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Volunteered geographic information, urban forests, & environmental justice

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ABSTRACT

Volunteered Geographic Information (VGI) and urban forests have recently become topics of increasing interest in the social sciences. While social and environmental justice concerns have been applied to each of these topics individually, this paper addresses VGI, urban forests, and social justice simultaneously. VGI has often been hailed as an empowering and democratic new form of citizen science that allows data collection tasks to be distributed to a large group of people; however, concerns have emerged about whose geographies will be volunteered, and for what purpose. This research addresses these concerns, with an understanding that VGI has the potential to strengthen, rather than dissolve the digital divide. This is accomplished by determining the completeness of coverage of user-generated urban forest mapping on the interactive website PhillyTreeMap (http://www.phillytreemap.org/) by comparing it with high resolution remotely sensed canopy coverage data. These coverage levels are then regressed against Census demographic data at the block group level to determine if there are inequities in the coverage of this urban forest VGI project based upon socioeconomic status. Results indicate that sociodemographic variables influence the likelihood of increased coverage of the VGI urban forest data, presenting equity concerns surrounding the coverage of this VGI urban forest data. The presence of these social and environmental justice concerns indicates the need for expanded research into this new frontier of geographic data. Geographically weighted general linear models show non-stationarity in the relationships between VGI coverage and sociodemographic predictors, demonstrating the importance of incorporating local models.

1. Introduction

Volunteered Geographic Information (VGI) and urban forests have recently both became major objects of research focus in both geography and the wider social sciences. While social justice concerns have been applied to each of these topics individually, this paper begins to address VGI, urban forests, and social justice simultaneously.

Urban forests – broadly defined as any tree in an urban area regardless of land use (Konijnendijk, Ricard, Kenney, & Randrup, 2006) – are an important part of urban ecosystems that provide many benefits to urban residents and visitors (Bolund & Hunhammar, 1999; Chen & Jim, 2008; Kielbaso, 2008), helping to make urban areas more pleasant places to live and work. These benefits include: amelioration of the urban heat island effect (Bolund & Hunhammar, 1999; Chen & Jim, 2008; Heidt & Neef, 2008; Kielbaso, 2008; Sailor, 1995; Sampson, 1989; Simpson, 2002), energy conservation (Andreu, Friedman, Landry, & Northrop, 2008; Chen & Jim, 2008; Donovan & Butry, 2010; Dwyer, Mcpherson, Schroeder, & Rowntree, 1992; Ebenreck, 1989; Kielbaso, 2008; Sailor, 1995), reduction of atmospheric pollution (Bolund & Hunhammar, 1999; Dwyer et al., 1992; Nowak, Hoehn, Crane, Stevens, & Walton, 2007), carbon storage and sequestration (Andreu et al., 2008; Chen & Jim, 2008; Dwyer et al., 1992; Kielbaso, 2008; Sampson, 1989), reduction of stormwater runoff (Bolund & Hunhammar, 1999; Chen & Jim, 2008; Dwyer et al., 1992; Ebenreck, 1989; Kielbaso, 2008; Xiao & McPherson, 2003), increased property values (Anderson & Cordell, 1985; Sander, Polasky, & Haight, 2010; Wachter & Wong, 2008), reduction of urban noise (Bolund & Hunhammar, 1999; Chen & Jim, 2008; Dwyer et al., 1992; Ebenreck, 1989), physical and psychological health benefits (Chen & Jim, 2008; Ebenreck, 1989; Ulrich, 1984; Velarde, Fry, & Tveit, 2007), and recreational benefits (Chen & Jim, 2008). Unfortunately, urban trees and their benefits are often not considered when making broad policy decisions that affect the fate of urban socioecological systems (Dwyer et al., 1992). Research detailing these benefits is often the best way to move toward a consideration of urban forests in urban policy (Dwyer et al., 1992; Kielbaso, 2008).

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VGI has become an increasingly important subject in geography. Following Elwood, Goodchild, and Sui (2012), it is defined here as: "geographic information acquired and made available to others through the voluntary activity of individuals or groups, with the intent of providing information about the geographic world (page 575)." While the point is often made with the example of Audubon's Christmas Bird Count that VGI is hardly a new phenomenon (Connors, Lei, & Kelly, 2012), the advent of web 2.0 technologies has exponentially increased the amount of VGI available for analysis (Elwood et al., 2012). This increase in data availability has been heralded as containing both the potential to improve upon traditional sources of authoritative geographic information (Coleman, Georgiadou, & Labonte, 2009; Elwood et al., 2012) and increase equity (Crutcher & Zook, 2009). However, this optimism has been tempered by concerns about the quality of VGI (Connors et al., 2012; Elwood et al., 2012; Girres & Touya, 2010; Haklay, 2010) and its potential to increase, rather than decrease the digital divide (Crutcher & Zook, 2009; Tulloch, 2008; Elwood, 2009; Cinnamon & Schuurman, 2012; Connors et al., 2012; Elwood et al., 2012; Haklay, 2010).

This research begins to combine these two concerns with issues of social justice and the digital divide. This is accomplished by analyzing the completeness of coverage of the VGI urban forest dataset PhillyTreeMap, then determining whether this coverage is influenced by demographic variations. Preliminary results show that population density, housing vacancy rate, median home value, and percentage of white residents all positively influence the likelihood of block groups having a higher level of VGI coverage. This raises concerns about the equity of this urban forest VGI data. The presence of these social and environmental justice concerns indicates the need for expanded research into this new frontier of geographical information and representation. Furthermore, results from GWRGLM models display spatial non-stationarity in the relationships between VGI coverage and demographic variables, indicating the need for multiple scales of analysis. This expanded research should be both qualitative and quantitative, taking care to properly theorize issues of environmental justice and the digital divide.

The paper proceeds as follows: Section 1.1 reviews the relevant literature connecting urban forests, volunteered geographic information, environmental justice, and the digital divide. Section 1.2 introduces Philadelphia, the site for this study. Section 2 presents the data and methods utilized to examine the completeness of VGI coverage and its correlation with demographic variables. Section 3 displays the results from these analyses, with a more detailed discussion in Section 4. Finally, Section 5 proposes some conclusions along with avenues for future research.

