NO WALK IN THE PARK: URBAN GREEN SPACE PLANNING FOR HEALTH EQUITY AND ENVIRONMENTAL JUSTICE

by

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DISSERTATION ABSTRACT

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Cities are complex socio-ecological systems where social, cultural, economic, political, and environmental factors influence health outcomes. With the global population growing increasingly urbanized, understanding how urban environmental conditions affect human health has become a topic of interest among researchers across multiple disciplines. Urban green space—which includes all vegetated land cover (e.g., trees, grass, shrubs, and woodlands), as well as any land uses with publicly available recreational amenities (e.g., parks, schoolyards, university campuses, and conservation areas) located within a city's geographic boundary—provides multiple health and health-promoting benefits. As such, disparities in park access, park quality, and green cover exposure (i.e., tree canopy and all other vegetation) are considered environmental justice and health equity issues. A wealth of recent research has found that, in general, increased access to parks has been associated with greater likelihood that residents will participate in physical activities and meet physical activity guidelines, and increased exposure to vegetated land cover has corresponded with improved psychological well-being and reduced risk of some mental illnesses. Yet, urban green spaces, and the health benefits such spaces afford, are not distributed equitably, and disparities in urban green space access and exposure based on race, ethnicity, or income represent environmental justice and health equity concerns.

In this dissertation, I build upon the existing body of knowledge to 1) investigate how issues of health have shaped urban landscapes in the United States and how the policies and decisions that have shaped urban landscapes have exacerbated health inequities, 2) build upon existing research at the nexus of health and urban green space to improve understanding of relationships between urban green space

access/exposure, physical activity, and mental well-being, and 3) develop a method for identifying distributional justice concerns related to urban green space access/exposure to inform urban green space planning for health equity.

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CHAPTER I

INTRODUCTION: RESEARCH AT THE INTERSECTION OF URBAN GREEN SPACE, HEALTH, AND ENVIRONMENTAL JUSTICE

Studying Urban Green Space, Health, and Environmental Justice: Context and Approach

> *The urban landscape should be considered a tenet of well-being, a physical factor reflecting social needs that ensures quality of life and health equity.* (Carr, 2021, p. 7)

Cities are complex socio-ecological systems where social, cultural, economic, political, and environmental factors influence health outcomes (U.S. Department of Health and Human Services, 2022). In the United States, landscape architecture and urban planning have been tied to public health since their inception. In the 19th century, city planners, landscape architects, and sanitation officials were determined to mitigate the spread of infectious disease through a combination of landscape design, infrastructure investment, and regulation (Carr, 2021). Whether due to advances in epidemiology or improved hygiene practices, mortality rates from infectious diseases were surpassed by mortality rates from chronic diseases (e.g., cancer, diabetes, and cardiovascular disease) in the mid-20th century (Susser & Susser, 1996). Unlike infectious diseases, however, chronic diseases were noncommunicable and did not have clear causal mechanisms, necessitating a new approach that considered multiple causal factors. The "web of causation" associated with chronic physical and mental health issues is now referred to as the social determinants of health (World Health Organization, 2011, 2014), defined as "the conditions in which people are born, grow, work, live, and age, and the wider set of forces and systems shaping the conditions of daily life" (World Health Organization, n.d.). The Healthy People 2030 initiative, established by the U.S. Department of Health and Human Services, identified health care, economic stability, social and community context, education, and natural and built environmental conditions as fundamental to health outcomes (U.S. Department of Health and Human Services, 2022). With the global population growing increasingly urbanized (United Nations, 2019), and with 80.0% of the United States population living in urban areas (United States Census Bureau, 2022), understanding how urban environmental conditions affect human health has become a topic of interest among national and international health organizations, as well as researchers across multiple disciplines.

