Article

Exploring Relationships between Socioeconomic Background and Urban Greenery in Portland, OR

Lorien Nesbitt and Michael J. Meitner *

Department of Forest Resources Management, Faculty of Forestry, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada; lorien.nesbitt@ubc.ca
* Correspondence: mike.meitner@ubc.ca; Tel.: +1-604-822-0029

Abstract: Do urban residents experience societal benefits derived from urban forests equitably? We conducted a broad-scale spatial analysis of the relationship between urban greenery and socioeconomic factors in the Portland metropolitan area. The Normalized Difference Vegetation Index was derived from National Agriculture Imagery Program images to map urban vegetation cover, and Outdoor Recreation and Conservation Area data were used to identify green spaces. These measures of urban greenery were correlated with census data to identify socioeconomic factors associated with high levels of green inequity. Population density, house age, income, and race were strongly correlated with vegetation cover. However, the distribution of green spaces showed a much weaker relationship with socioeconomic factors. These results highlight the importance of different measures of access to urban greenery and suggest potential solutions to the problem of urban green inequity. Cities can use our methods to conduct targeted urban forest management to maximize urban forest benefits received by residents.

Keywords: climate change; equity; Portland; socioeconomics; urban forests; well-being

1. Introduction

Trees and green spaces are important to human well-being [1]. In cities, it is well established that trees and green spaces provide important environmental, economic, social and psychological benefits [2–9]. Trees and green spaces influence urban microclimates to reduce the "urban heat island effect" [10], improve air quality [5], and reduce surface water runoff [8]. They help us recover from stress [7], improve public health outcomes [11–13], increase social cohesion [14,15], may reduce violent crime [16], can increase property values [6], and support urban biodiversity [17,18]. As more and more people make cities their home, cities and societies need to consider how best to maximize the benefits of urban greenery and ensure that urban residents are all able to experience these benefits.

Although urban greenery has important, positive impacts on various aspects of urban quality of life, the distribution of urban greenery appears to be inequitable in many cities around the world [19–24]. Urban green spaces are most often located in wealthier neighbourhoods [6] and trees on private property are often larger and more abundant in high income neighbourhoods [25]. The canopy cover of public street trees can also vary widely within cities, and lower levels of canopy cover are more often found in lower-income neighbourhoods [20,23].

This disparity in access to urban greenery is central to the idea of *urban green equity*. We define urban green equity as equitable access to urban greenery, regardless of differentiating factors such as socioeconomic status, race, cultural background, or age. Equitable greenery access helps ensure that all residents have equitable access to the services and benefits provided by urban greenery that may be associated with higher levels of societal well-being [12,13,26]. Equitable access to urban greenery may be most important for lower socioeconomic groups. For example, the positive effects of urban greenery

on health seem to be strongest among lower income groups who are more likely to suffer poor health outcomes and higher levels of mortality [11,13,27]. The availability of urban greenery also appears to have a stronger positive effect on residents' perceived general health in lower income groups [12].

While most cities likely experience some form of urban green inequity, it is not yet clear how this inequity should be defined and measured and what causes it. A diversity of study sites and measures of green cover and green access (or equity) has demonstrated general relationships between measures of privilege and urban green access but has yet to clarify the relative roles that these factors play [19–22,24,28–31]. As a first step in examining the concept of urban green equity and exploring its potential relationships to socioeconomic patterns, we undertook an analysis of the availability of urban greenery in the Portland–Vancouver metro area, United States of America (US). This first-step analysis does not seek to uncover causal relationships. Rather, our analysis examines correlations between the distribution of urban greenery and socioeconomic factors that may be related to this distribution. Further analysis would be needed to develop a theory of urban green equity that clarifies causal relationships.

Portland is considered an urban forestry leader in the US and was named one of the "10 Best Cities for Urban Forests" in 2013 by American Forests [32]. The City of Portland has a public tree inventory and a tree species diversity plan [33]. Urban forestry appears to be integrated with other municipal planning initiatives, including the city's climate change and green infrastructure plans [34,35]. From a regional perspective, while there is variation in local urban forestry policies and programs, as of 2010, 25 out of 30 jurisdictions (municipalities, counties, or regions in the Portland–Vancouver metro area) had ordinances regulating tree removal or preservation on private land, and 22 out of 30 jurisdictions regulated street tree removal on public land [36]. Five jurisdictions had adopted urban forestry management plans and four jurisdictions had an urban tree inventory [36].

A review of local plans and policies suggests that the City of Portland has some understanding of the importance of urban green equity. The Portland Urban Forestry Management Plan 2004 includes a "commitment to equity so environmental impacts and the costs of protecting the environment do not unfairly burden any one geographic or socioeconomic sector of the City" [37] (p. 105). While the 2007 Urban Forest Action Plan has no mention of or strategies to address urban green equity or socioeconomic inequalities through urban forest management [38], by 2015, the Implementation Update discusses an equity scan completed by the Environmental Services Tree Program in the 2013/2014 fiscal year and efforts to address inequities through programming [39]. The Update includes efforts to ensure equitable service delivery in low-income communities and communities of colour, and optimize tree planting to "support the equitable distribution of street trees throughout the city" [39] (p. 16). The City's new tree code, which took effect at the beginning of 2015, includes a "Tree Planting and Preservation Fund", one of the purposes of which is to advance the equitable distribution of tree-related benefits [40].

2. Materials and Methods

2.1. Data Collection

Our study site was the Portland–Vancouver metro area. Our analysis included the portion of the Portland–Vancouver metro area that falls within the state of Oregon in order to capture a range of development types and to better reflect the experiences of urban residents who may live and work in different parts of the metro area. We excluded the portion of the metro area that falls within the state of Washington due to data limitations. The metro area used in our analysis was the "Portland OR–WA" Urbanized Area (UA) as defined by the US Census Bureau for the most recent census year (2010) [41]. The Census Bureau defines urban areas as " . . . a densely settled core of census tracts and/or census blocks that meet minimum population density requirements, along with contiguous territory containing non-residential urban land uses as well as territory with low population density

included to link outlying densely settled territory with the densely settled core." [42]. Those urban areas with populations of 50,000 or more are designated as UAs by the US Census Bureau [42].

To better understand how different segments of the Portland population may access urban greenery in different parts of the metro area, we measured urban greenery cover and park access by Block Group, the smallest unit for which US decennial census data and American Community Survey data are publicly-available across a wide range of topics [43]. Only Block Groups located entirely within the state of Oregon in the Portland OR–WA UA were included in the analysis. Block Group boundaries were obtained from the 2013 TIGER/Line Shapefiles produced by the US Census Bureau [44].