1.1. Literature review

Urban forest inventory type analyses are extremely important, as they allow urban forest managers to make informed decisions to maximize benefits and evaluate programs and policies (Kielbaso, 2008). While there have been two recent analyses of Philadelphia's urban forest (Nowak et al., 2007; O'Neil-Dunne, 2011), one is based on sampling performed in 1996 (Nowak et al., 2007) and the other solely describes tree canopy cover (O'Neil-Dunne, 2011). While both of these analyses provide very important information to urban forest managers and Philadelphia residents (and are better sources of information than many cities' urban forest managers have at their disposal), more recent and detailed inventory of urban tree species and condition information would allow for more efficient management of Philadelphia's urban forest.

This is where VGI can act as a supplement or even replacement for geographic data generated in a traditional manner. Launched in April of 2011, PhillyTreeMap (http://www.phillytreemap.org/), allows users to create free accounts and enter trees as points geocoded on a map with species, condition, and planting site information. Users are also able to geocode empty tree pits. The system warns users attempting to add trees that are too close to existing trees to prevent double-counting errors and allows for previous entries to be modified by other users to improve accuracy. The website was developed through a grant from the U.S. Department of Agriculture, with the goal of creating an accurate inventory of trees in the Philadelphia region. The ability for anyone to contribute to this urban forest inventory allows for the creation of this large dataset at a low cost when compared to the two traditional types of urban forest inventories discussed above.

It is also important to examine concerns surrounding environmental justice and the digital divide when analyzing urban forest VGI. While environmental justice research has maintained its focus on hazards and disamenities (Heynen, Perkins, & Roy, 2007; Perkins, Heynen, & Wilson, 2004), researchers are beginning to also examine unequal and inequitable spatial distributions of rural and urban amenities, including urban forests. It is important to ensure that all city residents and visitors who so desire achieve equal opportunities to enjoy these amenities and the benefits that they provide. The majority of studies conducted thus far have confirmed the hypothesis of unequal access to urban forests based upon factors of race/ethnicity and class (Iverson & Cook, 2000; Comber, Brunsdon, & Green, 2008; Dai, 2011; Heynen & Lindsey, 2003; Heynen, Perkins, & Roy, 2006; Jensen, Gatrell, Boulton, & Harper, 2004; Landry & Chakraborty, 2009; Pedlowski, Carneiro Da Silva, Adell, & Heynen, 2002). The greater portion of urban forest environmental justice investigations thus far have been either highly sophisticated in terms of social or spatial theory, and more research is needed that synthesizes both topics.

Concerns have been raised by several researchers about the VGI phenomenon increasing the digital divide (Crutcher & Zook, 2009; Tulloch, 2008; Elwood, 2009; Cinnamon & Schuurman, 2012; Connors et al., 2012; Elwood et al., 2012; Haklay, 2010). The digital divide has largely been theorized as disparities in access to and use of information and communication technologies based upon race/ethnicity, class, gender, or other social and economic factors (Chakraborty & Bosman, 2005; Gilbert, 2010). When extended to the burgeoning VGI movement, the digital divide involves both who originates, and who is represented by this data (Elwood et al., 2012). The early returns on this important topic have confirmed that advantaged people and places are overrepresented in VGI efforts (Crutcher & Zook, 2009; Haklay, 2010). With regards to PhillyTreeMap, these issues of environmental justice and the digital divide are especially important because the data is intended to inform urban forest management decisions. If certain groups of people or neighborhoods are not represented by this urban forest VGI, they might be excluded from tree planting or management programs.

The theorizations of both environmental justice and the digital divide here are necessarily simplistic for this first look at urban forests, VGI, and environmental justice. Both concepts are reduced to spatial abstractions of having and not having access to amenities, resulting in descriptive mapping and counting rather than theoretical breakthroughs or progressive praxis (Gilbert, 2010; Pulido, 2000). While Census block groups are a suitable level of analysis, they still serve to mask differences between those who live and work in these Census boundary areas. Analyses based upon socially constructed demographic variables such as "race" further serve to obscure the differences within these groups based on a multitude of factors. Finally, limiting the research to Philadelphia removes the consideration of regional, national, and global forces that influence contribution to and representation by urban forest VGI. The purpose of this critique is not to dismiss the importance of mapping and counting hazards, amenities, and access to communications technologies, which is an essential component of understanding these issues. Rather, the goal here is to draw attention to the often overlooked need for nuanced qualitative work informed by social theory that can complement currently existing quantitative work. Further research on the synthesis of these topics should employ multiple scalar perspectives, examining both the larger webs of power that influence access to urban forests and the ability to generate VGI, along with the micro scale of daily individual practices and experiences that influence the way urban forests and VGI technologies are encountered.

1.2. Study site

In the late 1600s, when William Penn was considering the original plan for Philadelphia, he envisioned a "widely dispersed, low-density, countrified town," a "Greene Country Towne," as many European cities of the time were struggling with problems of fire and disease that resulted in part from cramped confines and lack of planning (Dunn & Dunn, 1982). The grid plan developed by Thomas Holme in 1687 included wide streets and five squares set aside as public parks. The city was originally planned with 530 individual one acre and half-acre parcels meant for large estate houses; however, landowners divided the original lots into as many as 20 lots and row housing, thus eliminating orchards and gardens (Dunn & Dunn, 1982). Later in the city's history, Fairmont Park was established in 1855 in part to protect the Schuylkill River, which was used for drinking water (Weigley, 1982). The Fairmount park system had expanded to include 3000 acres of public land by 1869 (Beers, 1982).

Today, Philadelphia is the largest city in Pennsylvania, with an estimated population of approximately 1.5 million in 2011 (United States Census, 2011). The city (41% white) is more ethnically diverse than both the United States (78.1% white) and Pennsylvania (81.9% white). Philadelphia is also poorer, with 25.6% of residents falling below the poverty line between 2007 and 2011, compared to 14.3% in the United States and 12.6% in Pennsylvania. Geographically, Philadelphia is comprised of 134.1 square miles of land area, with an average population density of 11379.5 persons per square mile.

