Exploring a Just and Diverse Urban Forests' Capacity for Mitigating Future Mean Radiant Temperatures

Travis Flohr[1], Lara Garcia[2], Caio Figueiredo[2], Mehdi Heris[3], Margaret Hoffman[2], Justine Lindeman[2], Hong Wu[2], Lilliard Richardson[2]

[1]Penn State University, Pennsylvania/USA · tlf159@psu.edu
[2]Penn State University, Pennsylvania/USA
[3]Hunter College, New York/USA

Abstract: The Pittsburgh Metropolitan Region in Western Pennsylvania, U.S., like many cities globally, historically has an inequitably distributed urban forest and faced street tree biodiversity challenges. Additionally, Pittsburgh faces several barriers and threats to maintaining and expanding its urban tree cover, including pests, diseases, social acceptance, built environment obstacles, and climate change. To address these concerns, in 2012, Pittsburgh created an Urban Forest Master Plan setting equitable forest cover and biodiversity benchmarks. This paper documents the status of achieving these benchmarks and uses microclimate simulations to assess the capacity of these benchmarks in mitigating future mean radiant temperatures. Results demonstrate that the story of Pittsburgh's urban forest cover, street tree biodiversity, and age diversity is complex, but inequities are primarily driven by income. However, if Pittsburgh can achieve its forest cover benchmarks, it can reduce its neighbourhoods' 2050 mean radiant temperature below 2010 temperatures, even under climate change-fuelled extreme heat events. The process and results reported in this paper allow designers and decision-makers to calibrate localized urban forest benchmarks more effectively based on various future scenarios while ensuring the equitable distribution of heat mitigation.

Keywords: Urban forest, urban heat island, climate change, environmental justice, simulation

1 Introduction

This paper explores the equitable distribution of urban forests and the diversity of urban street trees in Pittsburgh, Pennsylvania, U.S., to understand their resiliency and capacity to mitigate future mean radiant temperatures (MRT)[1]. Research has shown that urban forests and street trees provide valuable ecosystem services, such as stormwater management, air quality improvement, landslide protection, and urban heat island (UHI) mitigation (WONG et al. 2021). However, nationally, urban forests and street trees have declined (NOWAK & GREENFIELD, 2018) and are inequitably distributed (RILEY & GARDINER, 2020), exacerbating environmental injustices (HOFFMAN et al. 2020). HOFFMAN et al. (2020) found that people living within historically redlined neighbourhoods were exposed to higher land surface temperatures nationally than in non-redlined neighbourhoods. Redlining was the practice of denying mortgages. The Home Owners' Loan Corporation (HOLC) produced maps that graded neighborhoods' mortgage risk levels; neighborhoods deemed "declining" (graded C) and "hazardous" were given a grade of "D" and colored red (NELSON & WINLING 2023). At the same time,

[1] MRT is a critical physical quantity indicating how humans experience radiation in their surrounding environment. Outdoor MRT depends on the temperatures of the sky, ground, vegetation, and surrounding buildings.

Journal of Digital Landscape Architecture, 9-2024, pp. 302-313. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-752-6, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537752028.

redlined neighbourhoods often have the lowest adaptive capacity to mitigate UHI but the most severe extreme heat event health outcomes because they are underresourced in ways that decrease resiliency (e. g., lower-income households are less likely to have air conditioning or access to cool places during the hottest parts of summer) (LEHNERT et al. 2020). Despite these findings, initial forays into describing urban forest cover and inequities were limited in two ways: 1) they did not define or provide what an appropriate amount of forest cover is, and 2) they only reported the proportion of cover inequalities (LOCKE et al. 2021, RILEY & GARDINER 2020). Subsequent research suggests guiding benchmarks are needed to understand the relationship between forest cover and diversity, ensure the continuity of expected ecosystem services, and track progress towards established goals (KONIJNENDIJK 2023, LEFF 2016, NING et al. 2017, SANTAMOUR JR. 2004).

KONIJNENDIJK (2023) introduced the 3-30-300 rule as a benchmark to ensure equitable access to the benefits of trees and urban green spaces. Thresholds include having at least three well-established trees in view of every home, school, and place of work, no less than a 30% tree canopy in every neighbourhood, and no more than 300 meters to the nearest public green space from every residence. This project focuses on the 30% neighbourhood tree cover aspect of Konijnendijk's benchmark, as this measure is directly linked to UHI mitigation. Research supports a minimum threshold between 30-40% tree cover to attain desired ecosystem benefits (KONIJNENDIJK 2023, NIEUWENHUIJSEN et al. 2022). For example, watersheds in the U.S. Mid-Atlantic region are said to have "good" health if tree canopy cover exceeds 45% (DAVEY RESOURCE GROUP 2012). Additionally, ZITER et al.(2019) found that daytime air temperatures were non-linearly associated with tree cover, and the most significant cooling effect occurred when tree cover exceeded 40%. However, these studies often relied on coarse (e. g. 30- or 90-meter resolution) landcover datasets or surrogate variables like the Normalized Difference Vegetation Index, often undercounting urban forests (HERIS et al. 2022). Few studies have assessed whether specific benchmarks can mitigate UHI under future climatic conditions using high-resolution landcover datasets.