Ecosystems provide a suite of benefits that support human health and well-being, termed ecosystem services, and the supply of ecosystem services is influenced by urban development patterns (Millennium Ecosystem Assessment, 2005). Although highly variable, urban development prompts physical landscape changes that alter hydrological, ecological, biogeochemical, and climate systems from local to global scales (Grimm et al., 2008). Replacing native vegetation and soil with impervious surfaces for roads, parking lots, and buildings reduces stormwater infiltration, leading to higher quantities of stormwater and pollutant runoff into local and regional waterbodies which impacts downstream flooding potential, water quality, and freshwater ecology. Land cover conversion associated with urbanization reduces albedo and evapotranspiration, resulting in increased surface temperature retention which contributes to localized urban heat islands. Urbanization transforms local ecological communities into a patchwork of smaller habitats, generally reducing biodiversity—although plant biodiversity may increase depending on planting choices—and favoring species that are well-adapted to survive in edge habitats at the expense of native species. Cities create areas with concentrated motor vehicle traffic, producing carbon dioxide and a slurry of air pollutants that affect local air quality and contribute to global climate change (Health Effects Institute, 2010). In addition to producing elevated concentrations of air pollution and islands of extreme heat (Heaviside et al., 2017; Liang & Gong, 2020; Uejio et al., 2011; Voelkel & Shandas, 2017), urban environmental conditions have been associated with other health risk factors, including physical inactivity, stress, and anxiety (Alcock et al., 2014; Bailey et al., 2018; Frank et al., 2005; Gruebner et al., 2017; Hockey et al., 2022; Khomenko et al., 2021; Maas, 2006; Sallis et al., 2016; Shindell et al., 2020; Ulrich et al., 1991; Velarde et al., 2007; World Health Organization, 2009).

Urban green spaces provide various ecosystem services that contribute to positive physical and mental health outcomes (Elmqvist et al., 2015; Gómez-Baggethun et al., 2013; Haase et al., 2014). Urban green space has been defined variably (Taylor & Hochuli, 2017), and for the purpose of this dissertation, the term “urban green space” will refer to all vegetated land cover (e.g., trees, grass, shrubs, and woodlands), as well as any land uses with free and publicly available recreational amenities (e.g., parks, schoolyards, university campuses, and conservation areas) located within a city's geographic boundary. Health, as defined by the World Health Organization, encompasses "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organization, 2006, p. 1), and researchers have investigated associations between urban green space access/exposure, physical activity, and mental health using various urban green space measures (Bratman et al., 2019; Ekkel & de Vries, 2017; Rigolon, 2016; van den Berg et al., 2015; Velarde et al., 2007). Physical activity is an important protective factor against negative mental and physical health outcomes (World Health Organization, 2022a), and findings suggest that residents with greater access to parks and recreational facilities are more likely to be physically active and meet guidelines for physical activity (Astell-Burt et al., 2013; Coombes et al., 2010; James et al., 2015; Kaczynski, Besenyi, et al., 2014; Mytton et al., 2012). Mental health is more than the absence of a mental illness, including components of mental well-being such as happiness, anxiety, and life satisfaction (Bratman et al., 2019; Office of National Statistics, 2018; World Health Organization, 2022b), and exposure to vegetated land cover has been associated with both improved mental well-being and diminished risk of mental illness (Bratman et al., 2012, 2019; Engemann et al., 2019; Maas et al., 2009; van den Berg et al., 2015; Velarde et al., 2007). The preponderance of evidence supporting the theory that access and exposure to urban green space influences health outcomes has prompted questions regarding the distribution of these environmental assets.