The City of Philadelphia's urban forest has been subject to two recent general analyses (Nowak et al., 2007; O'Neil-Dunne, 2011). Nowak et al. (2007) used 210 plots sampled in 1996 to estimate an urban forest inventory for Philadelphia. The results estimated that there were 2.1 million trees in the city, or a 15.7% tree canopy cover (Nowak et al., 2007). O'Neil-Dunne (2011) used high resolution remote sensing techniques to evaluate Philadelphia's existing and potential tree canopy based upon 2008 data. Results showed present tree canopy cover to be at 20%, an over 4% increase from Nowak et al.'s (2007) findings based on 1996 data. The City of Philadelphia is committed to increasing this canopy cover to 30% throughout the entire City as part of its GreenWorks Sustainability Plan (Nutter, 2009). This 10% average increase citywide (O'Neil-Dunne, 2011) is supported by a goal to plant 300,000 trees by 2015 (Nutter, 2009). The importance of urban forests to Philadelphia is nothing new, as the City established a street tree ordinance in 1700 and hired what was possibly the first urban forester in the United States in 1896 (Gerhold, 2007). Philadelphia's interest and investment in urban forests can be directed more efficiently and equitably if more information surrounding urban forests is obtained through both qualitative and quantitative research, either of which VGI has the potential to enrich.

2. Data and methods

This analysis involves the integration and manipulation of data from several different sources: geographical boundaries from the United States Census, trees entered into the website http://www.phillytreemap.org/, and high resolution land cover raster data from the Pennsylvania Geospatial Data Clearinghouse (PASDA). A TIGER boundary shapefile of Philadelphia County 2010 Census block groups was the first building block. Next, the trees entered into the PhillyTreemap as of November 8th, 2012 (52,225) were downloaded in Google's Keyhole Markup Language (KML) before being transformed into a shapefile for integration into ArcGIS. It should be noted that this is a static snapshot of trees entered into the website at a single point in time, and as of March 28th, 2013 the number of trees had increased to 53,495. The fact that 1226 trees were added in this period of five and a half months seems to indicate that contributions to the VGI dataset are slowing down, as the 52,225 trees added in the previous 19 months that the website was live means that an average of over 2700 trees were added per month during that period. This may be due to the majority of the data being generated by previous tree inventories of horticultural associations and other community groups (PhillyTreeMap., N.D.). Another possible explanation is seasonable variation in contributions to this dataset, as the winter months make it harder to both move around the city and identify deciduous trees without their leaves. It would be useful to readily available have data on the date each tree was added.

The next step was to use the Philadelphia County block group boundaries to clip the points from the PhillyTreemap, as it included trees from neighboring Montgomery County. This was necessary due to the unfortunate fact that the high resolution land cover raster data was only available for Philadelphia County. This process resulted in a total of 22,498 trees represented on http://www.phillytreemap.org/ as of November 8th, 2012. The block groups comprised of major parks within the Fairmount Park System (Fairmount, Wissahickon, Pennypack, and Cobb's Creek Park) were also removed from the analysis. This is due to the fact that these areas contain a great deal of forest canopy, but have not been a major focus of PhillyTreeMap's efforts thus far, as the vast majority of trees entered into the VGI database are street trees. Removing these park areas allows the analysis to focus on areas where trees are being mapped and improves the accuracy of the coverage estimates.

The next data source incorporated was high resolution land cover raster data from the Pennsylvania Geospatial Data Clearinghouse that was initially prepared by the Spatial Analytic Laboratory at the University of Vermont as part of O'Neil-Dunne's (2011) report. This data classifies every single square meter of Philadelphia County into one of seven land cover types: tree canopy, grass/shrub, bare soil, water, buildings, roads/railroads, and other paved. The next step was a consideration of only the tree canopy class of land cover. This was accomplished by separating out the classes.

Comparing the two datasets, there were clearly some disparities between the remotely sensed tree canopy cover and the trees entered into PhillyTreemap. The real challenge of this research was to develop a means to estimate and display these disparities at the Block Group level. Since the remotely sensed data reveals tree canopy cover percentage and the TreeMap data only counts the number of trees, a simple one to one comparison was not available. Several steps were involved in making these two data sets commensurable. First, the percentage canopy per block group from the remotely sensed data was transformed into canopy area per block group by multiplying the percentage of canopy cover by the area of the entire block group. Next, at an extremely high level of resolution, four block groups from different parts of Philadelphia County were selected where every piece of canopy cover from the remotely sensed data was represented by a tree placed on PhillyTreemap. These block groups represent differing levels of canopy cover and demographic statistics. These block groups were used

Table 1
Descriptive Statistics.

Variable	Min	Max	Mean	SD
Population density	0	62,298	8760	5028
Percent white	0	100	38	34
Vacancy rate	0	84	10.7	6.8
Median HHI $	0	190,592	39,191	21,218
Median home value $	9999	1,000,001	152,136	111,302

to create an average amount of canopy per tree of 28.772 square meters, as the area of canopy given by the remotely sensed data was divided by the number of trees from the website. This average canopy per tree was then multiplied by the number of trees in each block group to get an expected canopy area based on the trees inputted into PhillyTreemap. Finally, this expected canopy area was divided by the actual canopy area revealed by the remotely sensed data to give an estimated percent accuracy. This estimated percent accuracy had a mean of 6.1%, with 315 of the 1336 block groups having a value of zero (although none of the block groups had zero tree canopy according to the remotely sensed data). Notably, 11 of the block groups were "overrepresented", with estimated percent accuracy scores of greater than 100%. Reasons for this overrepresentation could be the result of: additional trees being planted since the remote sensing imagery was taken in 2008, these areas having smaller trees than the average canopy amount estimated, and/or genuine overrepresentation where trees that do not actually exist have been entered into PhillyTreeMap. This estimated percent accuracy should perhaps be better understood as coverage or completeness.