Monitoring forest cover is not enough. COWETT AND BASSUK (2017), MA et al.(2020), and SANTAMOUR JR. (2004) argue that a biodiverse urban forest is critical to absorbing pest, disease, and climate change shocks while still delivering ecosystem services. Two popular biodiversity benchmarks emerged to ensure urban forests' resiliency – the 10/20/30 and 5/10/15 rules. SANTAMOUR (2004) suggested no more than 10% of a single species, 20% of a single genus, and 30% of a single family. However, there has been a call for stricter guidelines due to the coalescence of the climate and biodiversity crises, resulting in the 5/10/15 rule proposed by LEFF (2016) and WATSON (2017): no more than 5% of a single species, 10% of a single genus, and 15% of a single family. RICHARDS (1983) extends arguments of diversity to include age and proposes a right-skewed distribution among the following age classes: 40% juvenile, 30% semi-mature, 20% mature, and 10% senescent. The previously discussed bio- and age-diversity benchmarks are critical for cities to sustain their forest cover and mitigate UHI amidst an uncertain future.

Cities are implementing a number of plans to address urban forest decline and monitor biodiversity and age diversity to ensure their urban forest are resilient to ongoing and future stressors. We focus on Pittsburgh, Pennsylvania because the city and its non-profit partners have created an ambitious urban forest plan to deal with legacy industrial environmental concerns and mitigate future climate concerns. Pittsburgh's urban forests are critical in addressing legacy air, water quality, and environmental health concerns. One initiative to address

Pittsburgh's environmental issues is the *Pittsburgh Urban Forest Master Plan* (DAVEY RESOURCE GROUP 2012), a collaborative effort guided by the Tree Pittsburgh non-profit organization. Pittsburgh hopes to achieve 60% urban tree canopy cover by 2032, doubling the minimum recommendation of the 3-30-300 rule. It also adopted the 10/20/30 biodiversity rule with slight modifications but no age diversity benchmarks. To evaluate the state of Pittsburgh's forest this research used publicly available geospatial data to evaluate the equity of forest cover, diversity, and current benchmarks' capacity to mitigate future MRT. Forest cover, biodiversity, age diversity, and equity of Pittsburgh's urban forest were first assessed. Then, literature, local government code and ordinance reviews, and a focus group involving local decision-makers and landscape architects informed the selection of four planning areas for simulations of MRTs in 2050 under five scenarios encompassing contrasting future forest cover and climate conditions.

2 Methods

The research methods are outlined in Figure 1, with details in the following subsections.

2.1 Forest Cover, Biodiversity, Age Diversity, and Equity Assessment

Forest cover equity was measured by calculating the proportion of forest cover by census tract and neighbourhood using the CDC/ATSDR Social Vulnerability Index (SVI)[2] (CENTERS FOR DISEASE CONTROL AND PREVENTION/AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY/GEOSPATIAL RESEARCH, ANALYSIS, AND SERVICES PROGRAM 2010) and Pittsburgh's neighbourhood boundaries (CITY OF PITTSBURGH 2022). Additionally, we compared existing forest cover with historic HOLC redlining (NELSON & WINLING 2023).

Biodiversity and age diversity were evaluated using Pittsburgh's urban street tree dataset (ALLEGHENY COUNTY DIVISION OF COMPUTER SERVICES GEOGRAPHIC INFORMATION SYSTEMS GROUP & UNIVERSITY OF VERMONT SPATIAL ANALYSIS LABORATORY, 2015) for both census tracts and neighbourhoods. We calculated the percent of single species, genus, and family and compared them to both the 10/20/30 and 5/10/15 urban tree diversity measures. Additionally, we calculated a functional diversity index (SHAH et al. 2021) for each CDC SVI census tract. The following describes the index:

