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Efficient assessments of urban tree planting potential within or near the southern Piedmont region of the United States

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ABSTRACT

Urban forest carbon offset projects have the potential to draw substantial amounts of carbon dioxide (CO_2) from the atmosphere, increase green space, and possibly generate revenue for landowners in cities capable of trading credits associated with these projects. The area of 15 cities in or near the Piedmont region of the southern United States on which trees could be potentially planted was explored in this analysis. The objectives were to assess a straightforward time-efficient method of classifying land and to determine the extent of the open and plantable areas in these cities. Overall accuracy of the classification process ranged from about 69% to 95%, and on average was 80.1%. The average producer's accuracy for all land classes in all 15 cities was 84.2%, while the average producer's accuracy for the open land class was 78.7%. The average user's accuracy for all land classes and the open class was about 80%. We estimate the amount of open, tree-plantable area in these 15 cities to be a little over 43,300 hectares (ha), comparable to the size of Washington, DC, or about 36 new Harvard Forests (Massachusetts). Extrapolating these results to the entire Piedmont region, the total plantable area in cities would amount to about 438,500 ha, and potentially allow 108 million tons of CO_2 to be sequestered, with a value of about 1.084 billion U.S. dollars. Given the small sample size and the variation within the results, the most conservative 95% confidence interval around these estimates suggests that the plantable area today is between about 274,300 ha and 645,100 ha.

1. Introduction

Global climate change is an important topic for natural resource managers, in part due to the potential to reduce additional atmospheric carbon dioxide (CO_2) levels through the photosynthetic processes of healthy plants. From a resource management perspective, sequestering carbon in trees is viewed as a relatively safe, environmentally acceptable, aesthetically appealing, and in many cases cost-effective option to address this issue (McHale, McPherson, & Burke, 2007). Several broad initiatives have been introduced to address the reduction in atmospheric greenhouse gas concentrations, including the Kyoto Protocol, the European Union's Greenhouse Gas Emission Trading Scheme (EU ETS), and the Regional Greenhouse Gas Initiative (RGGI) in the United States. The carbon sequestration options suggested through the forest management practices noted in the Kyoto Protocol can be used to help offset carbon dioxide emissions (Fang, Chen, Peng, Zhao, & Ci, 2001). Had the U.S. Congress passed into law the American Clean Energy and Security Act of 2009, it would have set targets for reductions in greenhouse gas emissions and provided mechanisms for forest carbon offsets in the United States.

In some areas of the world, financial incentives have emerged to encourage additional tree planting efforts on current treeless land; these include tradable carbon credits (Cairns & Lasserre, 2004). However, there is considerable risk and uncertainty in the carbon credit market, due to world-wide economic instability and security concerns of the various carbon registries (ICIS Heren, 2011). For example, prices of tradable European Union Allowances (EUAs), which are equivalent to 1 metric ton of CO_2 emissions, have ranged from 7 to 20 Euros over the past 2 years (Thomson Reuters Point Carbon, 2012), and Internet attacks on carbon registries have been documented (ICIS Heren, 2011). Voluntary forest carbon markets account for most of the forest carbon transactions, and a majority of these have originated in North America. However, a key trading mechanism, the Chicago Climate Exchange, recently (2010) collapsed. On a positive note, approval of registered afforestation/reforestation projects under the Clean Development Mechanism (CDM) seems to be increasing (Neeff et al., 2010). While risk exists, creating a carbon offset project and selling the associated carbon credits is one method to encourage the tree planting in urban areas. These efforts may lead to reductions in atmospheric CO_2, making it necessary to assess potential planting opportunities.

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Unlike commercial forests that are usually situated in rural areas and occasionally harvested and regenerated, urban forests can, under certain conditions, be considered as a permanent repository of carbon. In cities across the United States, research efforts have sought to identify the potential for carbon sequestration. For example, Hutyra, Yoon, and Alberti (2011) used site visits and data obtained from sample plots throughout Seattle, WA in order to develop land cover data across varying degrees of urban development, and to identify potential carbon stocks. While site visits may be ideal in estimating carbon potential in an urban environment, they can be cost prohibitive and time consuming efforts.

The use of remotely sensed data provides an alternative to on-the-ground sampling processes. Using Landsat TM/ETM+ data from 1991 and 1999, Zhao, Brown, and Bergen (2007), combined housing density and land cover classification to estimate changes in gross primary production (GPP) in the Detroit-Ann Arbor-Flint Metropolitan Statistical Area of Michigan. They concluded that low density development in urban areas that maintain a combination of productive trees and grasses can increase the CO_2 sequestration in the area, while high density development will decrease sequestration. Nowak and Crane (2002) once suggested that Atlanta, GA stored approximately 1,220,000 metric tons of carbon in urban trees. Nowak (1994) also suggested that Chicago's Cook and DuPage counties were capable of storing approximately 855,000 metric tons of carbon in urban trees, with residential land (1–3 occupants), parks, forests, and open areas having the greatest potential for carbon storage and sequestration. Certain types of land in urban areas (vacant lots, open areas along roads and among housing developments) can support additional tree plantings, and therefore contribute to reductions in atmospheric CO_2. Given the capacity of urban forests to store carbon in trees and soils and the interest in research linking urban forests to carbon storage, there is a need to develop procedures and protocols that would facilitate assessments (financial, environmental, social) of carbon projects and transactions.

