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Urban tree cover change in Detroit and Atlanta, USA, 1951–2010

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ABSTRACT

We assessed tree cover using random points and polygons distributed within the administrative boundaries of Detroit, MI and Atlanta, GA. Two approaches were tested, a point-based approach using 1000 randomly located sample points, and polygon-based approach using 250 circular areas, 200 m in radius (12.56 ha). In the case of Atlanta, both approaches arrived at similar estimates of tree cover (50–53%) for both time periods, yet they show that roughly one-third of the tree-covered land area in 1951 was also tree-covered in 2010 and about 30–31% of the sampled land area lacked tree cover during both assessment periods. In the case of Detroit, the two approaches resulted in different estimates of tree cover (19.6% vs. 30.8% in 2010), yet similar levels of transitions over time. The only similarities between the two cities were that about 15–20% of each city's land area was covered with trees in 1951, yet lacked tree cover in 2010. While the polygon-based approach to estimating tree cover may result in a product that more explicitly represents covered areas, the point-based approach is recommended due to the time and effort involved with the polygon-based approach and potential error introduced through topographic displacement of trees and shadows. Overall, canopy cover over time remained stable while distribution varied greatly. However, while multi-decade change in aggregate is undetectable at the scale of a city, there seems to be substantial shifts in the spatial arrangement of the tree canopy.

Introduction

Urban forestry and tree programs have been found to provide a number of positive benefits including the reduction of energy costs, an increase in quality of life, and the mitigation of environmental extremes (i.e. increased temperatures and high levels of pollution) for people who live within, or who have access to these areas (Perkins, Heynen, & Wilson, 2004). Biomass that is created by urban forests has also been suggested as a potential source of bio-based fuel that could help lower human consumption of fossil fuels, reduce waste, and lessen commercial pressure on natural forests (MacFarlane, 2009). The amount of canopy cover, usually presented as a percent of land area, is often used as a basis for urban tree canopy assessments and management decisions, and, therefore, might be viewed as necessary information for goal setting in managing urban forest resources effectively (McGee, Day, Wynne, & White, 2012; Walton, 2008). For example, tree canopy assessments have been used in the Chesapeake Bay region to inform the management goal of reducing urban water runoff into the bay (Jantz, Goetz, & Jantz, 2005). McPherson, Simpson, Xiao, and Wu (2011) used urban tree canopy assessments to estimate the capacity of Los Angeles to add one million trees into the existing canopy with the goal of increasing long-term benefits such as air pollution reduction, water quality improvement, and decreased urban flooding. The amount of tree canopy cover in urban areas can be increased through planting efforts or other initiatives that promote urban tree cover. However, some suggest that urban tree planting efforts and natural regeneration of abandoned areas may be insufficient to counteract recent losses of established urban tree canopies in the United States (Nowak & Greenfield, 2012). Additionally, tree planting programs and associated policies may not be appreciated by the general public (Rae, Simon, & Braden, 2010), who may be opposed to tree planting efforts conducted on or near their property, given the maintenance required and the potential damage that may arise to both their homes and their property (lawns, sidewalks) (Perkins, 2011). Opportunities to increase urban tree canopy cover, such as allowing an abandoned lot to revegetate naturally, may also be inconsistent with desired positive changes in the socio-economic position of the urban area (Emmanuel, 1997). Identifying the amount of urban tree cover over time is a crucial part of identifying the effectiveness of current management practices, assessing the environmental impact of

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existing cover along with the potential impact of new canopy cover, and informing future management goals.

Our goal is to compare the change in urban tree canopy cover in two large United States cities (Atlanta, GA and Detroit, MI) that have different developmental histories with respect to human population change. Increases in population density have been found to negatively impact the quantity of the forest cover and, in turn, increase the detrimental effects associated with forest loss including poor air quality, decreased carbon sequestration and storage, and the urban heat island effect (Lo & Yang, 2002; McGee et al., 2012; Boone, Cadenasso, Grove, Schwarz, & Buckley, 2009; Cook, Hall, & Larson, 2012). However, both Atlanta and Detroit currently have urban tree programs that promote the management of trees and tree planting (The Greening of Detroit, 2012; Trees Atlanta, 2014). Ideally, tree planting programs and policies will have a positive impact on the quantity of urban tree canopy cover.

In order to understand tree canopy cover and how it changes over time, it is important to understand the developmental history of Atlanta and Detroit. Detroit is situated on the south side of what is now known as the Detroit River. The region is classified as a humid continental climate which is greatly influenced by proximity to the Great Lakes. Average temperatures range from 25.6°F (−3.6 °C) in the winter to 73.6°F (23.1 °C) in the summer. The forests of the broader southern Michigan region are dominated by broadleaf deciduous trees including oaks (*Quercus* spp.), aspens (*Populus* spp.), and maples (*Acer* spp.). Additional species include pines (*Pinus* spp.), cedars (*Cedrus* spp.), and northern hardwood species (Michigan Society of American Foresters, 2014). When it was first settled in the early 18th century, the land was described as a meadow, lined with fruit trees and surrounded by dense forests (Martelle, 2012). Given its strategic geographic location on the United States–Canada border between Lake Erie and Lake Huron, Detroit became a staging point for the European settlement and economic development of the northwestern (as it was called at the time) United States (Martelle, 2012; McCarthy, 1997). By the late 19th century, the city road system had become well-developed, and was lined with numerous shade trees (Martelle, 2012). Since the early 1900s, the fate of the city has been closely tied to the growth and success of the automobile industry (McCarthy, 1997). By 1910, seven of the top 10 automobile producers were situated in the Detroit area, and together they claimed a market share of 65% of the industry (Klepper, 2010). Between 1910 and 1950, Detroit's population rose 297% to approximately 1.85 million people. By the middle of the twentieth century, Detroit was encountering economic and racial tension, along with housing shortages, signaling the beginning of the collapse of an industrial society (Martelle, 2012). The resulting development of the urban fringe led to the core city of Detroit losing tax revenue, services declining, and the beginning of decay and disinvestment (McCarthy, 1997).