Urban green spaces, and the health benefits such spaces afford, have not been equally available to all people, and disparities in urban green space access and exposure based on race, ethnicity, or income represent potential environmental justice and health equity concerns. The environmental justice movement built on momentum from the civil rights and environmentalism movements to decry systemic disparities in exposure to toxic environments faced by predominantly Black/African American and low-income communities (Frumkin, 2005; Jennings et al., 2019; United States Environmental Protection Agency, 2022). Health equity has been defined as "the absence of systematic disparities in health (or in the major social determinants of health) between social groups who have different levels of underlying social advantage/disadvantage" (Braveman & Gruskin, 2003, p. 254), and the environmental justice discourse expanded to consider the inequitable access and exposure to environmental amenities as a health equity issue (Jennings et al., 2019). While findings vary by city, persistent disparities in area of accessible parkland, park quality, and tree canopy cover have been observed based on race, ethnicity, and income (Gerrish & Watkins, 2018; Rigolon, 2016; Watkins & Gerrish, 2018).

Studying relationships between health and urban landscapes is inherently complex due to the variability in individual habits, lifestyles, and life histories as well as the numerous cultural, political, and socioeconomic factors that influence the spatial distribution of people and resources. The extensive body of research on relationships between health, equity, and urban green space has clarified that access and exposure to urban green space are positively associated with increased physical activity as well as improved mental well-being and that the distribution of urban green space needs to be considered through an environmental justice lens. Various individual and neighborhood factors (i.e., socioeconomic and demographic characteristics, individual health, lifestyle preferences, priorities in housing selection, and neighborhood walkability) mediate or moderate relationships between green space access/exposure, physical activity, and mental well-being (Cerin et al., 2008; Frank et al., 2005; Jones et al., 2009; Kaczynski, Besenyi, et al., 2014; Kaczynski et al., 2008; Kaczynski, Koohsari, et al., 2014; Kaczynski & Mowen, 2011; Reis et al., 2009). Yet no studies, to my knowledge, have factored all these components into a comprehensive and unified analytical approach. Furthermore, while equity assessments have investigated disparities in park access, park quality, and vegetation exposure independently, these disparate urban green space measures have not been considered all together. Consequently, further research is needed to inform urban green space design and planning for health equity by 1) contextualizing relationships between urban green space access/exposure, physical activity, and mental well-being within the interconnected system of individual and community factors that influence health outcomes, and 2) developing and testing methods for identifying environmental justice and health equity concerns based on the distribution of a diverse set of urban green space characteristics.

To address these gaps in knowledge with this dissertation, I seek to 1) investigate how issues of health have shaped urban landscapes in the United States and how the policies and decisions that have shaped urban landscapes have exacerbated health inequities, 2) build upon existing research at the nexus of health and urban green space to improve understanding of relationships between urban green space access/exposure, physical activity, and mental well-being, and 3) develop a method for identifying distributional justice concerns related to urban green space access/exposure to inform urban green space planning for health equity.

Dissertation Organization

This dissertation consists of five chapters, including this introductory chapter, three body chapters (Chapters 2-4), and a concluding chapter. Chapters 2, 3, and 4 are formatted as stand-alone works, but they were intended to be read together to contextualize and advance research at the intersection of urban green space and health equity in the United States. Chapters 3 and 4 are situated in Portland, Oregon and are intended to inform local urban green space decision-making, as well as provide a template for future urban green space research and planning.

Chapter 2 explores historical connections between landscape architecture, urban planning, and public health and calls on landscape architects to engage the collaborative, multidisciplinary effort to promote health equity through urban green space planning. It traces the recurrent theme of urban landscapes as fundamental to health throughout the 19th and 20th centuries and positions urban green space policy and planning as central to creating healthy and equitable cities in the 21st century. It also discusses how urban planning decisions exacerbated income- and race-based health disparities through a process of systematic segregation and disinvestment in marginalized communities followed by a pattern of urban renewal and displacement. In this chapter, I argue that the intertwined histories of landscape architecture, urban planning, and public health combined with the explosion of research investigating relationships between urban green space, health, and environmental justice over the past few decades demonstrate the collective interest in design and planning to promote community health and well-being.