$$BiodiversityIndex = \frac{1}{\sum_{i \in S} SpeciesFreq_i^2}$$

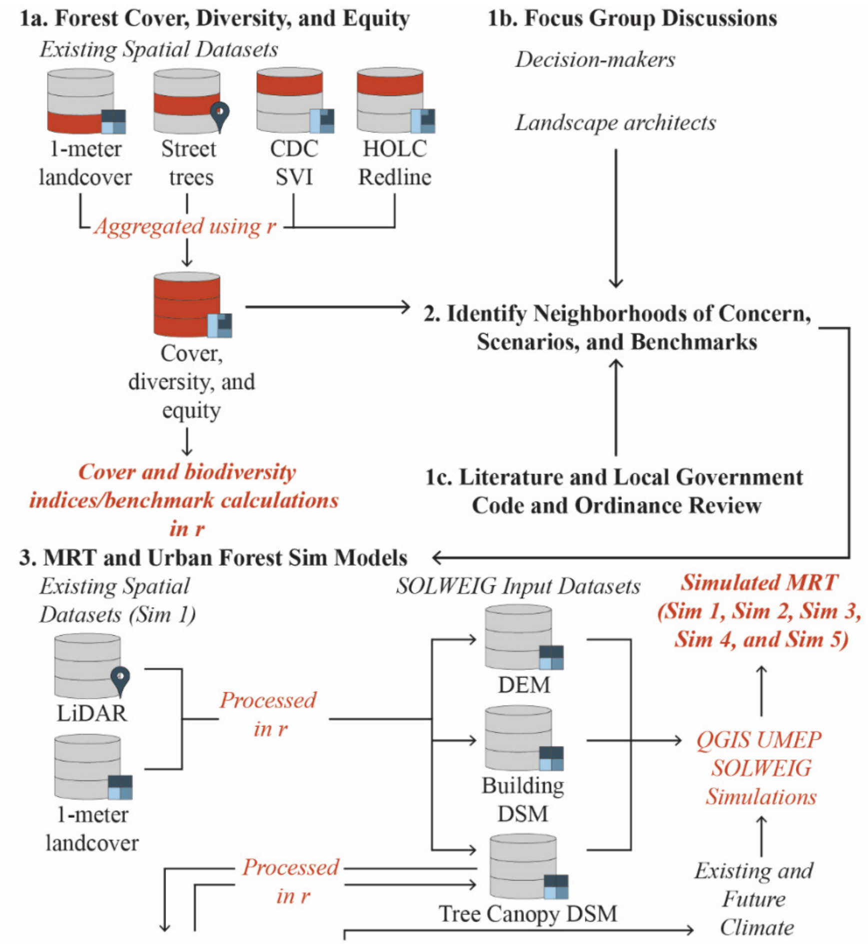
S is the set of species

Since none of the tracts or neighbourhoods met the 40/30/20/10 age benchmark, we utilized the Euclidean distance between the age and benchmarks. That is, the proposed age index is the square root of the sum of the square difference between age frequency and the benchmark:

[2] The CDC SVI contains 16 U.S. census variables related to the potential negative effects on communities caused by external stresses on human health, a critical concern in UHI mitigation. Example variables include race, ethnicity, age, and income.

$$TreeAgeDiversityIndex = \sqrt{\sum_{i \in G} (AgeFreq_i - AgeBenchmark_i)^2}$$

G={Juvenile, Semi-mature, Mature, Senescent}



Simulation Names	Total Forest Cover	Sim Starting Air Temperature (Celsius)	Scenario Descriptions		
			Landcover	Forest Cover	Climate
Sim 1	43.7%	35°	2010	2010	2010
Sim 2	43.7%	38.7°	2010	2010	2050
Sim 3	19.7%	38.7°	2010	-24%	2050
Sim 4	60%	38.7°	2010	60%	2050
Sim 5	50%	38.7°	2010	50%	2050

Fig. 1: Research design, methods, and simulation processing diagram

Two Ordinary Least Squares (OLS) models tested whether biological and age diversity can be associated with CDC SVI's socioeconomic control variables, such as the percentage of population below the poverty line and the percentage of people of colour.

2.2 MRT Simulations

We simulated MRT, representing UHI, using SOLWEIG's (LINDBERG et al. 2018) QGIS (QGIS DEVELOPMENT TEAM 2023) plugin for four planning areas in Pittsburgh. Informed by a focus group with local decision-makers, these areas include Beltzhoover, the Hill (comprised of Bedford Dwellings, Crawford-Roberts, Middle Hill, Terrace Village, and Upper Hill neighbourhoods), Homewood (comprised of Homewood North, South, and West neighbourhoods), and Larimer, because they have experienced forest decline, known biodiversity issues, historic systemic racism, or concerns of future forest loss (e. g. known disease concerns). Five simulations (sim) with contrasting forest cover and future climate conditions were computed (Fig. 1). Sim 1 represents existing conditions in 2010. Sim 2 represents 2010 land and forest cover conditions with 2050 climate. While, Sim 3 represents a trend of continuous forest cover decline, resulting in a 24% loss by 2050, and Sims 4 and 5 represent new benchmarks of 60% and 50% forest cover, respectively. Weather information for 2010 was obtained from the *National Solar Radiation Database* (NATIONAL RENEWABLE ENERGY LABORATORY 2023), while future weather data was extrapolated from the *2021 Pennsylvania Climate Impacts Assessment* (ICF STRATEGIC CONSULTING AND COMMUNICATIONS 2021). Sims 2-5 used 38.7 °C, the middle range of extremely hot temperatures predicted for Pittsburgh, as the 2050 starting air temperature. Simulation MRT results were aggregated to the four planning area boundaries.

