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Analyzing Disparities in Ecosystem Services in U.S. Cities: The Relationship Between Tree Cover and Socio-Demographics

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It is a generally accepted fact that trees, and vegetation in general, provide many benefits to human beings. What has not been so extensively studied is how those benefits may be distributed across the United States. This research project aims to study that distribution by modeling and analyzing the land use data of US cities and the socio-demographic data available. We are looking specifically at tree cover as presented in the National Land Cover Dataset (NLCD) in order to determine what the general demographics are of those people that live in closer proximity to trees. We are also looking at percentage of development (or urban areas), water, and agricultural or wetlands. Our original expectation was that there is a correlation between the demographics and population of trees; specifically, those persons living in communities with a lower median income and majority nonwhite population are more likely to live in areas with less tree cover than those more socioeconomically well-off. Our research found that in most of the ecoregions studies, as well as in the amalgamation of all of the cities, there is a tendency toward more tree cover or greenspace in higher income and majority white communities, while there is less greenspace in lower income and majority nonwhite communities. These results are in accordance with those of other studies concerning urban tree cover, and with these results, urban planning committees could be better able to provide equitable tree cover to those more vulnerable and underserved communities.

1 INTRODUCTION AND MOTIVATION

It is no secret that the world is urbanizing, and urbanizing rapidly. According to the United Nations' 2018 Revision of World Urbanization Prospects, 55% of the world's population currently lives in urban areas [5]. By 2050, that number is expected to increase to 68% [5]. However, that 55% may be a bit misleading when talking specifically about the United States. The percentage of people living in urban areas in North America is closer to 82% as of 2018 [5]. As urbanization continues and expands, statistically significant annual loss of tree cover in the United States has been observed, be that by the clearing of trees to expand the urban area or to clear trees within the urban area [6]. With such a large percentage of the population living in or near cities and the loss of already standing trees, it is increasingly important to understand the demographics of different areas of cities and identify which of those areas are underserved. In this paper, we are looking specifically at how land cover is distributed across selected cities in the United States, and in specific climatic or ecological regions of the country.

In addition to land cover in general, we are focused on identifying the trends concerning tree cover in cities due to the many benefits that other studies have found urban tree cover to have. There have been a multitude of studies done concerning the benefits that trees and vegetation in general provide to the human population. A survey of over 100 papers performed by researchers at the Griffith School of Environment at Griffith University found that those papers demonstrated a number of benefits of urban tree cover. Those benefits include social, economic, health, visual and aesthetic benefits to humans. For example, some of the ecosystem services benefits of urban tree cover include removal of pollutants in air, storing or sequestering carbon, microclimate effects, and energy related benefits [8].

As is apparent, the benefits of tree cover have been studied thoroughly, but what has not been so extensively researched is the distribution of those benefits across the United States of America. As mentioned above, ecosystem services plays a large part in not only the benefits of urban tree cover, but in this research as well. Ecosystem services are defined as the contribution of the ecosystem on

human well-being. In this case, we are interested in the contribution of trees and vegetation, and how accessible those benefits are across US cities. In this way, ecosystem services is at the core of this research. Identifying this distribution of tree cover and the socio-demographic trends behind the distribution are the purposes of this research.

The ultimate goal of this research would be to help urban planners and the public in these cities, and in the United States in general, to understand which communities, if any, are underserved in regards to tree cover. Then, they could use that information to help to provide more equitable tree cover to underserved communities and ultimately make their city better for everyone living there.

2 RELATED WORK AND BACKGROUND

There have been many studies done in the same vein as ours, specifically looking to identify if there is a correlation between socio-demographic data and some environmental factor, usually related to trees or vegetation, in an urban environment. What those environmental factors or data are, however, have been wildly different from study to study. Despite the differences in environmental or geographical data, almost all similar studies have found some sort of link between socio-demographics and their respective environmental or geographical data, with one notable exception [7]. Most of these studies rely on remote sensing technology of some sort, be it NDVI data, land cover data, satellite imagery, etc. One study reviewed utilizes a random field sampling approach instead of remote sensing, but due to the sheer scope of this project, this would not have been feasible here [2].