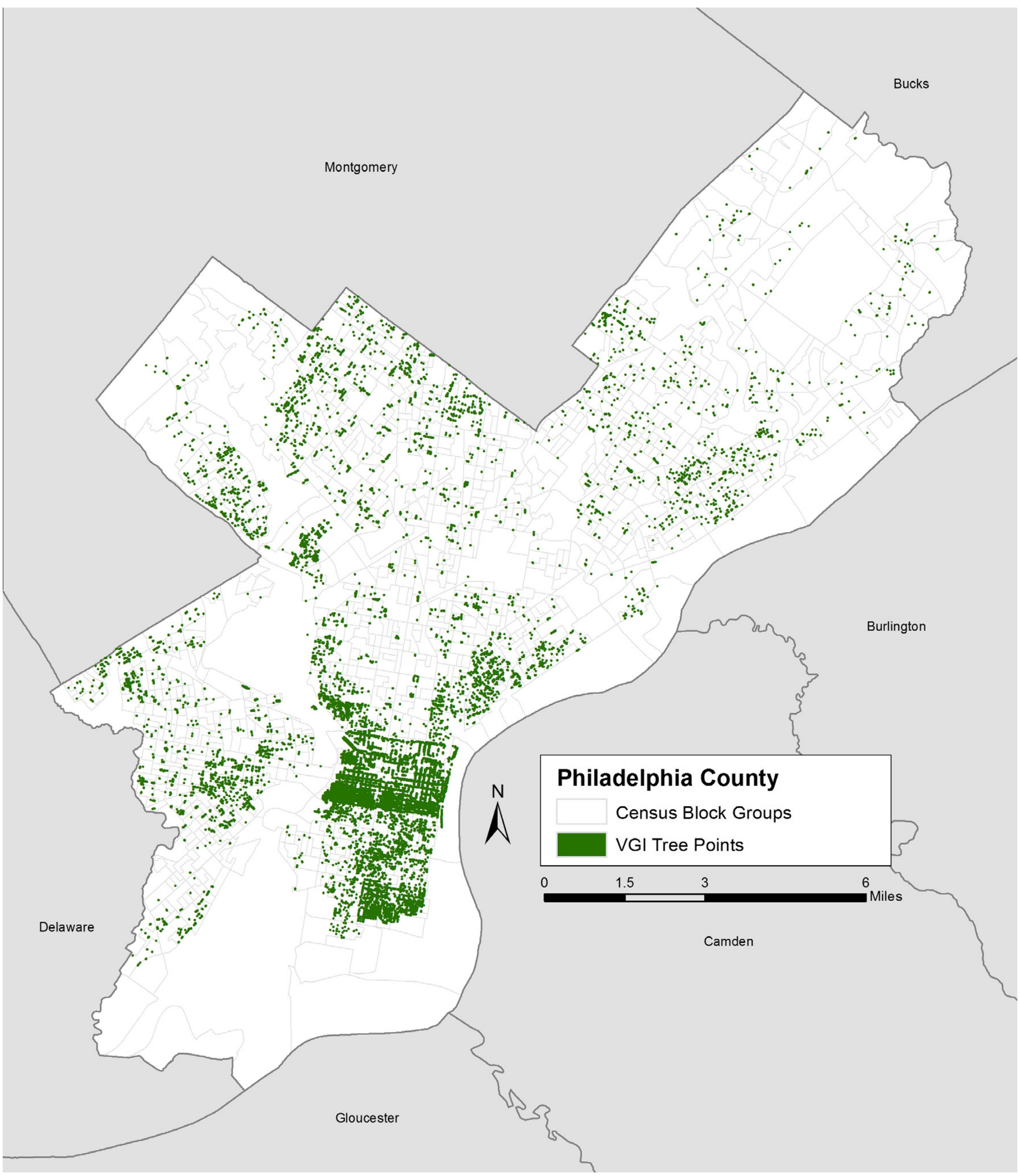

Fig. 1. VGI tree points in Philadelphia.

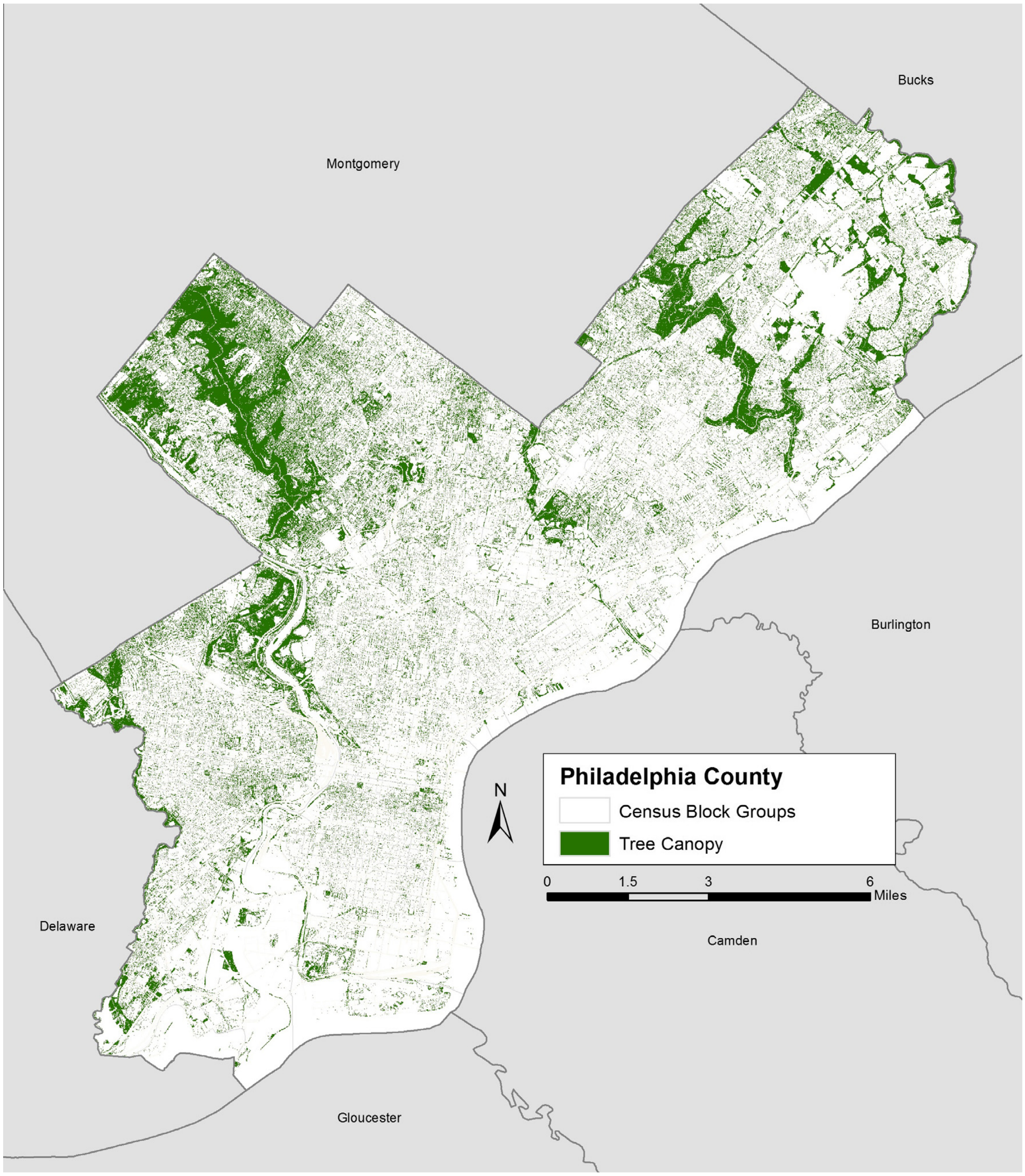

Fig. 2. Philadelphia tree canopy coverage.