2.1.1. Greenery Cover

We estimated greenery cover using aerial imagery produced by the US National Agriculture Imagery Program (NAIP). The imagery was acquired by the NAIP program during the growing season ("leaf on") in the year 2010 and has a resolution of 1 m^2. The images were captured with four bands of data: red, green, blue, and near infrared. The four-band imagery allows for the calculation of the Normalized Difference Vegetation Index (NDVI) using the formula (NIR − Red)/(NIR + Red), where NIR is the near infrared wavelength band and Red is the red wavelength band. NDVI is a measure of the visible and near-infrared light reflected by green vegetation and is commonly used to estimate the density and type of vegetation in remotely-sensed images [45,46]. The benefits of using the NDVI to measure vegetation are that (1) it provides data that are comparable across large areas and many different contexts; and (2) it allows for differentiation between broad greenery types (e.g., woody vegetation and grassy vegetation).

We calculated NDVI values for each 1 m^2 pixel and reclassified each pixel as either "mixed vegetation" or "predominantly woody vegetation". This distinction reflects the different benefits urban residents can derive from urban vegetation generally and woody vegetation specifically [7,47,48]. "Mixed vegetation" was defined as all pixels with values of 0.12 or higher and represents all urban greenery, including grass, garden and crop plants, shrubs, hedges, and trees [49]. "Predominantly woody vegetation" was defined as all pixels with values of 0.3 or higher and includes trees of all sizes, large shrubs, and hedges [49]. These reclassifications had accuracies of 93% for "mixed vegetation" and 81% for "predominantly woody vegetation", as determined by a 100-point random sample comparing the reclassified pixel values with aerial photos.

To estimate the availability of greenery in each Block Group, we calculated the mean "mixed vegetation" pixels (Figure 1) and "primarily woody vegetation" pixels (Figure 2) per area of land for each block group.

2.1.2. Green Spaces

We used the Outdoor Recreation and Conservation Area (ORCA) feature class produced by the Portland Metro Regional Government to identify green spaces in the study area. This dataset includes a variety of green spaces including parks and/or natural areas, cemeteries, golf courses, areas owned by private home owners associations, school lands, and areas not specifically designated as any other type of green space, such as privately-owned plots, transportation corridor buffers, and trails that are not large enough to qualify as parks [50]. The ORCA dataset is thus a wide definition of green spaces and represents both public and private land.

To estimate access to green spaces in each Block Group, we calculated the Euclidean distance between the Block Group centroid and the nearest park edge (Figure 3). This simple method provides a reliable estimate of the average distance to the nearest green space edge from any point in the Block Group. The method treats all green spaces equally, regardless of size and ownership.
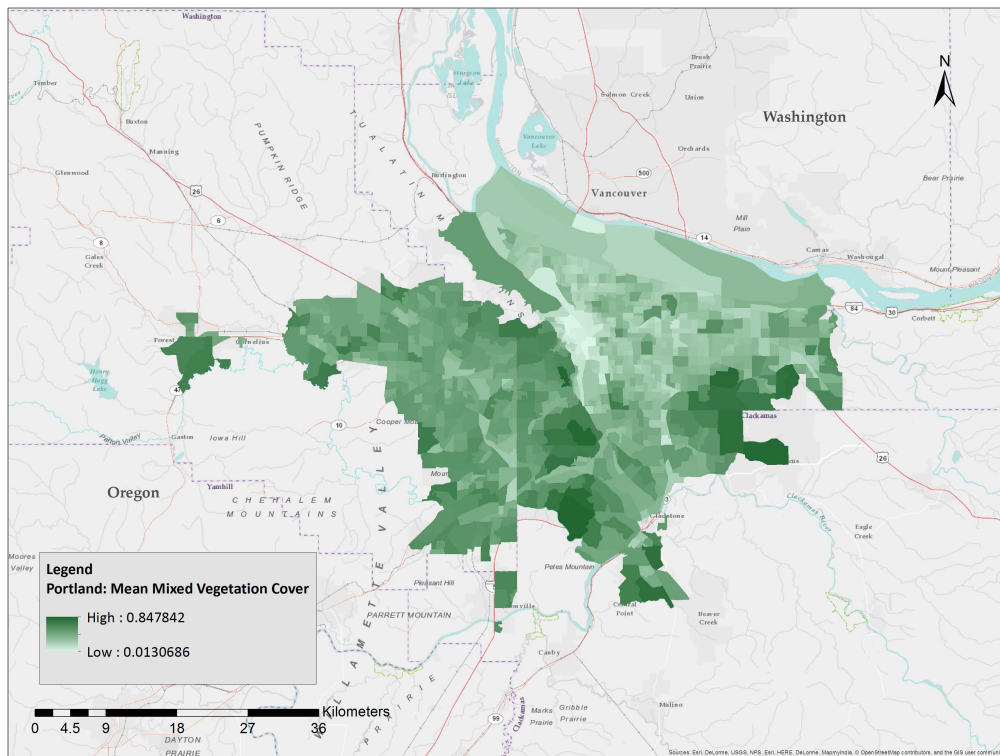
Figure 1. Mean number of pixels with Normalized Difference Vegetation Index (NDVI) values of 0.12 or greater per square metre of land in each Block Group.
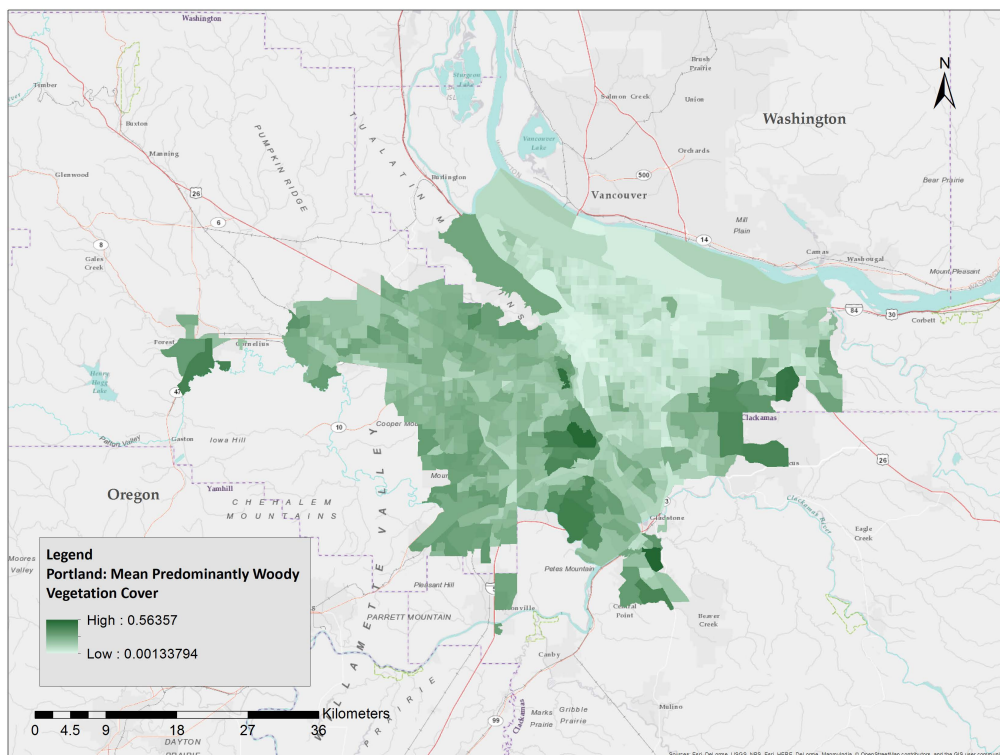