In one study done in Shanghai, China, released in 2016, accessibility and abundance of urban public green space was found to be lower in areas with higher socioeconomic disadvantage in the city center [4]. Another focused on Miami-Dade county, Florida using normalized difference vegetation index (NDVI) data found that white areas tended to have greater tree density, cover, diversity, and energy savings, while Hispanic and African American areas tended to have different tree characteristics [10]. Since our research is mainly focused on tree cover as opposed to vegetation or public greenspace, these are not as important to the work that we are doing, but it is still relevant and helps to establish a general trend in the results that previous research has found.

When focusing on trees and tree cover specifically, many studies have been performed attempting to find a link between socio-demographic trends and trees. One study released in 2015 by a working group for the National Center for Ecological Analysis and Synthesis (NCEAS) found that higher income areas are more likely to have a higher tree canopy cover than lower income areas, as did another similar study also completed in 2015 focused in Baltimore, Maryland [3, 9]. The NCEAS paper did not, however, find a significant relationship between canopy cover and race/ethnicity except in Sacramento and Los Angeles, contrasting the Miami-Dade county study mentioned above [9].

3 METHODOLOGY

For our research, we decided to use the recently released National Land Cover Dataset (NLCD) from 2016. The NLCD 2016 was only released a few months before this research began, so it was a timely choice for a land cover study. The NLCD 2016 dataset is a large raster dataset of the entire continental United States, and it accounts for seventeen different land use categories using LiDAR data. The granularity of the NLCD data is especially important in this research as the 30x30 m cell size allowed us to get more granular and specific ideas about the land cover in our study areas.

We also decided to use American Community Survey (ACS) 2016 five-year estimates for our socio-demographic data. We focused our data collection at the census block group level to allow for a decent amount of specificity without going all the way down to the block level. We chose to focus our analysis on income and race data specifically, choosing to analyze median household income,

Fig. 1. A bar chart showing the distribution of 82 US cities into six ecoregions.

percent identifying as white from the total population, and percent identifying as nonwhite from the total population.

In total, we included 82 cities in our analysis, and the census block groups that we used all came either from inside the city boundaries or just outside of the boundaries as census block groups do not adhere to city limits all the time. Using those 82 cities, we stratified them into the six EPA ecoregions that they fell into. Specifically, all of the cities fell into either the Marine West Coast Forest, Eastern Temperate Forests, Great Plains, North American Deserts, Mediterranean California, or Tropical Wet Forests ecoregions. We chose the EPA ecoregions because of the more rounded focus on "geology, landforms, soils, vegetation, climate, land use, wildlife, and hydrology" [1]. We chose this form of stratification as opposed specifically to the Köppen-Geiger Climate Classification's more vegetation-based approach. Not all of the ecoregions had equal numbers of cities within them, and the distribution of cities in each of the ecoregions is available above in Figure 1. In accordance with that graph, it is worth noting that the Marine West Coast Forest and Tropical Wet Forests ecoregions have the smallest number of cities of any of the regions we are analyzing. A map of the 82 cities and the ecoregions used is available below in Figure 2.

In order to do the actual analysis, we ran Zonal Statistics in ArcMap to be able to gather some summary statistics from the raster data. The zones in this case were the census block groups for each city. Then, for each EPA ecoregion and for all of the cities together, we ran counts both for each of the seventeen land cover types, and for a more simplified classification of urban, agriculture/wetland, trees/greenspace, and water. The classifications of these simplified land cover types is available in Table 1 below. These counts were specifically of the predominant land cover type in that area (the majority statistic). We did this five times for each of the seven larger categories (all cities and the ecoregions): once for all of the block groups in that section, once for all block groups in the bottom 20% income bracket, once for the block groups in the top 20% income bracket, once for all block groups with a majority (60%) of the population that identifies as white, and once for the majority