Between 1950 and 2010, the population of Detroit declined considerably (by about 61%) to 0.71 million (Bureau of the Census, 1952; U.S. Census Bureau, 2012), accompanied by a loss of job opportunities (Hall, 2011). In 2013, Detroit filed for bankruptcy, seeking protection from creditors of nearly $20 billion in debt. The evolution of Detroit is not unique for cities of the northern United States and revitalization efforts have been pursued for nearly four decades (McCarthy, 1997) including in Pittsburgh, PA (Detrick, 1999), Buffalo, NY (Shilling, 2008), and St. Louis, MO (Fey, 1993).

In addition to economic and demographic changes in Detroit, Dutch elm disease affected street trees in the mid-20th century. In the early part of the 21st century, the emerald ash borer (*Agrilus planipennis*) caused the death of millions of popular street trees, specifically ash (*Fraxinus* spp.), in the Detroit area (MacFarlane & Meyer, 2005). Some have suggested that the decline in urban forest quality is not yet complete, and educational and planting efforts have been mobilized to inspire local support (The Greening of Detroit, 2012). In the northern United States, it is estimated that it will cost nearly one billion U.S. dollars per year for treatment, removal, and replacement of urban trees due to the emerald ash borer (Kovacs et al., 2010). In some areas of Detroit, low land values have enabled residents to acquire adjacent properties, and thus there is localized transformation from former densely populated urban areas to areas with a housing and population density similar to suburban areas (Blanco et al., 2009). These drastic socio-economic changes combined with losses from emerald ash borer infestations and Dutch elm disease led to losses in tree cover across the city. While reduced city budgets limit tree planting programs and policy implementation, abandon property may provide an opportunity for tree planting programs to restore the urban tree canopy cover (The Greening of Detroit, 2012). In Nowak and Greenfield's (2012) short-term analysis of multiple U.S. cities, they found a 0.18% per year loss of tree cover in Detroit between 2005 and 2009. They found this estimated loss to be lower than expected and attributed it, in part, to increased tree planting efforts conducted in response to the onset of the emerald ash borer problem.

The city of Atlanta is situated in the Piedmont ecoregion of Georgia and is classified as a humid subtropical climate with an average annual rainfall of 50.2 in. (1275 mm). Average temperatures range from lows around 10–20°F (−12 to −6 °C) in the winter and highs between 90° and 100°F (32 °C and 38 °C, respectively) in the summer. The Piedmont area of the state is dominated by pine species including loblolly pine (*Pinus taeda*), slash pine (*Pinus elliottii*), shortleaf pine (*Pinus enchinata*), and longleaf pine (*Pinus palustris*). Additional tree species in the region include tulip poplar (*Liriodendron tulipifera*), hickories (*Carya* spp.), beech (*Fagus* spp.) and oaks (Harper et al., 2009). Its early developmental history was heavily influenced by manufacturing activities and rail transportation. Atlanta was mainly developed in the early 19th century primarily in an area that was previously forested. Perhaps the main impetus for the development of the city was for it to become a transportation hub, and thus as Reed (1889) once suggested, "all the roads running through this favored territory lead to Atlanta." The early history of this region of the South is marked by the displacement of Native Americans through territorial expansion of the United States, the destruction of the city during the American Civil War, and racial unrest in following decades. During the early to mid-19th century, much of the original forest that had covered the main city area had been removed, except in a few places where trees were allowed to remain to form parks (Garrett, 1969). Between 1910 and 1950, the population within the administrative boundary of the city rose 114%, to about 330,000. Since 1950, the population has risen by about 27% to 420,000 (Bureau of the Census, 1952; U.S. Census Bureau, 2012). In partial response to demographic and economic forces, Atlanta's population growth continued at the end of the 20th century, resulting in the rapid suburbanization of surrounding counties (Miller, 2012). While the population within the administrative boundary of Atlanta is relatively small compared to Detroit, the larger metropolitan area around Atlanta is home to over 5 million people, and Atlanta is now viewed as the center of a larger regional transportation system (Dablanc & Ross, 2012; Redondi, Malighetti, & Paleari, 2011). Recent (2005–2009) losses in land area covered with trees were estimated to be about 0.46% per year in Atlanta (Nowak & Greenfield, 2012). Educational and planting programs have been mobilized to engage neighborhoods in tree planting and maintenance in an attempt to counteract deforestation in the city (Trees Atlanta, 2014).