The process for estimating plantable areas is often achieved through interpretation and classification of remotely sensed imagery. For example, Nowak and Greenfield (2009) used National Land Cover Data (NLCD) to determine plantable areas in certain cities using a planting priority index. While NLCD is readily available and relatively easy to use, the data was derived from either 2001 or 2006 era Landsat imagery (Fry et al., 2011; Xian, Homer, & Fry, 2009). Further, the NLCD was created using an unsupervised classification process, and a formal accuracy assessment of the latest NLCD product has not yet been reported (Fry et al., 2011). Although of value for many purposes, we assume that 5–10 year old data is not appropriate for timely assessments of open, plantable land in areas that may be rapidly developing from a human infrastructure, business, and housing perspective. Due to increases in population between 2000 and 2010 in cities within our scope of analysis (Table 1), and the rapidity with which landscapes change in urban environments, we feel it is important to use the most current available remotely sensed imagery (Bowman, Thompson, Tyndall, & Anderson, 2012).

Several analytical methods and types of remotely sensed imagery have been used to estimate the extent of plantable lands within urban areas. For example, Wu, Xiao, and McPherson (2008) used QuickBird high resolution imagery to identify plantable areas in Los Angeles, California, and developed an automated process for identifying plantable areas. However, QuickBird imagery may be cost-prohibitive for municipalities that seek to periodically replicate assessments of urban carbon tree planting potential. For instance, each 1 km^2 image from QuickBird can cost between 14 and 23 U.S. dollars (Land Info World Mapping, 2011) while other imagery sources (e.g., Landsat) may be free of charge. More recently, McGee, Day, Wynne, and White (2012) explored the potential of using U.S. National Agriculture Imagery Program (NAIP) digital aerial photography for the purpose of identifying broad land classes. NAIP imagery is freely available, yet with a 1 m spatial resolution it requires relatively more computer storage space and perhaps requires extensive image processing time. Additionally, NAIP imagery has only three spectral bands compared to other imagery platforms like Landsat 7 ETM+ with 8 bands, which may limit its utility. The methods employed by McGee et al. (2012) may lead to greater accuracy for certain types of land classes, yet multiple intermediate data management steps are necessary to alleviate classification errors including initial classifications using spectral signature groupings and ISODATA to develop "shadow" and "mixed" classes in order to reduce the impact of pixels not representative of land cover classes.

Table 1
Population change and land area of cities within or near the Piedmont of the southern United States.

City	Estimated population[a] (2000)	Estimated population[a] (2010)	Land area[a] (km^2)
Athens, GA	101,489	116,714	306.3
Atlanta, GA	416,474	420,003	343.2
Auburn, AL	42,987	53,380	241.7
Charlotte, NC	540,828	731,424	628.5
Chattanooga, TN	155,554	167,674	370.7
Columbia, SC	116,278	129,272	330.5
Greenville, SC	56,002	58,409	67.6
Hickory, NC	37,222	40,010	68.5
Laurens, SC	9916	9139	27.4
Lynchburg, VA	65,269	75,568	128.8
Mount Airy, NC	8484	10,388	21.7
Richmond, VA	197,790	204,214	162.1
Roanoke, AL	6563	6074	49.6
South Boston, VA	8491	8142	31.8
Toccoa, GA	9323	8491	21.7

[a] Within a city boundary, and not representative of a larger metropolitan area.

The goal of our research is to assess methodology for estimating the amount of urban area potentially plantable with trees within or near the southern Piedmont area of United States. The intent is to illustrate methods that can be employed for timely and cost-efficient data analyses. Therefore, we focus on a relatively straightforward method that could be used by city- or county-level planners for estimating plantable areas and for assessing the accuracy of the classification process. Extensions of the results are then made to assess land area plantable with trees, and the potential storage of carbon in urban areas of the southern Piedmont through additional tree planting efforts.

2. Methodology

2.1. Study area

This research focused on 15 cities (Table 1) within or near the Piedmont region of the southern United States. This region is situated between the Atlantic Coastal Plain and the Appalachian Mountains (Fig. 1) of the southern United States. Due to interests of the collaborative research team and the physical location of larger established cities, we were unable to select samples that were entirely contained within the Piedmont ecosystem of the southern United States. The 15 cities were selected based on their human population levels and their distribution throughout the study area. We selected five cities each from what we consider the small (population less than 10,000), medium (population greater than 10,000 but less than 110,000), and large (population greater than 110,000) population classes. These population classes were created because we wanted to assess whether differences in plantable area were