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A comparison of two sampling approaches for assessing the urban forest canopy cover from aerial photography

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ABSTRACT

Two different sampling approaches for estimating urban tree canopy cover were applied to two medium-sized cities in the United States, in conjunction with two freely available remotely sensed imagery products. A random point-based sampling approach, which involved 1000 sample points, was compared against a plot/grid sampling (cluster sampling) approach that involved a 1.83 m square grid of points embedded within 0.04 ha circular plots. The imagery products included aerial photography from the U.S. Department of Agriculture National Agricultural Imagery Program (viewed within ArcGIS), and Google Earth imagery. For Tallahassee, Florida, the estimate of tree canopy cover was 48.6–49.1% using Google Earth imagery and 44.5–45.1% using NAIP imagery within ArcGIS. Statistical tests suggested that the two sampling approaches produced significantly different estimates using the two different imagery sources. For Tacoma, Washington, the estimated tree canopy cover was about 19.2–20.0% using Google Earth imagery and 17.3–18.1% when using NAIP imagery in ArcGIS. Here, there seemed to be no significant difference between the random point-based sampling efforts when used with the two different image sources, while the opposite was true when using the plot/grid sampling approach. However, our findings showed some similarities between the two sampling approaches; hence, the random point-based sampling approach might be preferred due to the time and effort required, and because fewer opportunities for classification problems might arise. Continuous review of urban canopy cover estimation procedures suggested by organizations such as the Climate Action Reserve and others can provide society with information on the accuracy and effectiveness resource assessment methods employed for making wise decisions about climate change and carbon management.

1. Introduction

An urban forest can be described as the woody vegetation within a city that includes street trees located on both public and private lands, urban parks, and other trees located on residential properties, commercial land, and other lands. This resource provides a number of essential benefits to human beings, a few of which include providing aesthetic value, reducing energy use, facilitating cooling effects, improving water and air quality, providing diverse wildlife habitat, and increasing human health and well-being (Nowak, 1993; Jensen et al., 2004; Leuzinger et al., 2010; Nowak et al., 2010; McPherson et al., 2011; Richardson and Moskal, 2014). The ecosystem services derived from an urban forest are often directly related to the amount of tree canopy cover, which is ideally composed of healthy and functioning vegetation (Nowak and Greenfield, 2012). Tree canopy cover, generally estimated as the percentage of a site covered by tree canopies, is the simplest and most often used metric to quantify urban forest extent (Richardson and Moskal, 2014) and can be used to inform management decisions and policy analyses. For instance, a tree canopy assessment was conducted for Los Angeles to determine the capacity of the city to plant an additional one million trees (McPherson et al., 2011).

The human population of the United States increased from 281.4 million to 308.7 million between 2000 and 2010, and over 83.7% of the population now lives in metropolitan areas (large cities), where the population grew almost twice as fast as micropolitan areas (small cities with 10,000 to 50,000 people) (Mackun et al., 2011).

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Unless the administrative boundaries of cities expand, growth in the human population applies certain types of pressure upon the urban forests found there (Nowak, 1993; McPherson et al., 2011). For many United States cities, developed areas were created from areas once previously forested. In the 1990s, approximately 0.4 million hectares (ha) of forested land was converted each year to developed or other uses. Even if tree canopy cover increases in association with urban expansion of Great Plains and desert states, it is estimated that by 2050, an additional 9.3 million ha of forested area will become some other land use in the United States due to urbanization (Alig et al., 2003), thus population growth may result in direct or indirect negative impact on the structure, pattern and function of urban ecosystems in and around urban areas (Nowak, 1993).

In recent years, various approaches such as aerial photography interpretation, satellite-based image analysis, and aerial LiDAR (Light Detection and Ranging) analysis have proved useful for estimating tree canopy cover. These remotely-sensed sources of information can be both cost-effective when compared to field sampling, and can facilitate comparable analyses among different cities (McPherson et al., 2011). As examples, Irani and Galvin (2003) used 4 m resolution remotely sensed imagery to assess tree canopy cover in Baltimore. Nowak and Greenfield (2012) conducted a study using paired aerial photographs to determine tree canopy cover changes in 20 cities in the United States. Parlin (2009) also used digital land cover maps developed from 0.6 m resolution remotely sensed imagery to estimate tree cover change in Seattle. Remotely sensed imagery thus provides an opportunity to efficiently and effectively measure canopy cover across both space and time.

Specific tree canopy cover estimates can be developed using several different sampling approaches. The most common sampling approach involves random point-based sampling, where random points are located within the boundary of a city, and then are classified through aerial photo interpretation as either falling on a tree crown or not falling on a tree crown. The observation value from this sampling approach is binary (yes/no or 1/0), indicating presence or absence of tree canopy at the sample point, as interpreted from the imagery. As suggested above, for 20 cities in the United States, Nowak and Greenfield (2012) used random point sampling to assess tree cover change over a five year period. They found that there was a decreasing trend in tree cover, about 0.27% per year on average, in these cities. Walton et al. (2008) also used a random point sampling approach and compared their results to classified satellite images.