Our definition of urban forests in both Atlanta and Detroit includes plants found within urban parks, street trees, trees on private residential land, and natural regeneration on abandoned sites (Fig. 1). It stands to reason that the vegetation growing today could

Fig. 1. Example of Detroit's 2010 urban landscape including street trees, private residential land, and park space. *Source:* NAIP imagery.

be much different in amount than the vegetation that was present during the 1950s when economic and social conditions were more favorable. Modern landscapes can be landscape legacies or reflective of past management efforts, preferences of residents, and environmental and social characteristics of the communities. Landscape legacies can also be the result of harvesting practices, diseases, or the introduction of invasive plant species (Hostetler, Rogan, Martin, Delauer, & O'Neil-Dunnes, 2013). Assessing past land cover has been found to be a better indicator of modern landscapes than focusing solely on current landscape characteristics (Cook et al., 2012; Boone et al., 2009).

Tree canopy cover is a metric that can be used to compare the greenness of different cities (McPherson et al., 2011). In conjunction with aerial images, tree canopy cover can be estimated using templates, transects, point counts, or special scanning equipment (Nowak et al., 1996). For example, Nowak (1993) used random dot grids to assess urban tree cover, and Walton (2008) used the random point approach to sample urban tree cover proportion within defined areas (census designated places). These estimates of tree cover were used to determine whether changes had occurred over time. Nowak and Greenfield (2012) also used a random point approach to sample urban tree canopy cover within the boundaries of cities, and Nagendra and Gopal (2010) used a random sampling approach to identify segments of road in Bangalore upon which street trees would be counted for a specific length of the road in a randomly chosen direction.

The objective of this work was to estimate the change in urban tree canopy cover of both Detroit and Atlanta between 1951 and 2010 through two canopy cover sampling techniques (point- and polygon-based sampling). Additionally, we compare the effectiveness of both sampling approaches in assessing urban tree canopy cover. Aerial and satellite imagery is often employed to help estimate urban tree canopy cover. Examples of these include data provided by the Landsat program (e.g., Schneider, 2012), high-spatial resolution satellite imagery programs (Ardila, Bijker, Tolpekin, & Stein, 2012; Pu & Landry, 2012), and digital aerial photograph programs (Kendal, Williams, & Williams, 2012; McGee et al., 2012). Further, as Nowak and Greenfield (2012) note, paired images from different points in time can help determine both the spatial and temporal pattern and the rate of change in urban landscape cover. These estimates, in turn, can inform planners and managers and facilitate decisions regarding urban and suburban landscapes (Szantoi, Escobedo, Wagner, Rodriguez, & Smith, 2012). Aerial photographs are available as far back as the 1940s making them the perfect resource for assessing tree canopy change over time. Additionally, the interpretation of aerial photographs is often the most cost-effective method for these purposes and facilitates an analysis involving the most landscape detail (Nowak et al., 1996). Our null hypothesis is that the extent of tree cover has not changed, when examining the beginning and endpoint of the six decade period, indicating that the extent of urban forest cover was temporally static. We assume that tree planting programs in both cities along with the revegetation of abandoned property in Detroit offsets canopy losses to urbanization. The developmental history of these cities (one facing socio-economic decay, the other encountering developmental pressure) suggests that this hypothesis may be rejected. Further, evidence suggests that tree cover had declined in the late twentieth century in both

Atlanta and Detroit (for different reasons) (Nowak & Greenfield, 2012; American American Forests, 2002), even though both cities now have non-governmental groups engaged in promoting the benefits of urban forests (The Greening of Detroit, 2012; Trees Atlanta, 2014). Finally, we explore the benefits of the two sampling techniques (point- and polygon-based sampling) in comparison to each other. We hypothesize that the polygon-based approach would provide a more detailed assessment of canopy cover in both cities resulting in a more accurate estimation of canopy cover compared to the simple presence/absence canopy cover assessment derived with the point-based sampling approach.

Methods

We elected to use aerial photography from 1951 and 2010 to compare differences in tree cover for Atlanta and Detroit. For the 2010, analysis we used the United States Department of Agriculture's Farm Service NAIP (National Agriculture Imagery Program) digital orthophoto mosaics for each city. NAIP is available as natural color image digital ortho quarter quads (DOQQ) with 1 m spatial resolution acquired during the agricultural growing season of the continental U.S. (U.S. Department of Agriculture, 2011). For the 1951 data, individual aerial photographs were obtained from the United States Geological Society (USGS). Each was digitally orthorectified, using the 2010 NAIP imagery for reference, to form complete coverage for each city. Detroit was selected to determine the effect of recent assumed tree cover change as a result of the Dutch elm disease, emerald ash borer, and socioeconomic collapse of the core city while Atlanta was selected due to the pressure applied on forest cover as a result of urban expansion, and regional transportation issues (see Fig. 2).