Figure 2. Mean number of pixels with Normalized Difference Vegetation Index (NDVI) values of 0.3 or greater per square metre of land in each Block Group.
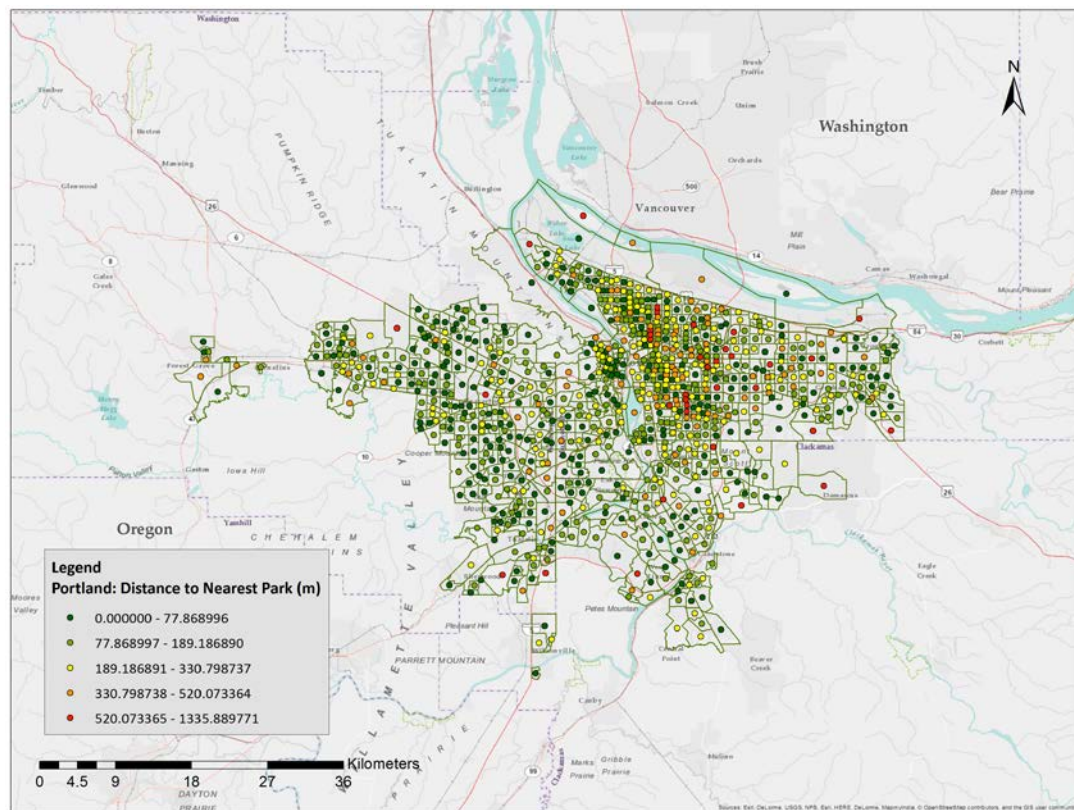
Figure 3. Euclidean distance from the Block Group centroid to the nearest park edge as defined by the Outdoor Recreation and Conservation Area (ORCA) feature class.

2.1.3. Socioeconomic and Land Use Data

We obtained socioeconomic data from the 2009–2013 American Community Survey 5-Year Estimates, produced by the US Census Bureau. The 2009–2013 American Community Survey 5-year estimates include results from the American Community Survey and describe the entire data collection period, from 1 January 2009 to 31 December 2013 [51]. We collected socioeconomic data on several topics, including:

- Age;
- Educational attainment;
- Employment status;
- Hispanic or Latino origin;
- House age (median);
- Income (annual per capita);
- Population density;
- Race.

We obtained zoning data for the Oregon counties and municipalities within the study area from the Portland Metro Regional Government. The dataset includes generalized zoning designation boundaries for the metro region in Oregon, including the City of Portland, Multnomah County, Washington County, and Clackamas County, Oregon. The generalized zoning categories are: Future Urban Development, Industrial, Commercial, Multi-family Residential, Mixed-Use Residential, Single-family Residential, Public Facility, Parks and Open Spaces, and Rural (Figure 4). Zoning data for Washington State were unavailable. Block Groups in Washington State were thus excluded from the analysis.
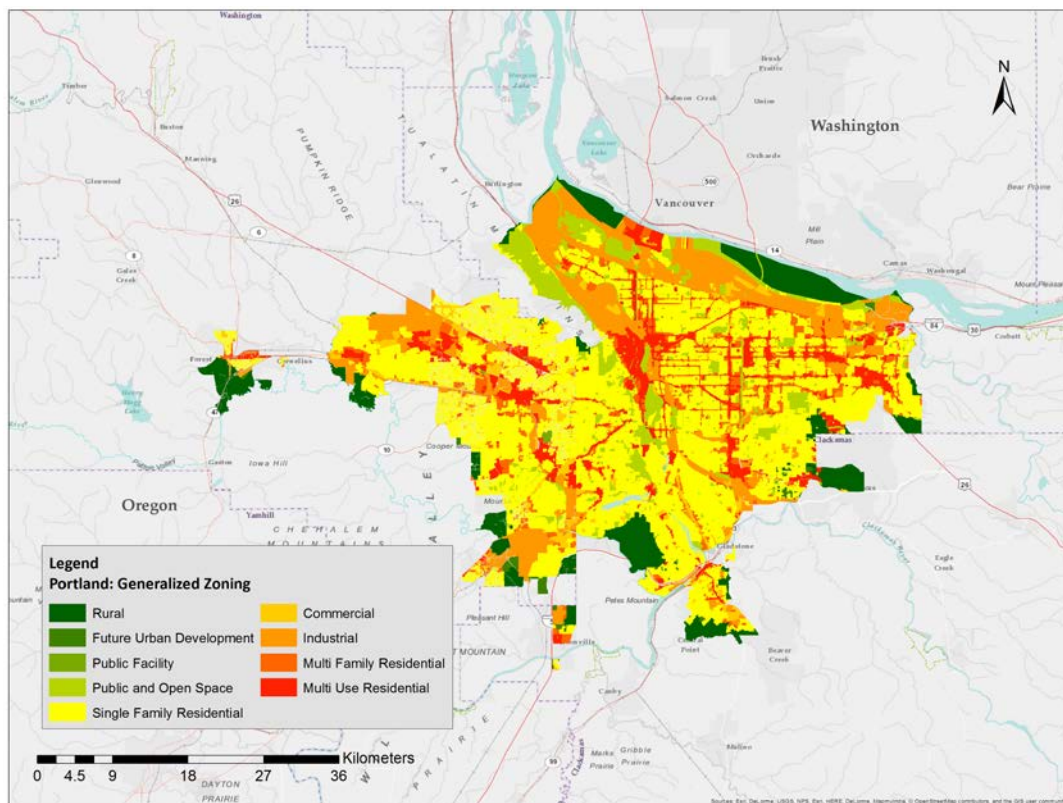
Figure 4. Zoning boundaries for nine generalized zoning categories.