3 Results and Discussion

3.1 Forest Cover and Equity Assessment

With 43.7% city-wide tree cover, Pittsburgh exceeds Konijnendijk's 30% benchmark but still falls short by 16.3% from their ambitious 60% goal. The equity of forest cover in Pittsburgh is more nuanced than previously reported in the literature. Previous research showed low-income black neighbourhoods have less forest cover; however, our statistical models of forest cover, race, and income do not produce significant results. When broken down by neighbourhood, some vulnerable and predominantly black neighbourhoods, such as the Hill, have significantly less than the minimum recommended 30%, while others contain some of the highest tree covers in the city (Beltzhoover – 52.3%). However, this is not to suggest that the urban forest in Beltzhoover is high quality, biodiverse, or age-diverse as its high forest cover is likely the result of ruderal, urban successional vegetation on steep undeveloped slopes, small-scale single-family home parcels, and vacant parcels from demolished homes. In contrast, the Hill, with its proximity to Pittsburgh's central business district, has shallower slopes and experiences larger-scale redevelopment that added larger building footprints, agglomerated parcels, and impervious surface infrastructure. Future research should confirm these hypotheses through archival research.

3.2 Biodiversity, Age Diversity, and Equity Assessment

City-wide, Pittsburgh is on the verge of succeeding in its 10/20/30 goal, as only one species is approaching 10% (*Acer platanoides),* and only one genus (*Acer*) exceeded the 20% threshold. Yet, the top five species city-wide are overly planted, non-native, or invasive. At the neighbourhood scale, biodiversity is a greater concern as most neighbourhoods break at least one, often multiple, aspect of the 10/20/30 rule. No neighbourhood meets any aspect of the more aggressive 5/10/15 rule. We do not believe the lack of neighbourhood biodiversity results from current urban forest or street tree regulations. Current regulations require 1) *Acer* may not comprise more than 5% of any given planting project, 2) Asian Long Horn Beatle host species may not comprise more than 5% of any given planting project, 3) any street tree planting project should have 10% of the species be conifers, and 4) recommend street trees be planted in alternating groups of 3-6 trees of different species. A public planting project moratorium has been placed on several of the most overly planted and problematic species and genera: *Acer platanoides, Fraxinus spp., Pyrus calleryana, Tilia cordata, and Ulmus americana*. Neighbourhood monocultures are more likely attributed to legacy plantings, lack of past regulations, ongoing design aesthetic choices beyond city review's control, or inadequate enforcement of existing regulations. Comparing our 2010 numbers to the reported 2005 numbers indicates an increase in Pittsburgh's tree biodiversity (Table 1) (DAVEY RESOURCE GROUP, 2012), highlighting that change is happening but requires sustained effort.

Table 1: Comparison of street tree species population percentages between 2005 and 2010

Street Tree Species	2005 Population Percentage	2010 Population Percentage
Acer plantanoides	14%	9%
Pyrus calleryana	10%	8%
Acer rubrum	10%	9%
Tilia cordata	10%	6%

Age diversity is a concern as >60% of street trees are juvenile, and no neighbourhood meets the 40/30/20/10 age rule. Due to the low numbers of semi-mature (3%) and mature (15%) trees, extreme care should be given to ensure their protection. Additionally, to achieve age diversity and ensure the continuity of ecosystem services, extra effort should be given to planting and managing younger age classes to ensure they make it to maturity and survive longer than an urban street tree's current average life span.

The two OLS models testing the relationships between biological (model a, Fig. 2) and age diversity (model b) and CDC SVI's socioeconomic control variables underscore the negative statistically significant relationships between the percentage of residents below the poverty line and both street tree biodiversity and age diversity. Model results are presented in Table 2. Such results suggest that more economically vulnerable communities have less access to climate-resilient urban forests, limiting their capacity to endure higher MRT. The mapped results (Fig. 2) appear to show a clear spatial pattern between biodiversity scores and historic redlining practices, as evident in the Hill area.

However, the OLS regressions suggest a more nuanced relationship driven more by income than race or ethnicity. This is concerning because income is a potential barrier to establishing and maintaining street trees in Pittsburgh, as the adjacent landowners bear partial responsebility for establishment and maintenance. To overcome this barrier, Pittsburgh should continue to maximize current tree planting grants in financially constrained neighbourhoods and explore alternative maintenance and revenue streams, such as volunteer efforts or urban wood reclamation.