We elected to perform the analysis using two different approaches. First, we randomly located 1000 points within the current administrative boundaries of both cities. Random points were generated within Erdas Imagine (2013) software through a random points generator. Congalton and Green (2009) suggest that a minimum of 100 samples per class are necessary for a large area. Our choice of 1000 points exceeds the minimum requirement. This sample size is similar to current research (Nowak & Greenfield, 2012; Richardson & Moskal, 2014) where 18 of the 20 cities analyzed utilized 1000 point sample. Manual photo interpretation methods were used to determine whether the location of each point consisted of (1), or did not consist of (0), tree canopy. The same 1000 sample points, by location, were associated with the two different dates of imagery in both cities. This level of sampling was designed to provide a maximum standard error of 1.6 percent (Lindgren & McElrath, 1969; Nowak & Greenfield, 2012). While mis-registration (introducing georeferencing error) of the images or the points may have occurred, it was not noticeable, and therefore the interpreter did not correct any of the point locations to ensure the exact same location was interpreted (as in Nowak & Greenfield, 2012). A point-paired image registration process was used in order to interpret the imagery and to minimize the effects of image parallax (i.e. object displacement). Aerial photographs from 1951 were selected that had been taken during spring months (leaf-on) in order to limit seasonal variability between the 1951 images and the 2010 NAIP imagery.

The percentage of tree cover (p) was estimated by dividing the number of sample points (x) representing tree cover by the total number of sample points (n) within each city (i.e., $p = x/n$). The standard error of the estimate (SE) was then determined using the equation $(p(1-p)/n)^{0.5}$ (Lindgren & McElrath, 1969; Nowak & Greenfield, 2012). A 95% confidence interval was then developed using the standard error. In order to place confidence around the difference in tree cover from 1951 to 2010, the standard error for the difference $((p_1\,(1-p_1)/n_1) + (p_2\,(1-p_2)/n_2))^{0.5}$ was developed and incorporated into a 95% confidence interval estimate. Here, p_1 and n_1 refer to the 1951 estimated percent tree cover and associated sample size, while p_2 and n_2 refer to the 2010 estimated percent tree cover and associated sample size. We also assess the transition of the entire set of points as they relate to four cases:

1. Tree canopy in 1951 → Tree canopy in 2010
2. Tree canopy in 1951 → Not tree canopy in 2010
3. Not tree canopy in 1951 → Tree canopy in 2010
4. Not tree canopy in 1951 → Not tree canopy in 2010

In the second analysis, a 250 point subsample of the original 1000 randomly sampled points was used and a 200 m buffer area around each point was derived. Within these buffers, the outline of tree canopies was photo-interpreted and digitized into closed polygons (Fig. 3). In this second analysis (polygons representing tree canopy), the percent of the area contained within a 200 m buffer is used as the estimate of canopy cover. Here, the mean, standard error, and confidence intervals were developed using the percent tree cover within each 200 m buffer sample area. The appropriate geographic information system databases for each city are then unioned, geographically intersected, to determine the tree canopy area shared during each time period (Case 1 above), the tree canopy area only noted in 1951 (Case 2), the tree canopy area only noted in 2010 (Case 3), and all other areas (Case 4). Statistical measures similar in concept to the first case were also applied using the data collected with this second method. However, in this case, each of the 250 polygons (sample units) have a percentage canopy cover (0–100%), and the mean $(\sum y/n)$ and standard error $(s_y/\sqrt{n})$ of these were used to determine the 95% confidence intervals for tree canopy cover. The sampling intensity of this process, when 250 plots were distributed within the administrative area of each city, was 8.5% for Detroit and 9.5% for Atlanta.

Results

Two different methods for estimating the amount of tree cover within the administrative boundaries of Detroit and Atlanta were pursued in this study. Therefore, the results are divided into two sections, each focusing on one of the methods.

Point-based sample

In assessing the tree cover of Atlanta using 1000 randomly located sample points, we estimated that 53.3% of the land within the administrative boundary of the city was covered with trees in 1951 and 51.2% was covered with trees in 2010. The 95% confidence intervals were [50.20%, 56.40%] and [48.10%, 54.30%] for 1951 and 2010, respectively (Table 1). Therefore, the detected net change is statistically indistinguishable from zero over the 59-year period, and the observed change might be attributed to sampling error. Our estimate of tree cover in Atlanta in 2010 was similar to the 2009 estimate (51.6%) provided by Nowak and Greenfield (2012). In examining the transitions over time, we estimate that only about 35.8% of the sampled land area was covered in trees during both periods of time (Table 2). About 17.5% of the sampled land area was covered with trees in 1951, but was not covered with trees in 2010. About 31.3% of the sampled land area was not covered in trees in 1951, and was also not covered in trees in 2010. The remaining 15.4% of the land area sampled was not covered in trees in 1951, yet was covered in trees in 2010.

Detroit tree cover was estimated to be lower than Atlanta, or about 32.3% in 1951 and 30.8% in 2010. The 95% confidence intervals for tree canopy cover were [29.38%, 35.22%] for 1951 and [27.94%, 33.66%] for 2010. As with Atlanta, the detected net change