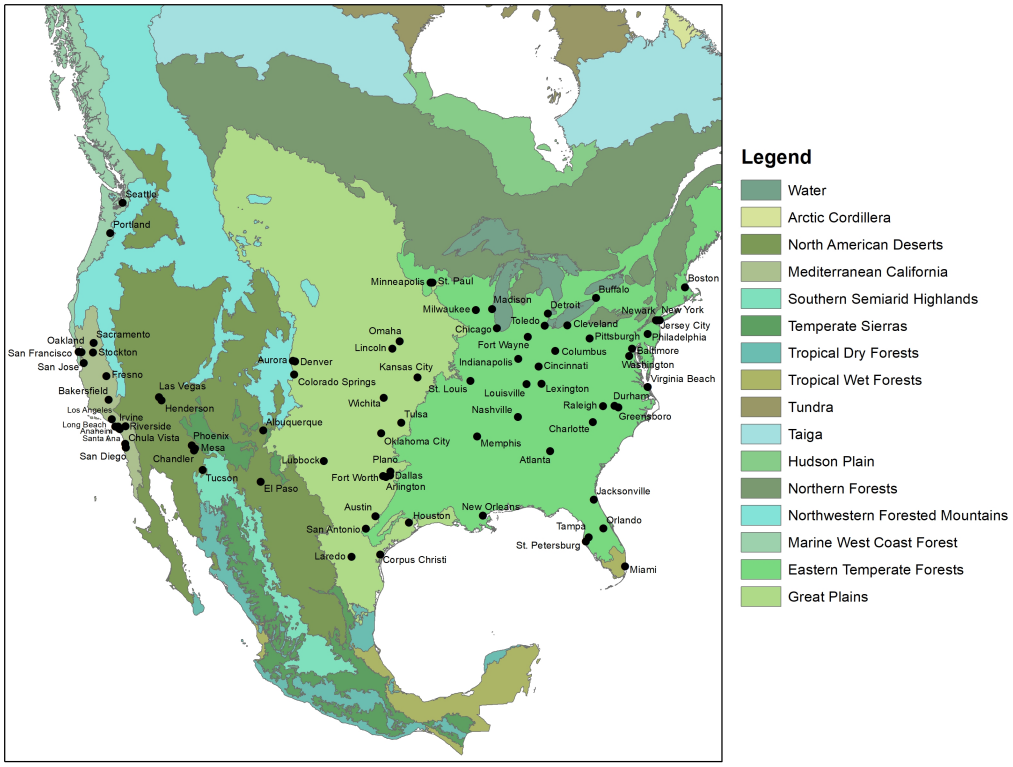

Fig. 2. A map of EPA ecoregions and the 82 cities included in this research.

(60%) of the population that identifies as nonwhite. We then analyzed and compared these counts to come to our results.

4 RESULTS AND DISCUSSION

When we began this research, we projected that we would see higher income and majority white communities having greater access to trees. This was not entirely wrong, although it was not the only observation that we were able to make. In four of seven samples, the population in the top 20% income bracket had a higher percentage of trees/greenspace and agriculture/wetlands in our simplified land cover model. Those in the top 20% income bracket also tended to have higher percentages of open water compared to the general population in all but the North American Deserts ecoregion, which only has one open water majority in the whole of the sample of 3877 block groups. So not only do wealthier populations tend to have more greenspace (trees, shrubbery, herbaceous areas, etc) and agricultural areas (hay/pasture), but they also tend to be in closer proximity to water. In retrospect, the cost of living near water does lend this result greater basis in reality. The top 20% income bracket was also found to be less developed, or urban, than the general population for each ecoregion studied with the exception of the Great Plains region.