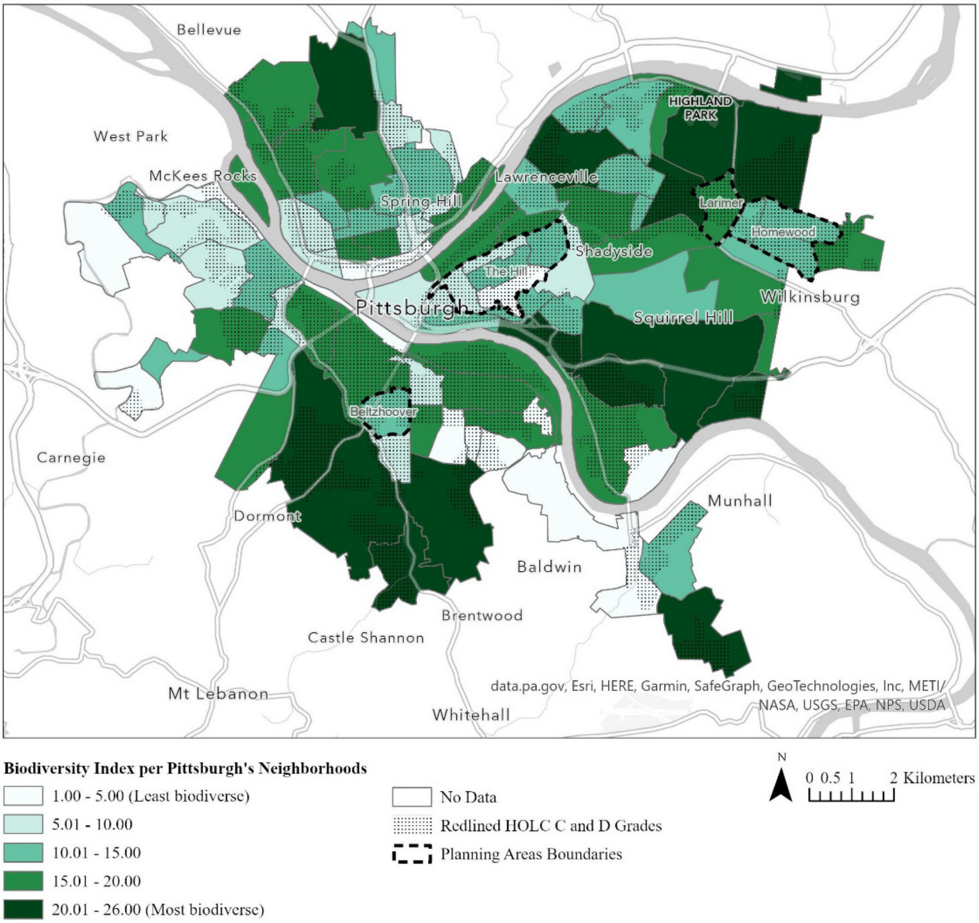


Fig. 2: Biodiversity weighted index score per neighbourhood with Redlined HOLC C and D grades

Table 2: Biological and age diversity OLS model results with t statistics reported in parentheses (*p<0.05 and **p<0.01)

Independent Variables	Model a: Biological Diversity	Model b: Age Diversity
Percent minority	-2.403 (-1.40)	-2.647 (-0.77)
Percent below poverty level	-8.549** (-2.81)	15.506* (2.52)
N	122	122
R-sq	0.166	0.355

3.3 MRT Simulations

A change of 3.7 °C simulation starting air temperatures (2010 versus 2050 climate) resulted in an increase of 3.7 °C in an average MRT increase of 3.5 °C across simulated planning areas (Figure 3), holding all other factors equal. If current forest loss trends continue (Sim 3), the MRT will increase by an average of 3.9 °C. An increase to 60% (Sim 4) and 50% (Sim 5) tree canopy cover creates an average decrease of -14.5 °C and -14.5 °C MRT, respectively. These similar decreases of -14.5 °C MRT may seem counterintuitive; however, they suggest that the percentages of asphalt land cover and tree cover are the main drivers of MRT, as is supported in previous research. Hence, prioritizing planting trees in areas with higher asphalt coverage will have a greater mitigation impact than planting tree cover in turf grass areas alone.

Figure 3 shows that Beltzhoover's forest cover change across simulations results in little gain or loss in MRT, while the other three planning areas exhibit dramatic changes. This is due to Beltzhoover having a starting forest cover of 52.3%, close to the 50% and 60% assigned tree cover Sims 5 and 6, whereas Homewood, Larimer, and The Hill started with 35.6%, 25.0%, and 38.1% forest cover, respectively. Despite starting with over 30% forest cover as per the 3-30-300 rule, Homewood and The Hill exhibited dramatic MRT changes, indicating the need for a higher forest cover threshold to mitigate extreme MRT adequately. While higher tree canopy cover offers additional ecosystem services, the negligible MRT changes between 50 and 60% forest cover (Sim 5 and Sim 4) suggest optimizing UHI mitigation efforts in neighbourhoods below 50% forest cover instead of increasing neighbourhoods from 50 to 60%. Both Sim 5 and 4 forest cover percentages will produce neighborhood MRTs below 2010 MRTs, if the neighborhood's existing forest cover is 30% or below.