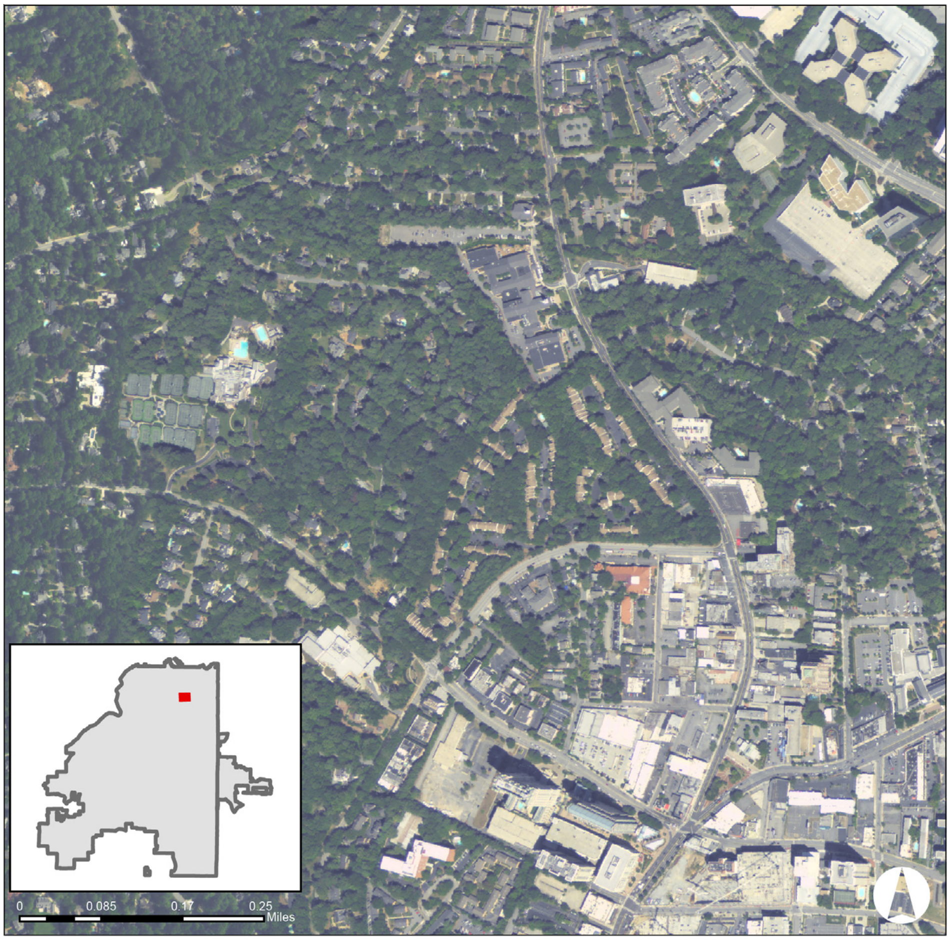

Fig. 2. Example of Atlanta's 2010 urban landscape highlighting urban encroachment into forested areas. *Source:* NAIP imagery.

is statistically indistinguishable over the 59-year period. As for the transitions in canopy cover within the administrative area of Detroit, about 16.9% of the land was covered with trees in 1951, and was also considered tree-covered in 2010. However, about 15.4% of the sample land area was covered with trees in 1951, yet not so in 2010. Of the sampled land area that was not covered with trees in 1951 (67.7% of the total), 53.8% was also not covered with trees in 2010, yet 13.9% was covered with trees. Interestingly, our estimate of tree cover in 2010 is greater than the Nowak and Greenfield (2012) estimate for the 2009 time period (23.2%).

Polygon-based subsample

In assessing the tree cover of Atlanta using 250 randomly located 200 m radius (12.56 ha) sample areas, we estimated that 50.9% of the land within the administrative boundary of the city was covered with trees in 1951, and 50.2% was covered with trees in 2010. These estimates are slightly less than what we found using the point-based approach. The 95% confidence intervals were [47.57%, 54.29%] and [47.30%, 53.03%] for 1951 and 2010, respectively. As with the previous approaches, the detected net change is statistically indistinguishable over the 59-year time period but the confidence intervals overlap. Similar to the point-based approach, our estimate of tree cover in Atlanta in 2010 was comparable to the 2009 estimate (51.6%) provided by Nowak and Greenfield (2012). In examining the transitions over time, we estimate that only about 30.7% of the sampled land area was covered in trees during both periods of time. About 20.2% of the sampled land area was covered with trees in 1951, yet was not covered with trees in 2010. About 29.6% of the sampled land area was not covered in trees in 1951, and was also not covered in trees in 2010. The remaining 19.5% of the sampled land area was not covered in trees in 1951, yet was covered in trees in 2010. These transitions are similar to what we found using the point-based approach.

In applying the polygon-based approach, Detroit tree cover was estimated to be about 28.4% in 1951 and 19.6% in 2010 (Fig. 4). These estimates are lower than the estimates provided using the point-based approach, with the 2010 estimate effectively 36% lower (19.6% tree cover vs. 30.8% tree cover). The resulting 95% confidence intervals for tree canopy cover were [25.92%, 30.97%] for 1951 and [17.98%, 21.27%] for 2010. This detected net change is statistically significant. As for the transitions in canopy cover within the administrative area of Detroit, only about 8.8% of the land was covered with trees in 1951, and was also considered tree-covered in 2010. However, about 20.1% of the sampled land area was covered with trees in 1951, yet not so in 2010. Of the sampled land area that was not covered with trees in 1951 (71.6% of the total), 60.3% was also not covered with trees in 2010, yet 11.3% was covered with trees. Our estimate of tree cover for 2010 using the polygon-based approach is lower than the Nowak and Greenfield (2012) estimate for the 2009 time period (23.2%).