The final data required was demographic data from the U.S. Census American Community Survey 5 Year Estimates at the block group level. The pertinent demographic variables included: housing vacancy rate, population density (persons per square kilometer), median household income, median home value, and percent white. These demographic variables were chosen based upon previous research into urban forest distribution and the digital divide that suggests race, class, and urban structure help to explain the uneven distribution of canopy cover or access to digital technologies (Chakraborty & Bosman, 2005; Comber et al., 2008; Gilbert, 2010; Heynen & Lindsey, 2003; Landry & Chakraborty, 2009). Descriptive statistics for these explanatory variables are shown in Table 1. A Poisson regression model was constructed in order to compensate for the highly skewed and overdispersed nature of the percent accuracy values, which were the dependent variable. The previously mentioned demographic variables served as the independent variables. Due to concerns about the construction of the ratio of average canopy per tree, a sensitivity analysis was conducted where this ratio was altered to both greater and lesser amounts of average canopy per tree, resulting in two more Poisson regression models. The models were checked for multicollinearity, outliers, and influential observations. Finally, due to concerns of spatial non-stationarity, a geographically weighted general linear model (GWRGLM) was constructed using GWR4 (Nakaya, 2012). The minimization of AICc was utilized as the bandwidth selection method for conceptualizing spatial relationships in this model.

3. Results

The distribution of trees entered into the PhillyTreeMap website is shown in Fig. 1. There is a strong spatial clustering of this

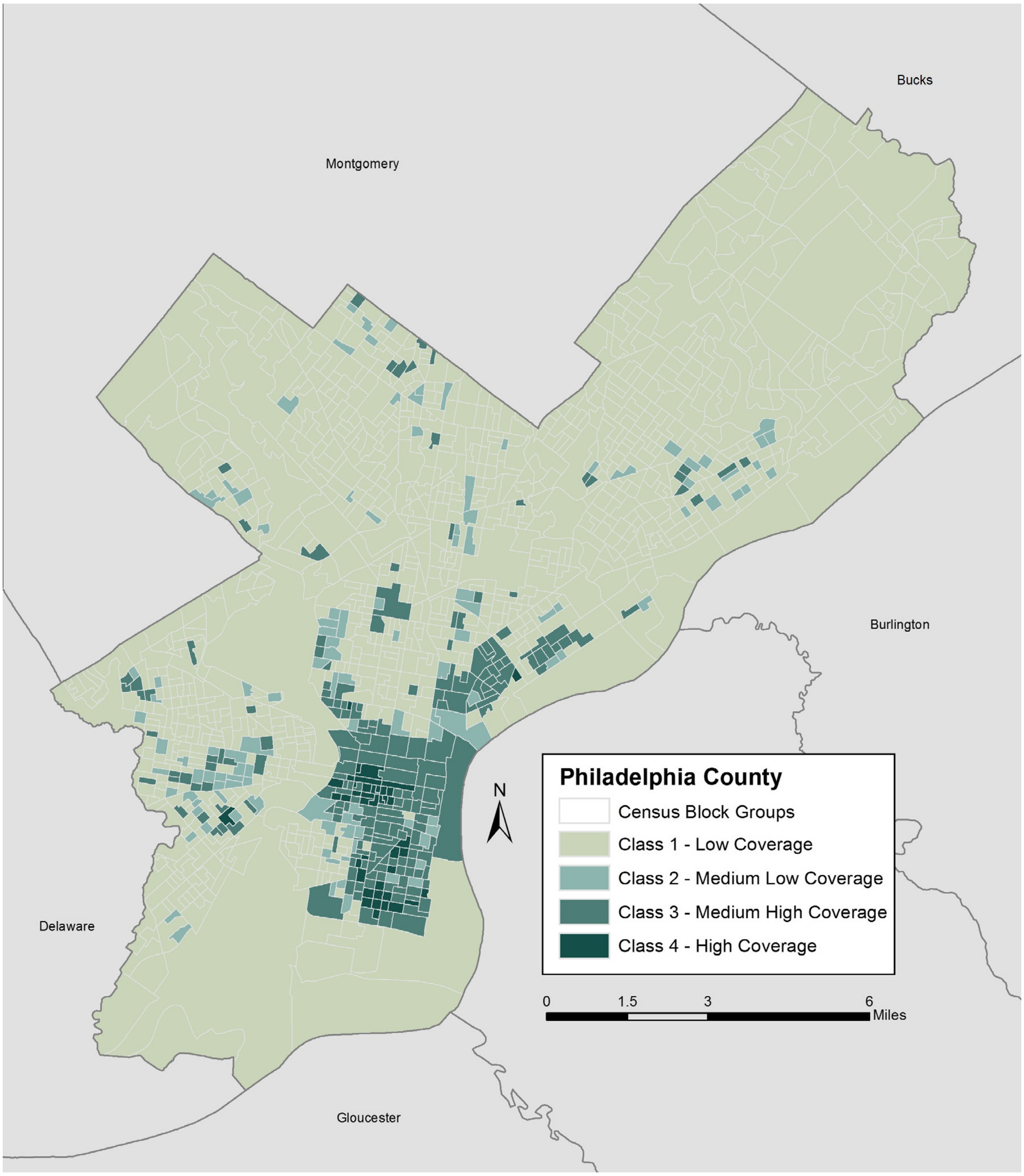

Fig. 3. Philadelphia urban forest VGI coverage classes.

urban forest VGI data in the Center City and South Philadelphia areas. The distribution of tree canopy derived from the high resolution LIDAR land cover data is shown in Fig. 2. Contrary to the VGI urban forest data, tree canopy coverage is centered in the major parks of Philadelphia's Fairmount Park system, with the Center City and South Philadelphia areas having some of the lowest tree canopy coverage percentages in the City. At the Census block group level, the mean tree canopy coverage is 13%, while the maximum canopy coverage is 68.2%, and the minimum is 0.5%.