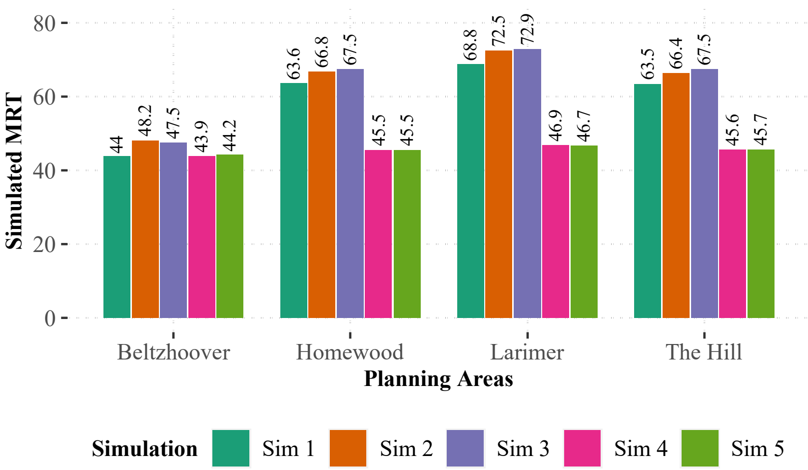


Fig. 3: Simulated median MRTs (°C) by planning area

Figure 4, comparing Beltzhoover and The Hill Scenarios 1, 3, and 5, demonstrates forests play a critical role in reducing neighbourhood, planning, and city- scale MRT. The general trend across all planning areas, as demonstrated in Figure 4, is that the higher or upper end of the MRT range gets significantly warmer from 2010 to 2050 across all scenarios. The extreme, upper ranges of MRT in all scenarios are spatially concentrated around buildings, parking lots, and street surfaces. These concentrations suggest 1) minimizing these surfaces and 2) planting high densities of larger mature shade trees to arch over and provide continuous canopy cover these surfaces. Implementing these two strategies will minimize high MRT exposure when people navigate transportation corridors. Pittsburgh should prioritize high-volume bike and pedestrian corridors. Increasing tree cover at the neighborhood, planning area, and city scales will dramatically moderate median MRT exposure, even under 2050 climate conditions in areas that are currently below 50% tree cover.

4 Conclusion

Pittsburgh, PA, has set aggressive forest cover and biodiversity benchmarks to ensure the continuation and expansion of ecosystem services with an eye to climate impacts, showing admirable progress in all of its goals at the city scale, according to this study. However, there remains work for landscape architects, planners, urban foresters, and decision-makers to address neighbourhood-scale inequalities in urban forest cover, biodiversity, and age diversity benchmarks. Pittsburgh's progress is not without its external and internal challenges. This research did not address specific threats to forest cover and biodiversity. Future research should explore external challenges, such as the coupling of climate change and disease and pest impacts on Pittsburgh's urban forest, to understand better how and where interventions should be pre-emptively directed. We also recommend that Pittsburgh continue leveraging opportunistic conservation and tree planting during land development reviews. Broader tree planting efforts should focus on low-income neighbourhoods with low forest cover, low biodiversity, low UHI adaptability as exhibited by higher CDC SVI flags, and high amounts of impervious surfaces.

Our work also shows that microclimate simulations of air temperature and MRT can effectively compare diverse alternative future scenarios regarding ecosystem service outcomes, helping to calibrate localized benchmarks and prioritize and target equitable UHI mitigation outcomes at both the metropolitan and neighbourhood scales. If Pittsburgh can achieve its forest cover benchmarks, it can reduce its neighbourhoods' 2050 mean radiant temperature below 2010 temperatures, even under climate change-fuelled extreme heat events. Such a process offers cities more nuance in assessing the spatial distribution of their tree-planting efforts to improve environmental justice and ecosystem services. By doing so, we fortify today's designs and plans against future internal and external shocks, support increased equitability of urban forest cover, and safeguard future ecosystem services.