Discussion

In some respects, our estimates of tree cover are similar to other recent estimates for the two cities (e.g., Nowak & Greenfield, 2012),

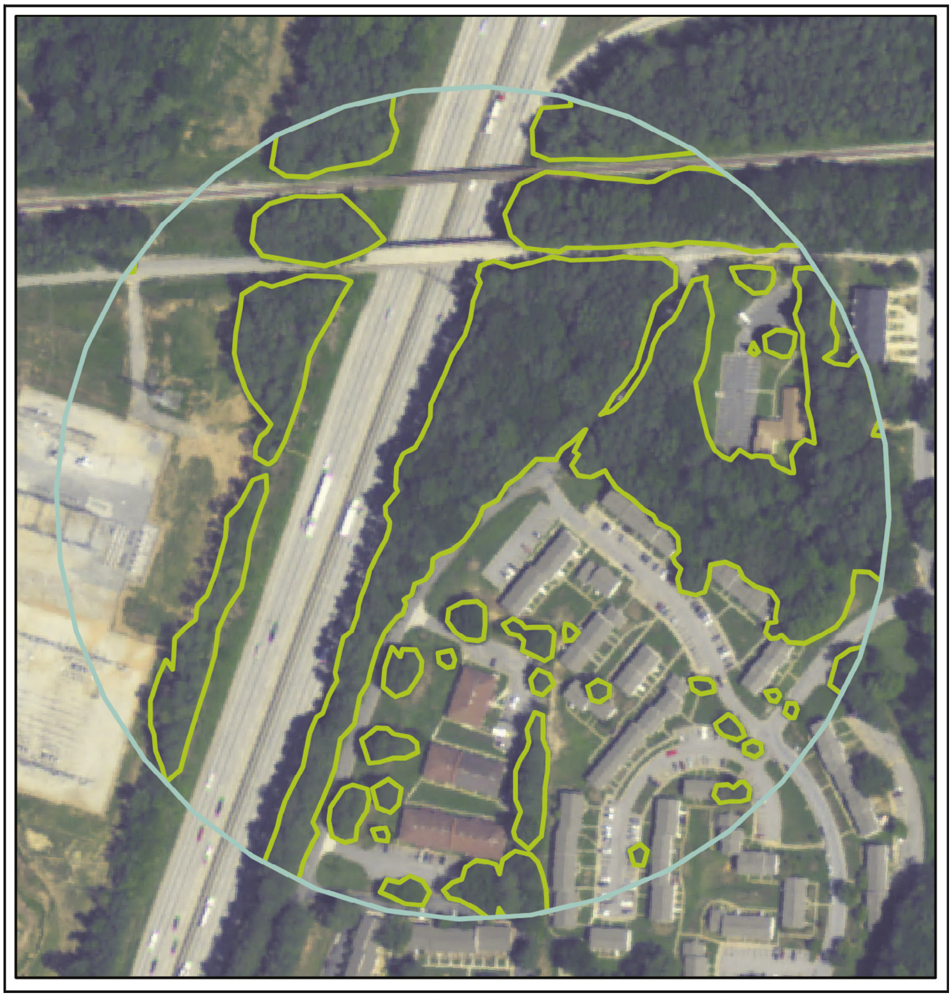

Fig. 3. Example of the digitized polygon approach in Atlanta.

Table 1
Confidence intervals (CI) for Atlanta, GA and Detroit, MI.

City	Sampling method	Year (%)	Canopy CI (%)	Lower CI (%)	Upper
Atlanta, GA	Points	1951	53.30	50.20	56.40
		2010	51.20	48.10	54.30
	Polygons	1951	50.90	47.57	54.29
		2010	50.20	47.30	53.03
Detroit, MI	Points	1951	32.30	29.38	35.22
		2010	30.80	27.94	33.66
	Polygons	1951	28.40	25.92	30.97
		2010	19.60	17.98	21.27

Table 2
Urban tree canopy cover transitions between 1951 and 2010.

City	Sampling method	Percent of land area			
		Case 1[a]	Case 2[b]	Case 3[c]	Case 4[d]
Atlanta, GA	Point	35.8	31.3	17.5	15.4
	Polygon	30.7	29.6	20.2	19.5
Detroit, MI	Point	16.9	53.8	15.4	13.9
	Polygon	8.3	60.3	20.1	11.3

[a] Tree canopy present in 1951 and tree canopy present in 2010.
[b] Tree canopy present in 1951 and tree canopy not present in 2010.
[c] Tree canopy not present in 1951 and tree canopy present in 2010.
[d] Tree canopy not present in 1951 and tree canopy not present in 2010.

yet we recognize that our tree canopy cover estimates may be biased due to several factors. Urban trees may be difficult to locate on vertical imagery due to low spectral separability between the trees and other nearby features, and due to shadows cast by their own crowns and other objects (Ardila et al., 2012). Shadows can make tree canopies appear dense, and can cause difficulties in the interpretation of background vegetation (Toney, Liknes, Lister, & Meneguzzo, 2012). Also, digital images, such as the NAIP product used here, might contain relatively oblique viewing angles within various pieces of the image and significant displacement of features. Therefore, the viewing angles can vary from location to location within a digital orthophotograph and adjustments for these problems are not presently feasible (Toney et al., 2012).