2.2. Analysis

To better understand how different segments of the Portland population experience urban greenery in different areas of the metro region, we used step-wise multiple linear regression to examine correlations between socioeconomic factors and (1) mean "mixed vegetation" pixels; (2) mean "predominantly woody vegetation" pixels; and (3) distance to nearest green space by Block Group.

We investigated the relationship between zoning and greenery cover ("mixed vegetation" and "predominantly woody vegetation") using univariate Analysis of Variance (ANOVA).

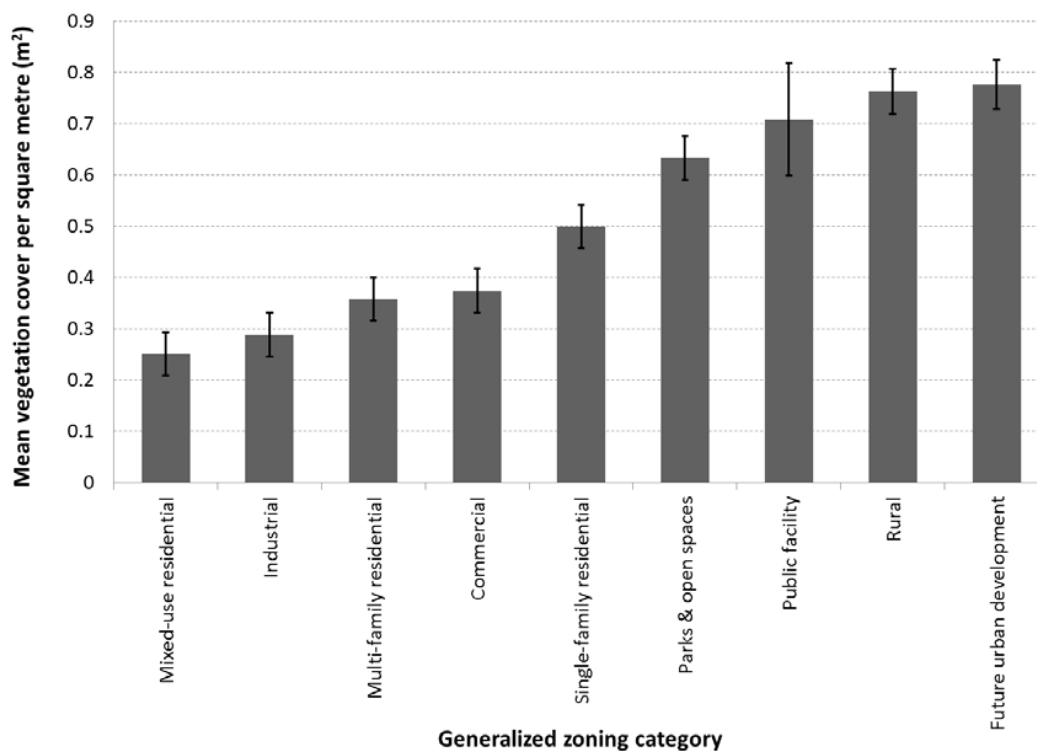**3. Results**

3.1. Greenery Cover

3.1.1. Mixed Vegetation

A multiple linear regression was calculated to predict mixed vegetation cover based on population density, median year built, income per capita, percent white, percent other race, percent professional degree, percent Master's degree and percent Asian. A significant regression equation was found ($F(8, 890) = 99.746$, $p < 0.01$) with an R^2 of 0.473 (Table 1). Predicted mixed vegetation cover is equal to $-6.643 - 30.532$ (population density) $+ 0.003$ (median year built) $+ 1.089 \times 10^{-6}$ (income per capita) $+ 0.312$ (percent white) $+ 0.337$ (percent other race) $+ 0.365$ (percent professional degree) $+ 0.171$ (percent masters degree) $+ 0.150$ (percent Asian). Population density, house age, and per capita income showed the strongest relationships with mixed vegetation cover (Table 1). Block Groups with higher population densities, older houses, and lower per capita incomes had lower levels of mixed vegetation cover.

Table 1. Regression results for "mixed vegetation" cover and socioeconomic variables.

	Mean "Mixed Vegetation" Pixels per Area Land		
Variable	B	SE B	β
Population Density	−30.532	2.175	−0.362 **
Median Year Built	0.003	0.000	0.424 **
Income Per Capita	1.089×10^{-6}	0.000	0.014 *
Percent White	0.312	0.046	0.259 **
Percent Other Race	0.337	0.072	0.150 **
Percent Professional Degree	0.365	0.131	0.095 **
Percent Masters Degree	0.171	0.073	0.081 *
Percent Asian	0.150	0.069	0.071 *
R^2			0.473
F			99.746 **

B, unstandardized regression coefficient; SE, standard error; β, standardized regression coefficient; *p*, calculated probability. * $p < 0.05$; ** $p < 0.01$.

The ANOVA showed significant differences in mixed vegetation cover among generalized zoning boundaries ($F(1, 9) = 480.54$, $p < 0.01$) and zoning accounted for over 22% of the variation in the mixed vegetation cover data ($R^2 = 0.225$). Zoning types with the lowest levels of mixed vegetation cover were mixed-use residential, industrial, multi-family residential, and commercial (Figure 5). Zoning types with the highest levels of mixed vegetation cover were parks and open spaces, public facility, rural, and future urban development (Figure 5). Among residential zoning types, single-family residential areas had much higher levels of mixed vegetation cover than any other residential zoning types (Figure 5).

Figure 5. Mean mixed vegetation cover per square metre by generalized zoning category.

3.1.2. Predominantly Woody Vegetation

A multiple linear regression was calculated to predict predominantly woody vegetation cover based on median year built, population density, income per capita, percent other race, percent white, percent some school completed, percent high school diploma, and percent some college completed.