Chapter 3 combines geographically explicit survey data from residents in Portland, Oregon, collected through an online non-probability sample, with spatialized urban green space and built environment metrics to identify relationships between urban green space access/exposure and park use, neighborhood-based physical activity, and mental well-being. This study developed upon previous research, taking an ecological approach—one that considers the complex network of individual, community, and environmental factors that influence health—to model relationships between urban green space and health. In addition to self-reporting park use, physical activity, and mental well-being, survey respondents provided information on their sociodemographic characteristics (e.g., race, ethnicity, income, age, gender), general health characteristics (e.g., sleep quantity, physical limitations, mental illness diagnoses, and perceived overall health), lifestyle preferences (e.g., smoking and dog ownership), resident self-selection (i.e., reasons for choosing their current housing), perceived neighborhood social cohesion, and perceptions of their neighborhood environment. Findings from this study provide evidence to support the management of urban green spaces for health equity and reveal a more complete understanding of associations between mental well-being, physical activity, and urban landscapes.

In Chapter 4, I present a methodology for identifying distributional inequities based on specific urban green space metrics and identify targeted green space planning priorities to improve the equitable distribution of urban green space at the city scale in Portland, Oregon. I evaluated urban green space equity by comparing a suite of urban green space variables (i.e., park access, park quality, and vegetation metrics) with aggregated race, ethnicity, income, and educational attainment data. In this chapter, I detail specific urban green space inequities observed in Portland and provide suggestions for urban green space enhancement based on existing inequities.

Finally, in Chapter 5, I provide a brief synthesis and interpretation of the findings from Chapters 2, 3, and 4 and propose opportunities to build on this body of work.

References Cited

Alcock, I., White, M. P., Wheeler, B. W., Fleming, L. E., & Depledge, M. H. (2014). Longitudinal Effects on Mental Health of Moving to Greener and Less Green Urban Areas. *Environmental Science & Technology*, *48*(2), 1247–1255. https://doi.org/10.1021/es403688w

Astell-Burt, T., Feng, X., & Kolt, G. S. (2013). Mental health benefits of neighbourhood green space are stronger among physically active adults in middle-to-older age: Evidence from 260,061 Australians. *Preventive Medicine*, *57*(5), 601–606. https://doi.org/10.1016/j.ypmed.2013.08.017

Bailey, A. W., Allen, G., Herndon, J., & Demastus, C. (2018). Cognitive benefits of walking in natural versus built environments. *World Leisure Journal*, *60*(4), 293–305. https://doi.org/10.1080/16078055.2018.1445025

Bratman, G. N., Anderson, C. B., Berman, M. G., Cochran, B., de Vries, S., Flanders, J., Folke, C., Frumkin, H., Gross, J. J., Hartig, T., Kahn, P. H., Kuo, M., Lawler, J. J., Levin, P. S., Lindahl, T., Meyer-Lindenberg, A., Mitchell, R., Ouyang, Z., Roe, J., … Daily, G. C. (2019). Nature and mental health: An ecosystem service perspective. *Science Advances*, *5*(7), eaax0903. https://doi.org/10.1126/sciadv.aax0903

Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health: Nature experience, cognitive function, and mental health. *Annals of the New York Academy of Sciences*, *1249*(1), 118–136. https://doi.org/10.1111/j.1749-6632.2011.06400.x

Braveman, P., & Gruskin, S. (2003). Defining equity in health. *Journal of Epidemiology & Community Health*, *57*(4), 254–258. https://doi.org/10.1136/jech.57.4.254

Carr, S. J. (2021). The topography of wellness: How health and disease shaped the American landscape. University of Virginia Press.