With respect to the point-based approach, the differences in canopy cover between 1951 and 2010 in each city are not significant. Each time period's estimate of tree cover is within the 95% confidence interval of the other estimate from the other time period. The same is true for the polygon-based approach when applied to Atlanta. When assessing the results of the polygon-based approach, the differences in tree cover over time in Detroit are significant. Each time period's estimate of tree cover is well outside the 95% confidence interval of the other estimate from the other time period. These findings may be reflective of the nature of random sampling. A significant amount of time was devoted to the interpretation and delineation of tree cover, and to the verification and editing of the polygons. We are confident that the

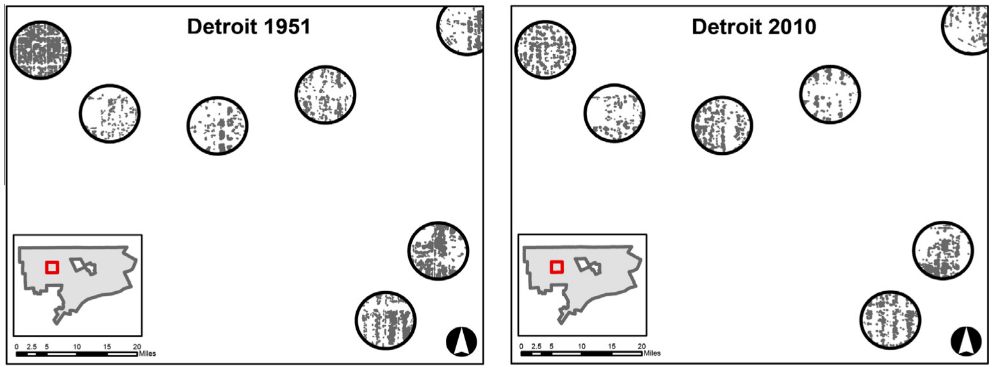

Fig. 4. Example of digitized polygons in 1951 and 2010 in Detroit illustrating canopy loss between the two time periods.

polygon-based estimates are correct for the areas sampled. Further, the point-based process may have covered more of the diversity in the system (1000 vs. 250 samples) even though the polygon-based process represented an 8.5–9.5% sampling intensity. Compared to the point-based process, these results illustrate that while the polygon-based approach may represent a more realistic estimate of tree cover, the time and effort involved and the potential problems imposed by topographic displacement and shadows suggest that the point-based approach should be preferred. This holds true for cases where an estimate is desired over a ground-based census. While these problems can influence estimates from both approaches, they may have more influence on the polygon-based approach due to the wider area of coverage of each individual sample unit.

In terms of broader implications, it appears that urban tree canopy coverage has experienced what we consider large changes over the period of investigation. While total canopy cover remained relatively stable over time, it appears that urban tree canopy coverage has experienced large changes in its geographic distribution over the period of its investigation. The combined share of land in tree cover in 1951 but not in tree cover in 2010, and land in tree cover in 2010 but not in tree cover in 1951, ranges from about 30 to 40 percent in both cities. In other words, the distribution and extent of urban canopy cover changed on at least a third of the cities' land area. We suspect that the composition and characteristics of tree cover has changed over the sixty year time period. Through urban development, disease, and invasive species introduction there is a likelihood that canopy composition varies between 1951 and 2010 but additional research would be required to estimate canopy composition. With respect to replacement trees, the change in tree cover could have been a matter of crowns positioned a few feet differently in one direction of another or a matter of crowns being different sizes due to age differences, damage, and other factors. While differences in tree cover position may have therefore influenced the results, one might expect with a large enough sample that the impact may not have affected the estimates of total tree cover area as much as transitions over times.

Our objective was to estimate the tree canopy cover of Atlanta and Detroit through two analytical methods each reflecting what can be interpreted through an examination of USDA NAIP aerial images. The use of aerial photographs provides an accurate and cost-effective alternative to more costly ground sampling efforts or ground-up hemispherical photography (King & Locke, 2013). These represent a two-dimensional perspective as viewed from above, and are limited to approximations of tree cover over land. They fail to provide information on tree quality, species composition, age, or health (McPherson et al., 2011). Therefore, a more comprehensive analysis requires richer data than simply tree canopy cover (McPherson et al., 2011). While historical street tree records may provide information on species and condition over time, a significant amount of tree cover may include vegetation not considered to be street trees, particularly in Atlanta and now in Detroit. Also, large amounts of urban tree cover canopy may be on private land making it more challenging to manage or to be left unmanaged.

The findings in both cities may be reflective of urban tree canopy maintenance programs or tree planting by the general public. While the replacement of trees could not be ascertained in our analysis, it is possible that two or more trees may have used the growing space over the 60-year time frame of the analysis. Our assessment of urban tree canopy cover transitions may reflect some of these issues. Unfortunately, street trees may have lower life spans than trees growing in more natural environments due to stresses imposed by transportation systems in the urban environment (Nagendra & Gopal, 2010). To further complicate the matter, in both Atlanta and Detroit some of the urban tree canopy cover is naturally regenerating, growing in interstitial spaces that accommodate their form. Therefore, the notion that tree planting programs facilitated the insignificant change in tree cover cannot be proven with our work given the naturally regenerated trees located in open spaces or on private property.