We also found our expectations concerning majority white populations to be true. Majority white populations tend to have lower urban percentages than the general populations in all ecoregions studied. They also tend to have more greenspace and agriculture in each ecoregion except the

Simplified Land Cover NLCD Translation

Simplified Value	Simplified Name	NLCD Value	NLCD Name
1	Water	11	Open Water
		12	Perennial Snow/Ice
2	Urban	21	Developed, Open Space
		22	Developed, Low Intensity
		23	Developed, Medium Intensity
		24	Developed, High Intensity
3	Trees/Greenspace	31	Barren Land
		41	Deciduous Forest
		42	Evergreen Forest
		43	Mixed Forest
		52	Shrub/Scrub
		71	Herbaceuous
4	Ag/Wetland	81	Hay/Pasture
		82	Cultivated Crops
		90	Woody Wetlands
		95	Emergent Herbaceuous Wetlands

Table 1. A table showing the translation of NLCD land cover types into the simplified land cover categories used in this research.

Number Block Groups Per Statistical Group Studied

	All Cities	Marine West Coast Forest	Eastern Temperate Forests	Great Plains	North American Deserts	Mediterranean California	Tropical Wet Forests
All Block Groups	50986	1048	26840	10242	3877	8604	375
Bottom 20% Income	24909	396	14023	5148	1954	3684	267
Top 20% Income	368	6	135	111	5	82	4
Majority White	28377	854	12480	7518	3202	4047	276
Majority Non-white	14300	72	10565	1163	147	2282	79

Table 2. A table of the number of block groups in each statistical study area for every ecoregion studied.

Marine West Coast Forest and Tropical Wet Forests ecoregions, our two smallest study regions. The number of census block groups in every subgroup analysis for each ecoregion is available below in Table 2. A table of the observed trends may also be observed in Table 3 below.

A closer examination of our results found that even the types of urban development in the different subgroups (all groups, bottom 20% income, top 20% income, majority white, and majority nonwhite) have vast differences across the subgroups. The bottom 20% income bracket is always more urban or developed than the general, and it is always more urban or developed than the top 20% except in the Great Plains region. Even with that exception, the top 20% of income brackets tends to have a different development scheme than the general population, with there being more "Developed: Open Space" in the top 20% than in the general population four of seven times. One of those exceptions was the North American Deserts ecoregion, which is also the ecoregion with the lowest percentage of "Developed: Open Space" of all of the ecoregions, and this holds true for every subgroup analysis. The nonwhite majority populations also tend to be more urban in all ecoregions except North American Deserts.

Simplified Land Cover Statistics

	Ag/Wet Land	Trees/ Greenspace	Urban	Water
All Cities				
All Block Groups	1.94%	3.82%	92.91%	1.33%
Bottom 20% Income	1.18%	2.17%	95.85%	0.79%
Top 20% Income	1.09%	7.34%	86.96%	4.62%
Majority White	2.78%	5.24%	90.21%	1.77%
Majority Nonwhite	0.50%	1.51%	97.48%	0.50%
Marine West Coast Forest				
All Block Groups	0.48%	1.05%	92.18%	6.30%
Bottom 20% Income	0.25%	0.25%	97.98%	1.52%
Top 20% Income	0.00%	0.00%	50.00%	50.00%
Majority White	0.59%	1.17%	91.22%	7.03%
Majority Nonwhite	0.00%	0.00%	98.61%	1.39%
Eastern Temperate Forest				
All Block Groups	1.81%	2.60%	94.02%	1.58%
Bottom 20% Income	0.90%	1.63%	96.42%	1.06%
Top 20% Income	2.22%	5.19%	89.63%	2.96%
Majority White	3.08%	3.83%	90.69%	2.40%
Majority Nonwhite	0.37%	1.19%	97.86%	0.58%
Great Plains				
All Block Groups	2.91%	6.79%	89.47%	0.83%
Bottom 20% Income	1.79%	4.16%	93.49%	0.56%
Top 20% Income	0.90%	2.70%	94.59%	1.80%
Majority White	3.42%	7.37%	88.35%	0.86%
Majority Nonwhite	1.12%	5.16%	93.38%	0.34%
North American Deserts				
All Block Groups	2.24%	8.33%	89.40%	0.03%