A significant regression equation was found ($F(8, 890) = 103.730$, $p < 0.01$) with an R^2 of 0.483 (Table 2). Predicted predominantly woody vegetation cover is equal to $-5.110 + 0.003$ (median year built) $- 17.728$ (population density) $+ 5.700 \times 10^{-7}$ (income per capita) $+ 0.296$ (percent other race) $+ 0.159$ (percent white) $- 0.175$ (percent some school) $- 0.134$ (percent high school diploma) $- 0.059$ (percent some college). House age, population density, and per capita income showed the strongest relationships with predominantly woody vegetation cover (Table 2). Block Groups with older houses, higher population densities, and lower per capita incomes had lower levels of predominantly woody vegetation cover.

Table 2. Regression results for "predominantly woody vegetation" cover and socioeconomic variables.

	Mean "Predominantly Woody Vegetation" Pixels per Area Land		
Variable	B	SE B	β
Median Year Built	0.003	0.000	0.493 **
Population Density	−17.728	1.451	−0.318 **
Income Per Capita	5.700×10^{-7}	0.000	0.079 *
Percent Other Race	0.296	0.046	0.199 **
Percent White	0.159	0.024	0.200 **
Percent Some School Completed	−0.175	0.042	−0.137 **
Percent High School Diploma	−0.134	0.035	−0.116 **
Percent Some College Completed	−0.059	0.029	−0.062 *
R^2		0.483	
F		103.730 **	

B, unstandardized regression coefficient; SE, standard error; β, standardized regression coefficient; *p*, calculated probability. * $p < 0.05$; ** $p < 0.01$.

The ANOVA showed significant differences in predominantly woody vegetation cover among generalized zoning boundaries ($F(1, 9) = 313.67$, $p < 0.01$) and zoning accounted for just over 15% of the variation in the predominantly woody vegetation cover data ($R^2 = 0.159$). Zoning types with the lowest levels of predominantly woody vegetation cover were mixed-use residential, industrial, multi-family residential, and commercial (Figure 6). Zoning types with the highest levels of predominantly woody vegetation cover were parks and open spaces, public facility, rural, and future urban development (Figure 6). Among residential zoning types, single-family residential areas had much higher levels of predominantly woody vegetation cover than any other residential zoning types (Figure 6).
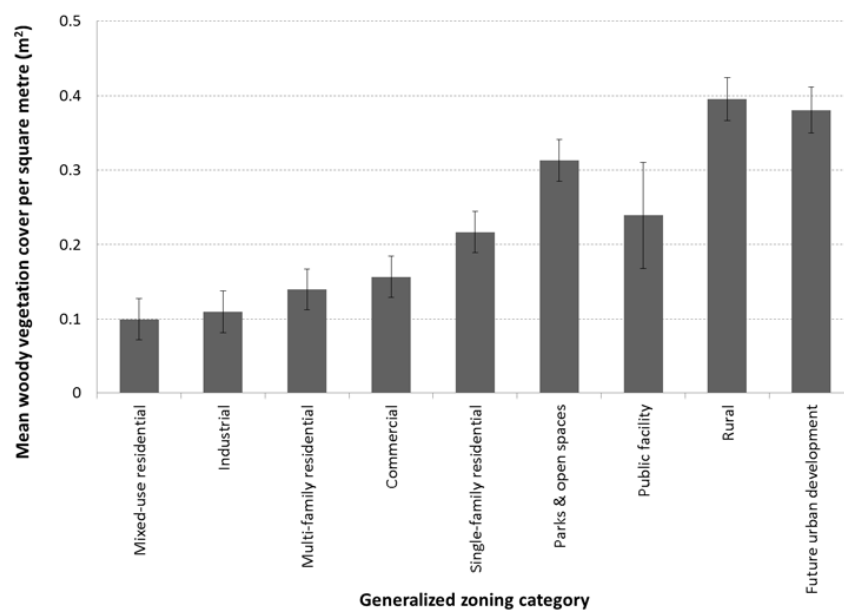
Figure 6. Mean cover of primarily woody vegetation per square metre by generalized zoning category.

3.2. Green Spaces

A multiple linear regression was calculated to predict distance to nearest park based on median year built, percent bachelors degree, and percent masters degree. A significant regression equation was found ($F(3, 895) = 24.089$, $p < 0.01$) with an R^2 of 0.075 (Table 3). Predicted distance to the nearest park is equal to $4725.338 - 2.289$ (median year built) $- 118.080$ (percent bachelors degree) $- 183.887$ (percent masters degree). Parks and green spaces thus appear to be more evenly distributed, showing a weak but significant relationship to socioeconomic factors. Block Groups with older houses, lower percentages of residents with bachelor's degrees, and lower percentages of residents with master's degrees had the largest distances to parks and green spaces.

Table 3. Regression results for park distance and socioeconomic variables.

	Distance to Nearest Park		
Variable	**B**	**SE B**	**β**
Median Year Built	−2.289	0.282	−0.271 **
Percent Bachelors Degree	−118.08	55.610	−0.840 *
Percent Masters Degree	−183.887	87.956	−0.083 *
R^2		0.075	
F		60.238 **	

B, unstandardized regression coefficient; SE, standard error; β, standardized regression coefficient; *p*, calculated probability. * $p < 0.05$; ** $p < 0.01$.

4. Discussion

The strong relationship between socioeconomic factors and greenery cover (Tables 1 and 2) suggests a somewhat uneven distribution of greenery in the Portland–Vancouver metro area. Population density and house age are the primary factors in this relationship, showing strong correlations with both mixed vegetation cover and predominantly woody vegetation cover. The correlation with population density is to be expected, given that higher population densities require higher building densities and thus reduced space for greenery near dwellings. This result is supported by the zoning analysis (Figures 5 and 6): mixed-use residential and multi-family residential zones, which are designed to accommodate higher residential population densities, showed some of the lowest levels of greenery cover among the zoning types analyzed. More surprisingly, the analysis indicates that greenery cover is more abundant in areas with newer houses, in contradiction to some previous research [19]. While this observation may appear to contradict the notion that older neighbourhoods generally contain older trees, it may reflect the fact that newer housing developments occur in peri-urban areas close to forested rural areas [52,53]. The zoning analysis supports this conclusion, showing the highest levels of urban greenery in rural areas and those zoned for future urban development (Figures 5 and 6).