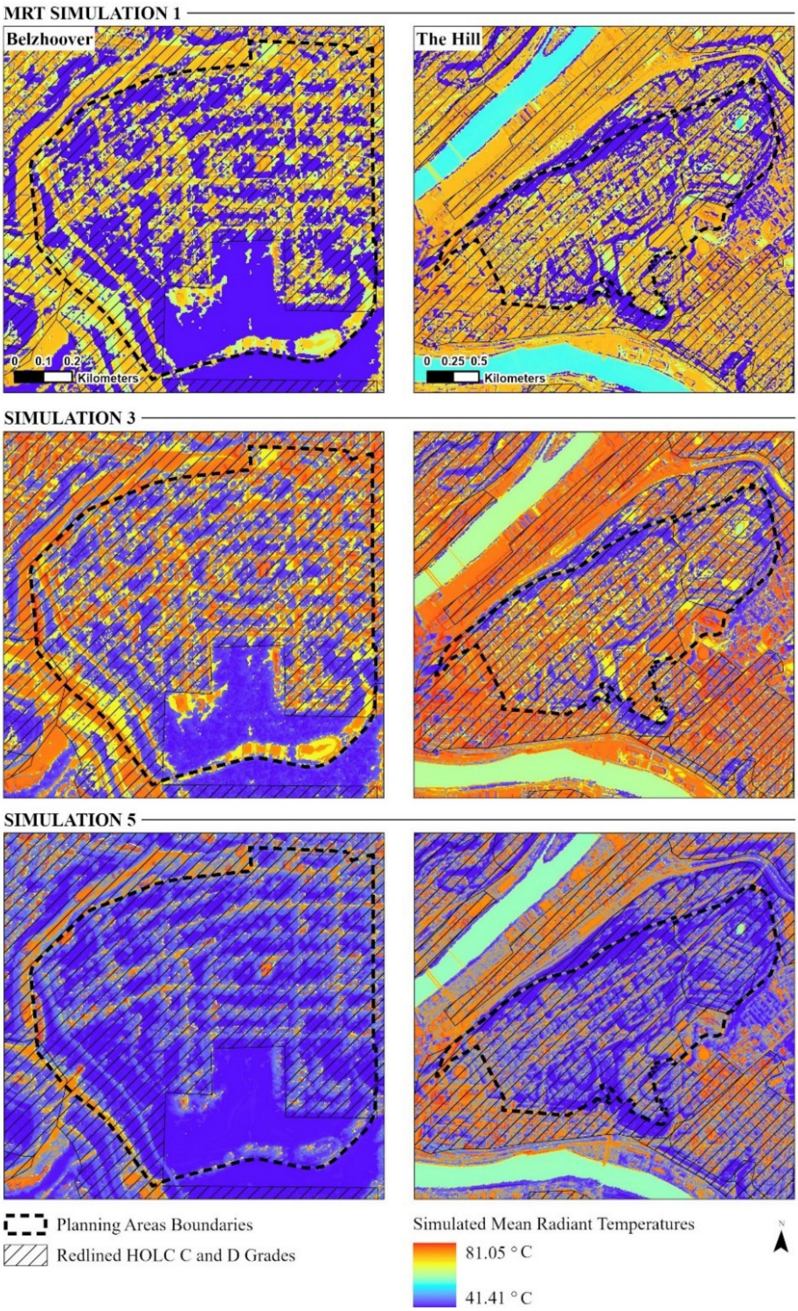


Fig. 4: Simulated MRT maps comparing Sim 1 (2010, existing conditions) with Sim 3 (2050, 24% forest loss) and Sim 5 (2050, 60% forest cover) in example neighbourhoods (Beltzhoover and The Hill), highlighting Redlined HOLC C and D grades

Acknowledgements

We acknowledge research grant support from Penn State's Institutes of Energy and the Environment Seed Grant program and travel support from Penn State's Stuckeman Center for Design Computing. The Penn State Institutional Review Board determined this study to be exempt research (Study Number: STUDY00022458). We also thank the Franco Harris Pittsburgh Center at Penn State for their assistance with the focus groups.

References

ALLEGHENY COUNTY DIVISION OF COMPUTER SERVICES GEOGRAPHIC INFORMATION SYSTEMS GROUP & UNIVERSITY OF VERMONT SPATIAL ANALYSIS LABORATORY (2015), Allegheny County Urban Tree Canopy 2010 Database [Map]. Southwestern Pennsylvania Commission. https://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=1603 (20.02.2024).

CENTERS FOR DISEASE CONTROL AND PREVENTION/ AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY/ GEOSPATIAL RESEARCH, ANALYSIS, AND SERVICES PROGRAM (2010), CDC/ATSDR Social Vulnerability Index 2010 Database Pennsylvania [Map]. https://www.atsdr.cdc.gov/placeandhealth/svi/data_documentation_download.html (20.02.2024).

CITY OF PITTSBURGH (2022), City of Pittsburgh Neighborhoods [Shapefile]. City of Pittsburgh. https://data.wprdc.org/dataset/neighborhoods2 (20.02.2024).

COWETT, F. D. & BASSUK, N (2017). Street Tree Diversity in Three Northeastern U.S. States.

DAVEY RESOURCE GROUP (2012), Pittsburgh urban forest master plan: A road map for the effective management of our urban forest. Tree Pittsburgh.

HERIS, M., BAGSTAD, K. J., TROY, A. R. & O'NEIL-DUNNE, J. P. M. (2022), Assessing the Accuracy and Potential for Improvement of the National Land Cover Database's Tree Canopy Cover Dataset in Urban Areas of the Conterminous United States. Remote Sensing, 14 (5). doi: 10.3390/rs14051219.

HOFFMAN, J. S., SHANDAS, V. & PENDLETON, N. (2020), The Effects of Historical Housing Policies on Resident Exposure to Intra-Urban Heat: A Study of 108 US Urban Areas. Climate, 8 (1), 12. doi: 10.3390/cli8010012.

ICF STRATEGIC CONSULTING AND COMMUNICATIONS (2021), Pennsylvania climate impacts assessment 2021. Pennsylvania Department of Environmental Protection (DEP).