The distribution of the VGI coverage estimates broken into four quintile classes at the Census block group level is presented in Fig. 3. The distribution of classes is similar to the distribution of tree points in Fig. 1, with the majority of medium and high coverage block groups occurring in the Center City and South Philadelphia areas. These areas are presented in greater detail in Fig. 4. This area of the City contained 41 out of the 42 block groups in the high coverage class.

The results of the Poisson regression analysis are presented in Table 2. The adjusted r-squared value of 0.411 suggests that a significant portion of the variance in completeness of VGI coverage is explained by this model. When examining the individual predictors, they are all statistically significant at the $p < .01$ level. Population density, percent white, and median home value were all strong positive predictors of an increase in completeness of VGI coverage in Philadelphia. Interestingly, median household income has a strong small but very statistically significant negative relationship with VGI completeness. Tests for multicollinearity and other assumptions of regression presented no troubling results. The sensitivity analysis produced no major changes in models results, reducing concerns that the findings are reflective of the

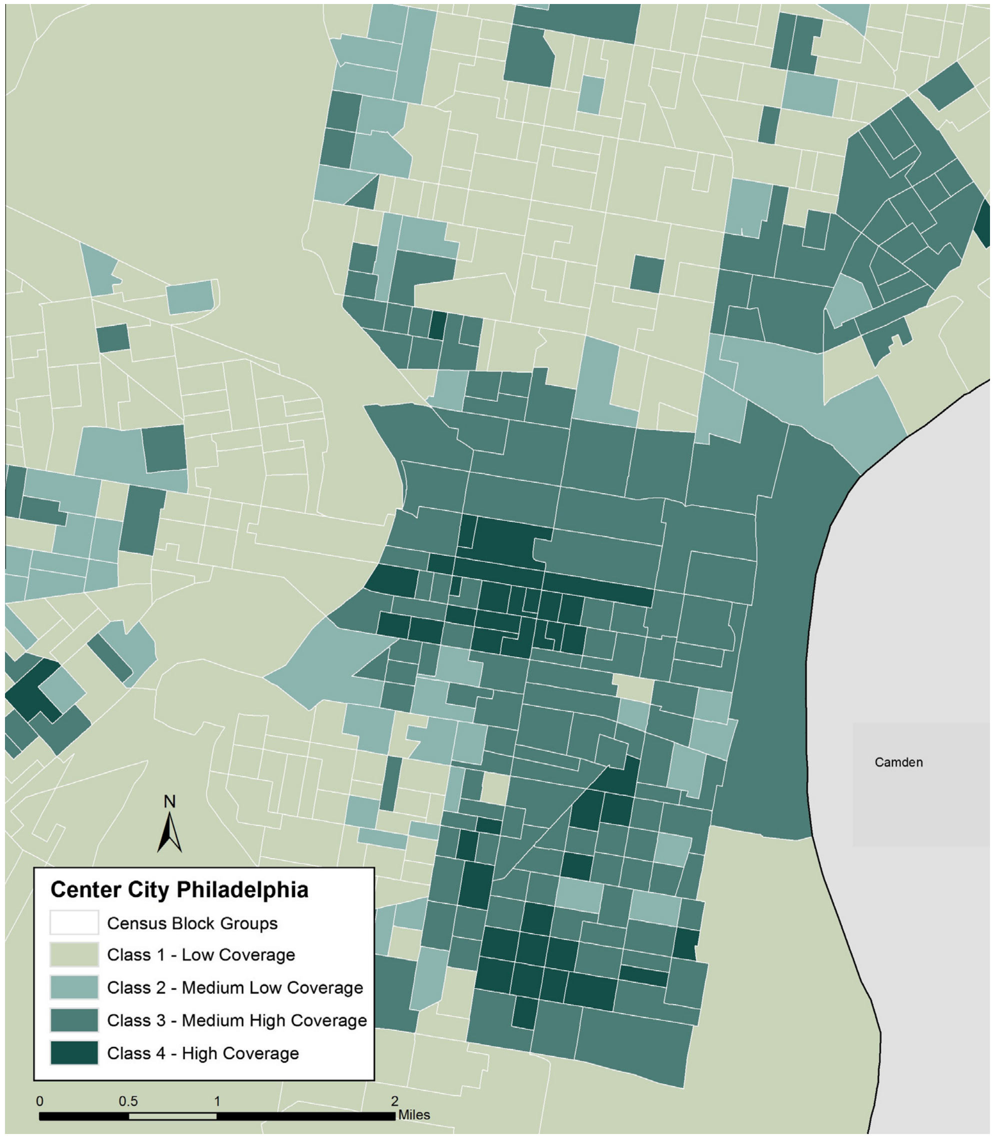

Fig. 4. Center city Philadelphia urban forest VGI coverage classes.

average canopy per tree index rather than more fundamental patterns.

The results from the geographically weighted generalized linear model (GWRGLM) are illustrated in Table 3. The GWRGLM model reduced the AICc and increased the adjusted *r*-squared, suggesting improved model fit. Furthermore, the negative values of the Diff of Criterion for all of the independent variables suggests the presence of spatial variability in their relationships to the completeness of VGI coverage in Philadelphia (Nakaya, 2012). Finally, the minimum and maximum local estimates for all of the independent variables display a change in sign of their relationship with VGI completeness, suggesting that they have negative effects in some block groups and positive effects in others. The predictive power of the model also varies locally, as illustrated by Fig. 5. When comparing this visually to the map of completeness of VGI coverage, it appears that the model function is not tied to the level of VGI coverage.

Table 2
Regression results.

Variable	*B*	*Z*
Intercept	−0.324	−9.53*
Population density	0.00009	79.28*
Percent white	2.56	57.57*
Vacancy rate	1.286	11.60*
Median HHI	−0.00002	−27.78*
Median home value	0.000002	20.87*
AICc	20138.96	
Adjusted *r*-squared	0.411	
N	1333	

* Significant at the $p < .01$ level.

4. Discussion

The positive effects that population density and vacancy rate have upon the likelihood of a block group being in a higher coverage class both seem counterintuitive at first glance. Areas with the highest population density have the least amount of trees, but that does not mean that those trees are represented less in the VGI dataset. On the contrary, the Center City and South Philadelphia areas shown in Fig. 4 that contain almost all of the block groups in the highest coverage class are also among the most densely populated areas in Philadelphia. This area may have also been targeted

Table 3
GWRGLM Results.