A second sampling approach for estimating tree canopy cover might be to create random polygons and delineate tree crowns within these polygons. Nowak et al. (1996) were perhaps the first to use a fixed polygon approach like this for estimating tree cover. Nowak et al. (2008) studied the impact of polygon size on urban forest estimates, and noted that an increase in polygon size meant (logically) an increase in time required to perform the assessment. For Detroit and Atlanta, Merry et al. (2014) used a polygon approach to estimate tree canopy cover from aerial photography, and noted that the estimate of tree canopy cover using a polygon sampling approach could be slightly different than the estimate derived from using a point-based approach. The combined effects of mis-registration, feature displacement, and shadows could have imposed minor challenges to either method.

A third sampling approach may be to create a random polygon and then create a grid of points within the polygon in order to estimate canopy cover. Therefore, rather than draw the outline of tree canopies within the polygon and compute the proportion of tree canopy cover using the tree canopy and non-tree canopy areas (as in Merry et al., 2014), the proportion of grid points that fall on tree canopies within the polygon is used as the estimate of canopy cover for the polygon. From this juncture forward we will refer to this cluster sampling process as the *plot/grid sampling approach*. This approach was proposed by the Climate Action Reserve (Nickerson, 2014a), in their draft Urban Forest Project Protocol. The Climate Action Reserve is a private nonprofit environmental organization and leading entity in the measurement of forest resources for carbon policy implementation. Their aim is to provide support to activities that decrease greenhouse gas emissions (GHG) by assuring the environmental entirety and economic benefits of emissions reduction projects. Along these lines, the Climate Action Reserve has a goal of establishing high quality standards for carbon offset projects and supporting activities that reduce air pollution, enhance growth in new green technologies, and facilitate the attainment of emission reduction goals. Since the cluster sampling approach for estimating canopy cover (when proposed) was different than other approaches described in the literature, we embarked on a study of its effectiveness for this purpose.

Interestingly, the cluster sampling process described in the draft Climate Action Reserve protocol (Nickerson, 2014a) was absent from the final protocol to allow people involved in these assessments the flexibility to respond to improvements in methodological and technological tools. However, they refer to desired sampling error in the *Quantification Guidance* (Climate Action Reserve, 2014a) and to verification of tree canopy cover estimates through a point-based sampling approach in the final protocol. Comments received with respect to the draft Urban Forest Project protocol (Climate Action Reserve, 2014b) suggested that the plot/grid sampling approach may have been reasonable for large, contiguous forest areas, but may have been unsuitable for urban areas that include a scattered arrangement of trees (street trees and others). However, this limitation would also seem to affect a point-based sampling approach. Further, it was suggested through feedback on the draft protocol that the processes used for estimating urban canopy cover needed to be less detailed and structured, and needed to allow for the use of other equally valid tree canopy cover sampling protocols. While not included in the final protocols for urban forest projects by the Climate Action Reserve, the plot/grid sampling approach has not heretofore been assessed; therefore, it is the focus of this study.

Our goal was to compare two sampling approaches for estimating urban tree canopy cover in two United States cities (Tacoma, Washington and Tallahassee, Florida), using remotely sensed imagery from two different sources. We wanted to determine the feasibility of each sampling approach and to compare the results of canopy cover estimates using the two different remotely sensed imagery sources. The two sampling approaches are (a) the random point-based and (b) the plot/grid approach. The two remote sensing imagery sources used in this study included (a) U.S. Department of Agriculture National Agriculture Imagery Program (NAIP) imagery viewed within ArcGIS (ESRI, 2013) and (b) Google Earth imagery (Google Inc., 2014). The NAIP imagery presents features in natural color (0.4–0.7 μm wavelengths of energy), is contained in compressed county mosaic form, and has a 1 m spatial resolution. The imagery is provided by the U.S. Department of Agriculture's Farm Service Agency (U.S. Department of Agriculture, 2013), and was captured between September 16th, 2013 and October 28th, 2013. Google Earth imagery arises from a variety of sources such as the U.S. Department of Agriculture, DigitalGlobe, GeoEye-1, Ikonos, MODIS Terra, city or state governments, and commercial aerial photographers (Taylor, 2014). Thus due to the use of third-party sources of imagery contained in Google Earth, and because the imagery is aggregated, the spatial resolution varies. The Google Earth imagery was dated as May 5th, 2013 and April 1st 2013 for Tacoma and Tallahassee, respectively. The most recent imagery available through Google Earth also presents features in natural color; the historical imagery available through Google Earth may be panchromatic. These two imagery sources (NAIP and Google Earth)