Integrative studies have revealed, however, that an increase in tree cover leads to reduced ozone formation (Nowak & Dwyer 2007, Nowak et al. 2014).

Trees remove $PM_{2.5}$ when particulate matter is deposited on leaf surfaces. This deposited $PM_{2.5}$ can be resuspended to the atmosphere or removed during rain events and dissolved or transferred to the soil. This combination of events can lead to interesting results depending on various atmospheric factors. It should be noted that i-Tree Eco removal estimates of particulate matter incorporated a 50 percent resuspension rate of particles back to the atmosphere (Nowak et al. 2014).

Our results indicate that in Scotlandville, although Live oak was not ranked among the top ten species by tree population size (Tab. 1), it ranked in the top five species for carbon storage, carbon sequestration, oxygen production, and first for structural value. Live oak is a native species to the southeastern US and the Gulf coast region. Scotlandville should increase the Live oak population size and have it as a priority species for future planting. Pecan and Red maple are also ranked among the top ten species for their ecological functions but not among the top ten by population size. The populations of these two species should also be increased through future planting.

Air quality can be maximized by using trees that have a better pollution tolerance and removal capacity (Yang et al. 2015) in areas that are prone to higher air pollutant concentrations, such as along the corridors where the Exxon Oil Refinery is located. Based on current urban forest structure and local condition in Scotlandville, to increase the air pollution removal capacity and species diversity, we suggest pollution tolerant species such as Southern magnolia (*Magnolia grandiflora*), slash pine (*Pinus elliotti*), and longleaf pine (*Pinus palustris*), among others, for future planting.

Among the 31 tree species in Scotlandville, two species are on the state invasive species list, Chinese Tallow (*Triadica sebifera*) and Callery Pear (*Pyrus calleryana*). Although their percentage is relatively small, comprising 6.7% of the tree population, and may only cause a minimal level of impact now, precautions should be taken and state regulation should be strictly enforced to prevent further spread of these exotics.

Conclusions

Urban forests are a significant and increasingly vital component of the urban environment that can impact human lives. Understanding the value of an urban forest can give decision makers a better understanding of urban tree management (Nowak et al. 2002). Our results on Scotlandville's urban forests can help urban forest managers and policy makers in future management decisions, as well as for policy and strategic planning. Results can also be used to educate the community members and increase their awareness and stewardship of the urban forests in their community.

The results of this study represent a baseline for the future development of a short- and long-term management plan for the urban forest in Scotlandville. The plan should be aligned with the Scotlandville Comprehensive Community Development Plan's core values of community image, environmental stewardship, economic prosperity, infrastructure development, social policies, community awareness, recreation, and entertainment. The plan should contain strategies and implementation actions to support the Scotlandville community in finding a sense of investment in and relatedness to urban trees, and to maintain and enhance conditions necessary for a healthy natural environment.

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