The majority of the socioeconomic variables showing significant correlations with urban greenery cover reflect the income, race and education of residents, and indicate that Portland's residents may, in fact, suffer from green inequity (Tables 1 and 2). According to our analysis, residents who have higher incomes or those who are white, Asian, or who self-identify as "other race" (some race other than white, black, Aboriginal, Hawaiian, and Asian), or who hold a professional or masters degree, are more likely to live in areas with high levels of mixed vegetation cover (Table 1). Those with higher incomes, those who are white, or those who self-identify as "other race" are more likely to live in areas with high predominantly woody vegetation cover while those with limited secondary and post-secondary education are less likely to live in those areas (Table 2). Urban greenery cover is thus somewhat distributed according to typical socioeconomic divisions. The City of Portland appears to be aware of the potential for these divisions in greenery cover, as evidenced by programming to prioritize street tree planting in low-income communities and communities of colour described in the 2014 Urban Forest Action Plan Implementation Update [39]. While street tree planting is an important part of increasing greenery abundance in low-canopy neighbourhoods, our analysis does not provide guidance as to

whether greenery on public or private land is primarily responsible for these inequities. Private land often provides a large portion of urban greenery [17,54] and is thus an important consideration in urban greening programs. Further analysis to differentiate between greenery on public and private land may help explain the relative contributions of public and private land to the observed green inequities and provide guidance for greening programs in low-canopy neighbourhoods.

While there is strong evidence of the environmental, psychological, physical health, and economic benefits of trees [2–8], and evidence of aesthetic preference for urban greenery [48], it is important to note that some urban residents may prefer not to live near urban greenery. Preferences for urban greenery appear to be influenced by culture [55–57] and may also be influenced by socioeconomic background [25]. Low levels of urban greenery and large distances to urban parks would not be considered to be problematic by such residents. Our current analysis cannot comment on such preferences and this may be an area for further research.

Interestingly, the distribution of green spaces in Portland appears to be highly equitable, with only weak relationships between the distance to the closest green space and socioeconomic variables (Table 3). While the analysis did not examine green space size or land tenure, it suggests that most Portland residents live within similar distances of green spaces of some size. Residents living in newer houses and with post-secondary degrees are more likely to live nearer to a green space, suggesting the presence of green inequity, but this does not appear to be a strong correlation. The relatively equitable distribution of green spaces in Portland highlights a policy tool that municipalities in the metro area may use to maintain or improve current levels of green equity. Although it may be difficult to influence greenery abundance on private property, maintaining or improving residents' access to high-quality green spaces would ensure that all residents are able to access greenery near their homes, regardless of socioeconomic status. Further analysis of green space access that considers size and land tenure would help clarify how green space development could be used to reduce green inequity.

The green inequities illustrated by our analysis become more serious when viewed through the lens of public health and well-being. Those residents of Portland who have the lowest levels of greenery access are also those who are most likely to suffer poor public health outcomes and who may experience the greatest benefits from higher greenery access [11–13]. In addition, these potential health inequities may be exacerbated by climate change. As climate change progresses and increases in intensity, cities may experience a range of changes and pressures that can have negative impacts on urban residents' health, such as rising sea levels and increased storm surges, heat stress, extreme precipitation events, flooding caused by increased precipitation and snow melt, landslides, drought, increased aridity, water scarcity, and air pollution [58]. Residents and communities with lower socioeconomic status may be more vulnerable to climate change impacts than other segments of the population [58,59], suggesting another way in which increased urban greenery may have stronger physical health benefits for lower socioeconomic groups. Although the specific impacts of climate change will vary by location, urban greenery can play a key role in moderating the impacts of climate change and helping urban communities adapt to its effects. The microclimatic regulation provided by urban greenery can work in concert with other types of infrastructure and adaptation programming in comprehensive climate change adaptation strategies that ensure adequate greenery cover in vulnerable areas [5,8,10,60–62].

Portland is clearly aware of the importance of urban green equity and some of its implications for urban forest management, although urban forest policy documents suggest that this awareness is relatively recent and it is thus unlikely that policy instruments will have had time to achieve any real reductions in urban green inequity [39]. Portland also appears to have begun integrating urban forest management with climate change and green infrastructure planning in the city [34,35]. Given the public health and climate change adaptation implications of urban green inequity, Portland would benefit from further integrating urban forest management into broader municipal planning initiatives, thereby attempting to ameliorate urban green inequities using a variety of policy mechanisms. Urban greenery

is part of the larger urban "ecosystem", working together with other infrastructure and programming to improve residents' well-being.

5. Conclusions

Our results suggest that urban green equity is an issue affecting disadvantaged urban residents. However, our analysis examines the issue in only one metro area. Urban forest management is clearly influenced by local environment, development history, and municipal and regional policies, and will thus vary among cities and metro areas [63]. To truly begin to understand patterns of urban green inequity and associated factors, this analysis should be extended to other cities that represent a diversity of geographies, development histories, and policy approaches to urban forest management. This broader analysis would help unpack general and locally specific factors associated with urban green inequity.

In addition to a broader analysis of the topic, a deeper, case study analysis of urban green inequity would help explain important aspects of the topic not examined in our analysis. Factors such as land tenure and access, tree species and condition, aesthetic and recreational quality, and cultural preferences will likely affect how urban residents experience and benefit from urban greenery [54,55,64,65]. While our analysis demonstrated broad patterns of access to urban greenery, these finer scale factors influence whether urban greenery is truly accessible and the magnitude of benefits urban residents derive from it.

Both of the broad and fine scale analyses suggested above require high quality data to accomplish. Broad-scale spatial analyses require high-quality aerial imagery and land use and land tenure data that are not always available across cities and metro regions. When they are available, differences in local definitions and data collection methodologies can impede comparisons. Large data collection programs, such as the NAIP, or online clearinghouses would facilitate analyses across several cities or metro areas.

On the other end of the spectrum, fine scale data on tree species, condition, and local cultural values and preferences generally require field research to obtain it. Some municipalities have begun sharing local, fine scale data such as tree inventories, online, representing an important source of urban forest data. As government, organizations, academics, and citizens continue to collect such data, collaboration and open data access have the potential to facilitate continued in-depth research. As we improve our understanding of urban green equity and the factors associated with it, cities and societies will be able to craft more effective approaches to reducing urban green inequity, thereby improving residents' quality of life.

Author Contributions: Lorien Nesbitt and Michael J. Meitner conceived and designed the experiments; Lorien Nesbitt performed the experiments; Lorien Nesbitt and Michael J. Meitner analyzed the data; Michael J. Meitner contributed analysis tools; Lorien Nesbitt wrote the paper with guidance from Michael J. Meitner.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

US	United States of America
UA	Urbanized Area
NAIP	National Agriculture Imagery Program
NDVI	Normalized Difference Vegetation Index
ORCA	Outdoor Recreation and Conservation Area
ANOVA	Analysis of Variance

References

1. Ward Thompson, C.; Aspinall, P.A. Natural environments and their impact on activity, health, and quality of life. *Appl. Psychol. Health Well Being* **2011**, *3*, 230–260. [CrossRef]
2. Kuchelmeister, G. Trees for the urban millennium: Urban forestry update. *Unasylva* **2000**, *51*, 49–55.