The political-economic processes including urban planning efforts, zoning regulations, urban forestry management plants, and private land ownership associated with an urban area can also have a profound effect on urban forest resources. Although cities may have tree planting and awareness programs that engage communities, a number of other factors (storms, tree age, land development) may counteract the positive efforts of concerned citizens, yet without these efforts, tree canopy losses would likely be greater (Nowak & Greenfield, 2012). Further, with the exception perhaps of parks and street trees, in many cities the open areas where trees can grow are located on privately-owned land, and thus the responsibilities for planting and tending to these trees are assumed by the landowners and their families. We noted earlier that in both cities an urban forestry program is active, yet these types of programs and associated policies may not be appreciated by the general public (Rae et al., 2010). Recently, in examining the *Greening Milwaukee* it was noted that while 89% of participants in the program were homeowners, and while there were 429 requests for applications, only 33% of the requests (141 applicants) completed the process and received a tree (Perkins et al., 2004). Residents who rent property, who lack the ability to transport a tree, and who lack the resources to plant a tree will also not likely have the motivation to engage in programs such as these (Perkins et al., 2004). However, this may be situational, as between 2007 and 2009, New York City received over 4000 items of correspondence regarding their tree planting process and policies (Rae et al., 2010). Community groups, in turn, may support these types of programs, thus in some urban areas an uneven distribution of urban forest area may develop (Conway, Shakeel, & Atallah, 2011).

The methodology we employed in order to understand changes in tree cover over the last six decades involved sampling-based protocols that were consistent with other work (Nowak, 1993, Nowak and Greenfield, Walton, 2008). However, remote sensing-based techniques could also be employed in order to understand the spatial distribution of urban tree canopy cover (Richardson & Moskal, 2014) or cultural issues involving the use of the landscape (Pham, Apparicio, Séguin, & Gagnon, 2011). Object-based image analysis is one of these techniques, and can be used in conjunction with digital imagery to classify an entire area into categories such as buildings, grass, developed areas, impervious surfaces, shrubs, trees, and otherwise open areas (as in Moskal, Styers, & Halabisky, 2011). In pursuing this type of classification process, information about the objects (e.g., typical textures and shapes, compactness, smoothness, land use context, etc.) can be used to discriminate each feature, and perhaps minimize the overall heterogeneity of the objects on the landscape (Pham et al., 2011). Rule-based systems in conjunction with LiDAR can also be employed to create precise canopy estimates (MacFaden, O'Neil-Dunne, Royar, Lu, & Rundle, 2012; O'Neil-Dunne et al., 2013). This type of analysis, while very worthwhile for current urban planning efforts, was beyond the scope of our project (examining changes in tree cover over time), but could have been employed to meet similar goals for more recent periods of time where imagery and other data were available. However, the methodology employed (classification process, accuracy assessment) would have been much different, and the development of a contiguous set of data for the 1950s-era Detroit and Atlanta areas may have been challenging.

Conclusions

Urban tree cover change in Atlanta and Detroit over the last six decades seems, overall, to be minimal across the entire system. The only similarities between the cities were that about 15–20% of each city's land area was covered with trees in 1951, yet lacked tree cover in 2010. We can only speculate about the underlying forces and the overall impact of these changes on the structure and quality of urban canopy cover, but it seems that such a change would present both management challenges and opportunities for those in charge of urban trees. The period of time we examined does not, however, address changes in city administrations, land-use trends, or other influential factors affecting tree cover. These can play important roles in how the forests and these cities have changed. Further, many urban trees are found on independent parcels and managed on a piecemeal basis by individual landowners, if at all. This makes it difficult to postulate what people may or may not have been able to do with regard to tree cover. Whether relying on regulatory or voluntary measures, one would expect that cities may have some opportunities to influence the process of urban tree canopy cover change in what could be considered a positive manner, helping to achieve some of urban tree resource management goals.

Another question that begs investigation is, in addition to the distribution and extent of urban canopy cover, the quality of that change. Did the cities lose high quality tree resource or low quality resource? Were the losses replaced with more or less desirable tree species and urban greenery structures? We also do not know how these changes in urban canopy are related to the provision of ecosystems services that are often attributed to urban trees, and the extent of their impact on the quality of living. Did the cities gain or lose trees close to offices, residential areas, and public spaces? Or did those changes occur in areas which can be considered industrial sites or even wasteland? Finally, the analysis possibly could be extended to include suburban areas. Both cities are surrounded by extensive suburban growth and what happens there will certainly have some bearing on urban canopies in the central cities.

Our two sampling processes were somewhat consistent in estimating the tree cover of Atlanta. When applied to Detroit, our 2010 estimate of tree cover when using the polygon-based approach was much lower than the estimate provided using the point-based approach. The two estimates were both above and below a recently reported third estimate for Detroit (Nowak & Greenfield, 2012). Therefore, we believe that while the polygon-based sampling method may provide a more reasonable depiction of the area of land covered with trees, due to the time and effort involved and the potential problems imposed by topographic displacement and shadows, the point-based approach is preferred. In sum, the point-based approach allows broader coverage of an area, given its efficient implementation, even though the polygon-based approach describes more clearly the covered areas of land.

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