Variable	Mean	Min	Max	Diff of criterion
Intercept	−1.552	−14.696	4.264	−810.668
Population density	0.0001	−0.0003	0.0007	−713.084
Percent white	1.276	−12.701	11.455	−244.738
Vacancy rate	−0.1195	−20.965	8.841	−262.389
Median HHI	0.000006	−0.000004	0.000069	−333.572
Median home value	−0.000001	−0.000004	0.000025	−142.144
AICc	5756.89			
Adjusted *r*-squared	0.84			

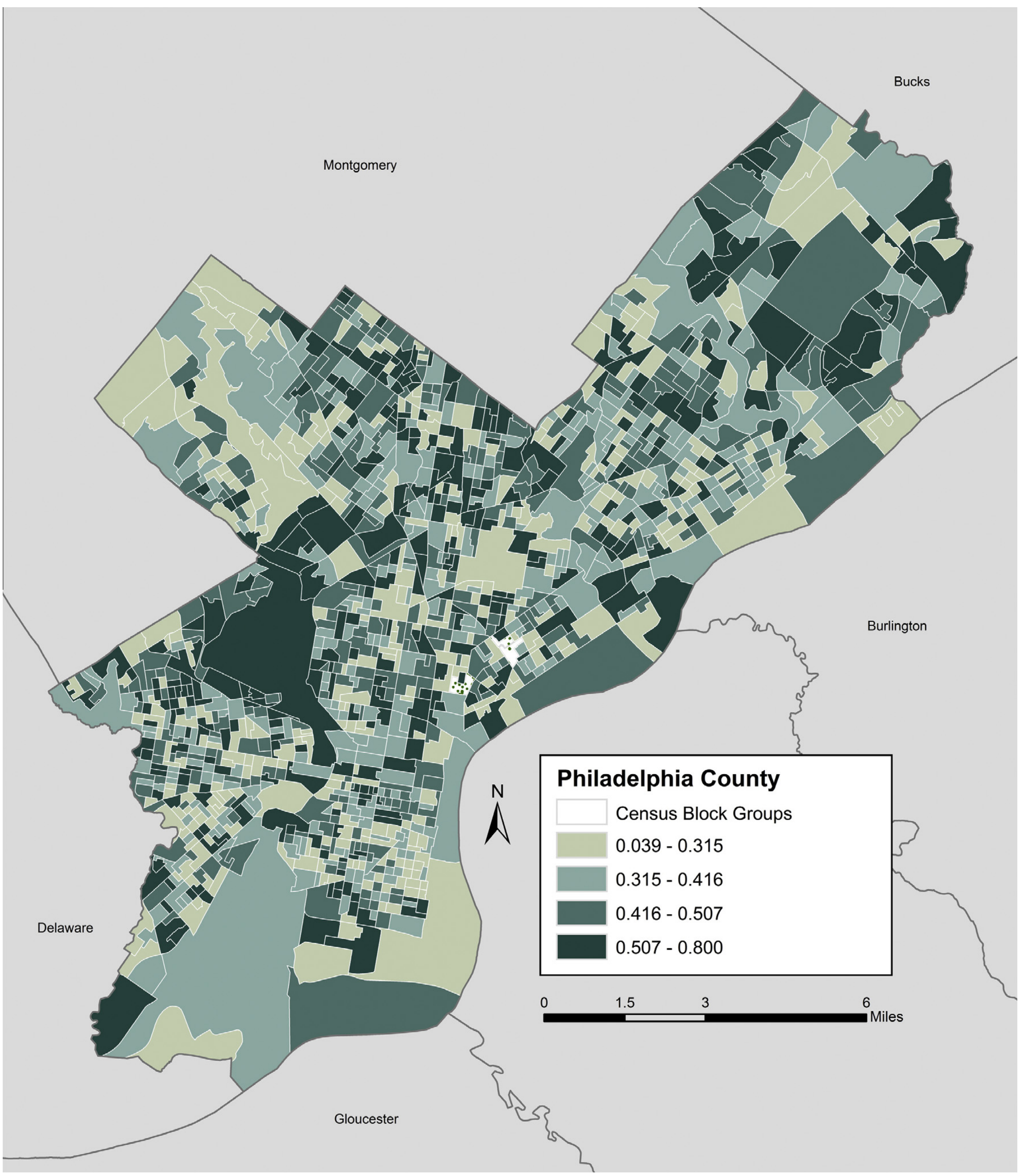

Fig. 5. Local Adjusted *r*-squared.

by recent tree planting campaigns, resulting in many of the trees present having less canopy area than the estimated average canopy area, positively influencing the coverage percent. The positive association of vacancy rate is possibly explained by the same factor, as these areas might have recently experienced new tree plantings.

The percentage of white residents in a block group having a positive effect upon the probability of that block group have a higher accuracy of VGI coverage raises equity concerns, as conversely, block groups with a higher percentage of nonwhite residents are more likely to have a lower level of coverage. There are several possible explanations for this racial disparity in coverage. The first and most obvious explanation is the issue of the digital divide discussed previously. The racialized differences in access to devices with internet connectivity (Chakraborty & Bosman, 2005; Gilbert, 2010) allowing for participation in the creation of this VGI dataset is a strong possible explanation for disparities in coverage between whites and nonwhites. This is of course assuming that these groups have equal wishes to participate.

Disparities in coverage based upon racial characteristics could also result from differential preferences for urban forests. While there have been only a few studies conducted examining urban forest and park preferences (that have been focused upon a single city for the most part), so far the general trend in this body of research is to confirm the hypothesis that racial/ethnic minorities and the poor have a lower level of demand for urban forest and park resources (Brownlow, 2006; Brownlow, 2011; Buijs, Elands, & Langers, 2009; Elmendorf, Willits, & Sasidharan, 2005a; Elmendorf, Willits, & Sasidharan, 2005b; Fraser & Kenney, 2000; Ho, Sasidharan, Elmendorf, & Willits, 2005; Kaplan & Talbot, 1988; Lohr, Pearson-mims, Tarnai, & Dillman, 2004; Payne, Mowen, & Orsega-Smith, 2002; Perkins, 2011; Pincetl, 2010), although this hypothesis has been contested (Hester, Blazej, & Moore, 1999). The one study on urban forest and park preference performed in Philadelphia (Ho et al., 2005) agrees with the postulation of lower urban forest and park preference among racial minorities.