3. Thompson, C.W. Urban open space in the 21st century. *Landsc. Urban Plan.* **2002**, *60*, 59–72. [CrossRef]

4. Kenney, W.A.; Van Wassenaer, P.J.E.; Satel, A.L. Criteria and indicators for strategic urban forest planning and management. *Arboric. Urban For.* **2011**, *37*, 108–117.

5. Heidt, V.; Neef, M. Benefits of urban green space for improving urban climate. In *Ecology, Planning, and Management of Urban Forests*; Carreiro, M., Song, Y., Wu, J., Eds.; Springer: New York, NY, USA, 2008; pp. 84–96.

6. Poudyal, N.C.; Hodges, D.G.; Merrett, C.D. A hedonic analysis of the demand for and benefits of urban recreation parks. *Land Use Policy* **2009**, *26*, 975–983. [CrossRef]

7. Ulrich, R.S.; Simons, R.F.; Losito, B.D.; Fiorito, E.; Miles, M.A.; Zelson, M. Stress recovery during exposure to natural and urban environments. *J. Environ. Psychol.* **1991**, *11*, 201–230. [CrossRef]

8. Konijnendijk, C.; Nilsson, K.; Randrup, T.; Schipperijn, J. *Urban Forests and Trees*; Konijnendijk, C.C., Nilsson, K., Randrup, T.B., Schipperijn, J., Eds.; Springer-Verlag: Berlin/Heidelberg, Germany, 2005.

9. Gatrell, J.D.; Jensen, R.R. Growth through greening: Developing and assessing alternative economic development programmes. *Appl. Geogr.* **2002**, *22*, 331–350. [CrossRef]

10. McPherson, G.; Simpson, J.R.; Peper, P.J.; Xiao, Q. Benefit-cost analysis of Modesto's municipal urban forest. *J. Arboric.* **1999**, *25*, 235–248.

11. De Vries, S.; Verheij, R.A.; Groenewegen, P.P.; Spreeuwenberg, P. Natural environments—Healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environ. Plan. A* **2003**, *35*, 1717–1731. [CrossRef]

12. Maas, J.; Verheij, R.A.; Groenewegen, P.P.; de Vries, S.; Spreeuwenberg, P. Green space, urbanity, and health: How strong is the relation? *J. Epidemiol. Community Health* **2006**, *60*, 587–592. [CrossRef] [PubMed]

13. Mitchell, R.; Popham, F. Effect of exposure to natural environment on health inequalities: An observational population study. *Lancet* **2008**, *372*, 1655–1660. [CrossRef]

14. Kweon, B.-S.; Sullivan, W.C.; Wiley, A.R. Green common spaces and the social integration of inner-city older adults. *Environ. Behav.* **1998**, *30*, 832–858. [CrossRef]

15. Sullivan, W.C. The Fruit of Urban Nature: Vital Neighborhood Spaces. *Environ. Behav.* **2004**, *36*, 678–700. [CrossRef]

16. Kuo, F.E.; Sullivan, W.C. Environment and crime in the inner city: Does vegetation reduce crime? *Environ. Behav.* **2001**, *33*, 343–367. [CrossRef]

17. Goddard, M.A.; Dougill, A.J.; Benton, T.G. Scaling up from gardens: Biodiversity conservation in urban environments. *Trends Ecol. Evol.* **2009**, *25*, 90–98. [CrossRef] [PubMed]

18. Rudd, H.; Vala, J.; Schaefer, V. Importance of backyard habitat in a comprehensive biodiversity conservation strategy: A connectivity analysis of urban green spaces. *Restor. Ecol.* **2002**, *10*, 368–375. [CrossRef]

19. Heynen, N.C.; Lindsey, G. Correlates of urban forest canopy cover: Implications for local public works. *Public Works Manag. Policy* **2003**, *8*, 33–47. [CrossRef]

20. Landry, S.M.; Chakraborty, J. Street trees and equity: Evaluating the spatial distribution of an urban amenity. *Environ. Plan. A* **2009**, *41*, 2651–2670. [CrossRef]

21. McConnachie, M.M.; Shackleton, C.M. Public green space inequality in small towns in South Africa. *Habitat Int.* **2010**, *34*, 244–248. [CrossRef]

22. Ogneva-Himmelberger, Y.; Pearsall, H.; Rakshit, R. Concrete evidence & geographically weighted regression: A regional analysis of wealth and the land cover in Massachusetts. *Appl. Geogr.* **2009**, *29*, 478–487.

23. *City of Vancouver Urban Forest Strategy*; Vancouver Board of Parks and Recreation: Vancouver, BC, Canada, 2014.

24. Talarchek, G. The urban forests of New Orleans: An exploratory analysis of relationships. *Urban Geogr.* **1990**, *11*, 65–86. [CrossRef]

25. Kirkpatrick, J.B.; Daniels, G.D.; Davison, A. Temporal and spatial variation in garden and street trees in six eastern Australian cities. *Landsc. Urban Plan.* **2011**, *101*, 244–252. [CrossRef]

26. Sanesi, G.; Gallis, C.; Kasperidus, H.D. *Forests, Trees and Human Health*; Nilsson, K., Sangster, M., Gallis, C., Hartig, T., de Vries, S., Seeland, K., Schipperijn, J., Eds.; Springer Netherlands: Dordrecht, The Netherlands, 2011.

27. Mitchell, R.; Popham, F. Greenspace, urbanity and health: Relationships in England. *J. Epidemiol. Commun. Health* **2007**, *61*, 681–683. [CrossRef] [PubMed]

28. Barbosa, O.; Tratalos, J.A.; Armsworth, P.R.; Davies, R.G.; Fuller, R.A.; Johnson, P.; Gaston, K.J. Who benefits from access to green space? A case study from Sheffield, UK. *Landsc. Urban Plan.* **2007**, *83*, 187–195. [CrossRef]

29. Lafary, E.W.; Gatrell, J.D.; Jensen, R.R. People, pixels and weights in Vanderburgh County, Indiana: Toward a new urban geography of human–environment interactions. *Geocarto Int.* **2008**, *23*, 53–66. [CrossRef]

30. Pearsall, H.; Christman, Z. Tree-lined lanes or vacant lots? Evaluating non-stationarity between urban greenness and socio-economic conditions in Philadelphia, Pennsylvania, USA at multiple scales. *Appl. Geogr.* **2012**, *35*, 257–264. [CrossRef]

31. Li, G.; Weng, Q. Measuring the quality of life in city of Indianapolis by integration of remote sensing and census data. *Int. J. Remote Sens.* **2007**, *28*, 249–267. [CrossRef]

32. American Forests American Forests Names the 10 Best U.S. Cities for Urban Forests. Available online: http://www.americanforests.org/newsroom/american-forests-names-the-10-best-u-s-citiesfor-urban-forests/ (accessed 21 April 2016).