Continuation of Simplified Land Cover Statistics

	Ag/Wet Land	Trees/ Greenspace	Urban	Water
Bottom 20% Income	1.74%	4.25%	94.01%	0.00%
Top 20% Income	0.00%	40.00%	60.00%	0.00%
Majority White	2.47%	8.62%	88.88%	0.03%
Majority Nonwhite	2.72%	9.52%	87.76%	0.00%
Mediterranean California				
All Block Groups	1.30%	2.58%	95.22%	0.89%
Bottom 20% Income	1.49%	0.41%	97.69%	0.41%
Top 20% Income	0.00%	14.63%	82.93%	2.44%
Majority White	1.58%	4.15%	92.98%	1.28%
Majority Nonwhite	0.70%	0.70%	98.33%	0.26%
Tropical Wet Forests				
All Block Groups	0.00%	0.00%	93.07%	6.93%
Bottom 20% Income	0.00%	0.00%	97.00%	3.00%
Top 20% Income	0.00%	0.00%	25.00%	75.00%
Majority White	0.00%	0.00%	91.30%	8.70%
Majority Nonwhite	0.00%	0.00%	98.73%	1.27%

Table 3. Percentage representations of simplified land use categories for each of the samples taken of each ecoregion and all of the cities together.

As has already been explored in our conclusions above above, although we set out with the goal of analyzing urban tree cover through our land cover analysis, we found many more generalizations than just those concerning tree cover. Much of that is due to our study area. Since we chose to focus on US cities, and then only looked at majority land cover statistics, it makes sense that we would see incredibly high percentages of developed, or urban, land cover as opposed to forested land cover. Because of this, we were not only able to come to some conclusions about tree cover, but we were able to make more conclusions about the other types of land cover, like the percentages and trends of water land cover and the different types of developed or urban land cover.

From these results, we can come to understand what communities are most likely underserved and are in need of more equitable urban planning and tree coverage. Our research has found the same results as many of the ones that came before it. The most underserved communities in our results seem to be those populations in the lower quintile of the income bracket and those living in majority nonwhite communities, while the most well off communities are those in the highest quintile of income brackets and those living in majority white communities. This research serves as simply another support that those living in minority and lower income communities are underserved and should be a priority for urban planners in regard to equitable tree planting programs.

5 CONCLUSIONS AND FUTURE WORKS

Using NLCD and ACS data to compose a complete demographic and land use profile of 82 US cities, we were able to stratify our results and find that lower income and majority nonwhite

communities have been underserved in regards to tree cover in cities. We were also able to observe that higher income communities and majority white communities often enjoy more open or low intensity spaces than their counterparts, indicating a further link into the underserved nature of those communities. Urban planners should use this data and other similar studies performed before this one to begin campaigns for providing more equitable tree cover to those underserved communities. This campaign for equality would help to equalize the benefits of tree cover across vulnerable and underprivileged communities.

Future continuation of this study would be highly encouraged in order to provide a better, more full picture of the land cover data and distribution of tree cover. Looking not only at the NLCD data, but maybe also at other means of quantifying or visualizing urban canopy cover would be beneficial. Other statistical models or methods concerning the NLCD data would also be beneficial. While zonal statistics and the minority summary statistic were able to assist in our research, a fuller understanding would be reached if we were able to look at the percentages of each land cover in each census block group, rather than the majority. That way, we could better account for the fact that the tree cover in many places is overshadowed by the greater percentage of urbanized or developed areas in cities. It also may be interesting to try to look at the Köppen-Geiger Climate Classification system to see if the results we observed here translate to stratification techniques other than EPA ecoregions. Factoring in other demographics data such as education level, housing type (renting or owning), and age would also be of interest. All in all, there is still much more work to be done concerning the socio-demographic causes of tree cover, or lack thereof, in US cities.

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