There have been several theories put forward to explain this difference in urban forest and park preferences between ethnicities. The simplest of these is similar to one put forward regarding environmental disamenities: that poor and racial/ethnic minority populations are so disadvantaged by other structural inequities that there are greater concerns for them than the presence or absence of urban forests and parks in their neighborhoods (Cutter, 1993). Others (Brownlow, 2006; Brownlow, 2011; Heynen et al., 2007) have suggested that the poor condition of urban trees in minority neighborhoods often causes them to be seen as disamenities rather than amenities. Martin (2004) hypothesizes that media generated racialized constructions of nature and wilderness have perpetuated a lower demand for natural areas among minorities, especially African Americans. Regardless of the reason(s) for this disparity in urban forest VGI based upon racial categories, it raises troubling questions about social and environmental justice implications that require further research.

Despite the results of the Poisson regression models that suggest equity concerns in the amount of urban forest VGI coverage in Philadelphia, the GWR models show that these relationships are not consistent across space. Indeed, the local estimates of each independent variable indicate both positive and negative effects upon the dependent variable of percent accuracy. The presence of spatial non-stationarity means that there may only be certain minority and low income neighborhoods where equity concerns are present, thus demonstrating the importance of examining local and global models. Furthermore, these results speak to the previously mentioned critique (Gilbert, 2010; Pulido, 2000) of the abstractions present in the traditional descriptive mapping and counting analyses found in most environmental justice and digital divide research, highlighting the need for concrete local research to address the disparities within groups along with those between them.

5. Conclusion

This paper represents a first look at combining the increasingly important concerns of volunteered geographic information, urban forests, and environmental justice. Using high resolution remotely sensed land cover data, VGI urban forest information, and Census block group level demographic data, a Poisson regression model is constructed to assess the effects of demographic variables on the completeness of VGI coverage. Results show that population density, housing vacancy, median home value, and percentage of white residents all have positive statistically significant effects. This suggests that there are social and environmental justice concerns surrounding the coverage of the data generated by the users of PhillyTreeMap. Furthermore, results from the GWRGLM models suggest that these environmental justice concerns vary over space in Philadelphia.

It should be emphasized that these findings are not a condemnation of the users and creators of the PhillyTreeMap website (nor VGI as a whole). This tool presents a unique opportunity to generate bottom up knowledge and promote public awareness of Philadelphia's urban forest. A complete dataset of every tree with location, species, and condition – the stated goal of the project – would be a great asset to urban forest managers, residents, and visitors. Unfortunately, in the early stages of the project the data is more accurate in areas with a lower percentage of racialized minorities. In the future, PhillyTreeMap should seek to equalize coverage across geographical and demographic boundaries.

This research has several limitations. The greatest of these lies in the possibilities for error in the estimation of the accuracy of the VGI data due to the availability of only tree locations from the website. Having tree species and condition data would allow for a better estimate of canopy coverage in the VGI dataset. The sensitivity analysis performed helps to assuage concerns surrounding these limitations. There is also the issue of temporality between these two datasets, as the land cover data is from 2008 and the VGI data is from 2012. The recent extensive tree planting efforts in the City of Philadelphia could explain some of the discrepancies in accuracy, although this predicts a higher rather than a lower level of coverage of the VGI dataset. Another temporal limitation of this research is the continuous addition of trees to the VGI website, which might result in a very different representation of its coverage and the equity implications if analyzed again in the future.

There are several possible ways to extend and improve this research in the future. Case studies of other communities that are using the application behind PhillyTreeMap (San Francisco, San Diego, Sacramento, Asheville, and Grand Rapids) will allow for additional comparisons of VGI accuracy and its relationship(s) with demographic factors so that further understanding of these processes can be achieved.

The GWRGLM analyses reveal that relationships between explanatory variables and the completeness of VGI coverage vary spatially. This opens up possibilities for a more situated understanding of environmental justice and digital divide issues that should be pursued further. This can be achieved by creating more localized neighborhood regression models to minimize spatial variations, or by using spatial autoregressive modeling to weight observations based upon spatial dependencies (Dunham & Foster, 2014).

Extending the investigation to examine contributors to this urban forest VGI would help to build an understanding of inequities in data coverage, among other things. Finding out who exactly is producing this VGI and for what reason through quantitative and qualitative research is a logical next step. Unfortunately, this information is not readily available on the website. Of the 52,225 tree locations, only 2949 had the names of uploaders attached to them. There were 2143 unique uploaders for these 2949 trees, with the maximum number of trees provided by a single uploader being 32 and the mean trees per uploader equaling 1.38. The availability of the users and groups that are contributing is another major potential improvement to PhillyTreeMap. Addressing concerns of anonymity, the names of contributors could be coded so at least the number of unique contributors is readily available. At this point it is unclear what the level of public participation in the generation of this VGI dataset has been.

While researchers have begun to explore why users contribute VGI in general (Cinnamon & Schuurman, 2012; Coleman et al., 2009), more research is needed on this topic along with specific analysis of this particular urban forest VGI dataset in Philadelphia. One possibility is that, similar to urban forest canopy coverage (Conway, Shakeel, & Atallah, 2011), the involvement of community groups is driving uneven VGI coverage. The differential preferences for urban forests discussed previously could also be investigated qualitatively to determine whether these influences are driving disparities in the coverage of PhillyTreeMap instead of digital divide issues. Another avenue of exploration is to determine how the opportunity to contribute urban forest VGI is marketed, and how the promotion of the website is possibly contributing to uneven coverage. This might also be connected to community groups being drivers of uneven VGI coverage, if they are the focus of the outreach for contributors.

Qualitative research with urban forest managers in Philadelphia would help to determine the extent to which PhillyTreemap is being used, or its potential to be used in the future, to assist in urban forest management and distribution choices in the City. If this VGI dataset with inequitable coverage based upon racial characteristics is being used to make urban forest management decisions, major concerns about the equity of those decisions are present.

This qualitative research would also allow for a richer conception of the digital divide, environmental justice, and urban forest VGI that moves beyond simplistic reductions to "race" and Census block groups to determine how race, class, gender, age, and other characteristics interact across different scales in webs of power relations, drawing connections between access to communications technologies, urban forests, and other urban inequalities.

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