33. American Forests. *Portland Urban Forest Fact Sheet*; American Forests: Washington, DC, USA, 2013.

34. *Climate Action Plan, Local Strategies to Address Climate Change*; City of Portland: Portland, OR, USA, 2015.

35. ENTRIX Inc. *Portland's Green Infrastructure: Quantifying the Health, Energy and Community Livability Benefits*; City of Portland: Portland, OR, USA, 2010.

36. Audubon Society of Portland; Portland State University. *Regional Urban Forestry Assessment and Evaluation for the Portland–Vancouver Metro Area*; Metro: Portland, OR, USA, 2010.

37. Portland Parks and Recreation; Urban Forestry Management Plan Technical Advisory Committee. *Portland Urban Forestry Management Plan 2004*; City of Portland: Portland, OR, USA, 2004.

38. Portland Parks and Recreation. *Urban Forest Action Plan*; City of Portland: Portland, OR, USA, 2007.

39. Portland Parks and Recreation. *Urban Forest Action Plan, 2014 Implementation Update*; City of Portland: Portland, OR, USA, 2015.

40. Bureau of Planning and Sustainability. *Title 11, Trees*; City of Portland: Portland, OR, USA, 2012.

41. US Census bureau. Qualifying urban areas for the 2010 census. *Fed. Regist.*; 2010; 77, pp. 18652–18669.

42. US Census bureau. Urban area criteria for the 2010 census. *Fed. Regist.*; 2010; 76, pp. 53030–53043.

43. US Census Bureau Geographic Terms and Concepts—Block Groups. Available online: https://www.census.gov/geo/reference/gtc/gtc_bg.html (accessed on 13 April 2016).

44. US Census Bureau. *2013 TIGER/Line Shapefiles (Machine-Readable Data Files)*; US Census Bureau: Washington, DC, USA, 2013.

45. Sellers, P.J. Relations between canopy reflectance, photosynthesis and transpiration: Links between optics, biophysics and canopy architecture. *Adv. Sp. Res.* **1987**, *7*, 27–44. [CrossRef]

46. Tucker, C.J. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sens. Environ.* **1979**, *8*, 127–150. [CrossRef]

47. Nowak, D.J.; Crane, D.E.; Stevens, J.C. Air pollution removal by urban trees and shrubs in the United States. *Urban For. Urban Green.* **2006**, *4*, 115–123. [CrossRef]

48. Chiesura, A. The role of urban parks for the sustainable city. *Landsc. Urban Plan.* **2004**, *68*, 129–138. [CrossRef]

49. McBride, J. Mapping Chicago area urban tree canopy using color infrared imagery. In *LUMA-GIS Thesis*; Lund University: Lund, Sweden, 2011.

50. Metro Regional Government RLIS Discovery: ORCA Sites. Available online: http://rlisdiscovery.oregonmetro.gov/metadataviewer/display.cfm?meta_layer_id=3332 (accessed on 20 April 2016).

51. US Census Bureau American FactFinder—About the Data. Available online: http://factfinder.census.gov/faces/affhelp/jsf/pages/metadata.xhtml?lang=en&type=dataset&id=dataset.en.ACS_13_5YR (accessed on 20 April 2016).

52. Sieghardt, M.; Mursch-Radlgruber, E.; Paoletti, E.; Couenberg, E.; Dimitrakopoulus, A.; Rego, F.; Hatzistathis, A.; Randrup, T.B. The abiotic urban environment: Impact of urban growing conditons on urban vegetation. In *Urban Forests and Trees*; Konijnendijk, C., Nilsson, K., Randrup, T., Schipperijn, J., Eds.; Springer-Verlag: Berlin/Heidelberg, Germany, 2005; pp. 281–323.

53. Jim, C.Y. Green-space preservation and allocation for sustainable greening of compact cities. *Cities* **2004**, *21*, 311–320. [CrossRef]

54. Greene, C.S.; Millward, A.A.; Ceh, B. Who is likely to plant a tree? The use of public socio-demographic data to characterize client participants in a private urban forestation program. *Urban For. Urban Green.* **2011**, *10*, 29–38. [CrossRef]

55. Fraser, E.D.G.; Kenney, W.A. Cultural background and landscape history as factors affecting perceptions of the urban forest. *J. Arboric.* **2000**, *26*, 106–113.

56. Buijs, A.E.; Elands, B.H.M.; Langers, F. No wilderness for immigrants: Cultural differences in images of nature and landscape preferences. *Landsc. Urban Plan.* **2009**, *91*, 113–123. [CrossRef]

57. Braverman, I. Everybody loves trees: Policing American cities through street trees. *Duke Environ. Law Policy Forum* **2008**, *19*, 81–118.

58. Revi, A.; Satterthwaite, D.E.; Aragón-Durand, F.; Corfee-Morlot, J.; Kiunsi, R.B.R.; Pelling, M.; Roberts, D.C.; Solecki, W. Urban areas. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., et al., Eds.; Cambridge University Press: New York, NY, USA, 2014; pp. 535–612.

59. Paavola, J.; Adger, W.N. Fair adaptation to climate change. *Ecol. Econ.* **2006**, *56*, 594–609. [CrossRef]

60. Mathey, J.; Rößler, S.; Lehmann, I.; Bräuer, A. Urban Green Spaces: Potentials and Constraints for Urban Adaptation for Climate Change. In *Resilient Cities: Cities and Adaptation to Climate Change Proceedings of the Global Forum 2010*; Otto-Zimmerman, K., Ed.; Springer: New York, NY, USA, 2011; pp. 479–485.

61. Fields, B. From green dots to greenways: Planning in the age of climate change in post-Katrina New Orleans. *J. Urban Des.* **2009**, *14*, 325–344. [CrossRef]

62. Tyler, S.; Moench, M. A framework for urban climate resilience. *Clim. Dev.* **2012**, *4*, 311–326. [CrossRef]

63. Hoalst-Pullen, N.; Patterson, M.W.; Gatrell, J. Empty spaces: Neighbourhood change and the greening of Detroit, 1975–2005. *Geocarto Int.* **2011**, *26*, 417–434. [CrossRef]

64. Gobster, P.H.; Westphal, L.M. The human dimensions of urban greenways: Planning for recreation and related experiences. *Landsc. Urban Plan.* **2004**, *68*, 147–165. [CrossRef]

65. Zhang, H.; Jim, C.Y. Species diversity and performance assessment of trees in domestic gardens. *Landsc. Urban Plan.* **2014**, *128*, 23–34. [CrossRef]