KONIJNENDIJK, C. C. (2023), Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: Introducing the 3-30-300 rule. Journal of Forestry Research, 34 (3), 821-830. doi: 10.1007/s11676-022-01523-z.

LEFF, M. (2016), The sustainable urban forest: A step-by-step approach. U.S. Department of Agriculture, Forest Service, Philadelphia Research Station and the Davey Institute.

LEHNERT, E. A., WILT, G., FLANAGAN, B. & HALLISEY, E. (2020), Spatial exploration of the CDC's Social Vulnerability Index and heat-related health outcomes in Georgia. International Journal of Disaster Risk Reduction, 46, 101517. doi: 10.1016/j.ijdrr.2020.101517.

LINDBERG, F., GRIMMOND, C. S. B., GABEY, A., HUANG, B., KENT, C. W., SUN, T., THEEUWES, N. E., JÄRVI, L., WARD, H. C., CAPEL-TIMMS, I., CHANG, Y., JONSSON, P., KRAVE, N., LIU, D., MEYER, D., OLOFSON, K. F. G., TAN, J., WÄSTBERG, D., XUE, L. & ZHANG, Z. (2018), Urban Multi-scale Environmental Predictor (UMEP): An integrated tool for city-based climate services. Environmental Modelling & Software, 99, 70-87. doi: 10.1016/j.envsoft.2017.09.020.

LOCKE, D. H., HALL, B., GROVE, J. M., PICKETT, S. T. A., OGDEN, L. A., AOKI, C., BOONE, C. G. & O'NEIL-DUNNE, J. P. M. (2021), Residential housing segregation and urban tree canopy in 37 US Cities. Urban Sustainability, 1(1), 15. doi: 10.1038/s42949-021-00022-0.

MA, B., HAUER, R. J., WEI, H., KOESER, A. K., PETERSON, W., SIMONS, K., TIMILSINA, N., WERNER, L. P. & XU, C. (2020), An Assessment of Street Tree Diversity: Findings and Implications in the United States. Urban Forestry & Urban Greening, 56, 126826. doi: 10.1016/j.ufug.2020.126826.

NATIONAL RENEWABLE ENERGY LABORATORY (2023), NSRDB: National Solar Radiation Database. https://nsrdb.nrel.gov/ (20.02.2024).

NELSON, R. K. & WINLING, L. (2023), Mapping inequality: Redlining in New Deal America. https://dsl.richmond.edu/panorama/redlining/ (20.02.2024).

NIEUWENHUIJSEN, M. J., DADVAND, P., MÁRQUEZ, S., BARTOLL, X., BARBOZA, E. P., CIRACH, M., BORRELL, C. & ZIJLEMA, W. L. (2022), The evaluation of the 3-30-300 green space rule and mental health. Environmental Research, 215, 114387. doi: 10.1016/j.envres.2022.114387

NING, Z. H., NOWAK, D. J. & WATSON, G. (2017), Urban Forest Sustainability. International Society of Arboriculture.

NOWAK, D. J. & GREENFIELD, E. J. (2018), US Urban Forest Statistics, Values, and Projections. Journal of Forestry, 116 (2), 164-177. doi: 10.1093/jofore/fvx004.

QGIS DEVELOPMENT TEAM (2023), QGIS Geographic Information System (3.32.3). QGIS Association. https://www.qgis.org (20.03.2024).

RICHARDS, N. A. (1983), Diversity and stability in a street tree population. Urban Ecology, 7 (2), 159-171. doi: 10.1016/0304-4009(83)90034-7.

RILEY, C. B. & GARDINER, M. M. (2020), Examining the distributional equity of urban tree canopy cover and ecosystem services across United States cities. PLOS ONE, 15 (2), e0228499. doi: 10.1371/journal.pone.0228499.

SANTAMOUR JR, F. S. (2004), Trees for urban planting: Diversity uniformity, and common sense.

SHAH, V., JAGUPILLA, S. C. K., VACCARI, D. A. & GEBLER, D. (2021), Non-Linear Visualization and Importance Ratio Analysis of Multivariate Polynomial Regression Ecological Models Based on River Hydromorphology and Water Quality. Water, 13 (19), 2708. doi: 10.3390/w13192708.

WATSON, G. (2017), Are There Practical Limits To Urban Tree Species Diversity? In Urban Forest Sustainability. International Society of Arboriculture.

WONG, N. H., TAN, C. L., KOLOKOTSA, D. D. & TAKEBAYASHI, H. (2021), Greenery as a mitigation and adaptation strategy to urban heat. Nature Reviews Earth & Environment, 2 (3), 166-181. doi: 10.1038/s43017-020-00129-5.

ZITER, C. D., PEDERSEN, E. J., KUCHARIK, C. J. & TURNER, M. G. (2019), Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer. Proceedings of the National Academy of Sciences, 116 (15), 7575-7580. doi: 10.1073/pnas.1817561116.