Cerin, E., Vandelanotte, C., Leslie, E., & Merom, D. (2008). Recreational facilities and leisure-time physical activity: An analysis of moderators and self-efficacy as a mediator. *Health Psychology*, *27*(2, Suppl), S126–S135. https://doi.org/10.1037/0278-6133.27.2(Suppl.).S126

Coombes, E., Jones, A. P., & Hillsdon, M. (2010). The relationship of physical activity and overweight to objectively measured green space accessibility and use. *Social Science & Medicine*, *70*(6), 816–822. https://doi.org/10.1016/j.socscimed.2009.11.020

Ekkel, E. D., & de Vries, S. (2017). Nearby green space and human health: Evaluating accessibility metrics. *Landscape and Urban Planning*, *157*, 214–220. https://doi.org/10.1016/j.landurbplan.2016.06.008

Elmqvist, T., Setälä, H., Handel, S., van der Ploeg, S., Aronson, J., Blignaut, J., Gómez-Baggethun, E., Nowak, D., Kronenberg, J., & de Groot, R. (2015). Benefits of restoring ecosystem services in urban areas. *Current Opinion in Environmental Sustainability*, *14*, 101–108. https://doi.org/10.1016/j.cosust.2015.05.001

Engemann, K., Pedersen, C. B., Arge, L., Tsirogiannis, C., Mortensen, P. B., & Svenning, J.-C. (2019). Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. *Proceedings of the National Academy of Sciences*, 201807504. https://doi.org/10.1073/pnas.1807504116

Frank, L. D., Schmid, T. L., Sallis, J. F., Chapman, J., & Saelens, B. E. (2005). Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ. *American Journal of Preventive Medicine*, *28*(2, Supplement 2), 117–125. https://doi.org/10.1016/j.amepre.2004.11.001

Frumkin, H. (2005). Guest Editorial: Health, Equity, and the Built Environment. *Environmental Health Perspectives*, *113*(5), A290–A291. https://doi.org/10.1289/ehp.113-a290

Gerrish, E., & Watkins, S. L. (2018). The relationship between urban forests and income: A meta-analysis. *Landscape and Urban Planning*, *170*, 293–308. https://doi.org/10.1016/j.landurbplan.2017.09.005

Gómez-Baggethun, E., Gren, Å., Barton, D. N., Langemeyer, J., McPhearson, T., O'Farrell, P., Andersson, E., Hamstead, Z., & Kremer, P. (2013). Urban Ecosystem Services. In *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities* (pp. 175–251).

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science*, *319*(5864), 756–760. https://doi.org/10.1126/science.1150195

Gruebner, O., Rapp, M. A., Adli, M., Kluge, U., Galea, S., & Heinz, A. (2017). Cities and Mental Health. *Deutsches Aerzteblatt Online*. https://doi.org/10.3238/arztebl.2017.0121

Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgstrom, S., Breuste, J., Gomez-Baggethun, E., Gren, A., Hamstead, Z., Hansen, R., Kabisch, N., Kremer, P., Langemeyer, J., Rall, E. L., McPhearson, T., Pauleit, S., Qureshi, S., Schwarz, N., Voigt, A., … Elmqvist, T. (2014). A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation. *Ambio*, *43*(4), 413–433. https://doi.org/10.1007/s13280-014-0504-0

Health Effects Institute. (2010). *Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects* (Special Report 17). https://www.healtheffects.org/publication/traffic-related-air-pollution-critical-review-literature-emissions-exposure-and-health

Heaviside, C., Macintyre, H., & Vardoulakis, S. (2017). The Urban Heat Island: Implications for Health in a Changing Environment. *Current Environmental Health Reports*, *4*(3), 296–305. https://doi.org/10.1007/s40572-017-0150-3

Hockey, M., Rocks, T., Ruusunen, A., Jacka, F. N., Huang, W., Liao, B., Aune, D., Wang, Y., Nie, J., & O'Neil, A. (2022). Psychological distress as a risk factor for all-cause, chronic disease- and suicide-specific mortality: A prospective analysis using data from the National Health Interview Survey. *Social Psychiatry and Psychiatric Epidemiology*, *57*(3), 541–552. https://doi.org/10.1007/s00127-021-02116-7

James, P., Banay, R. F., Hart, J. E., & Laden, F. (2015). A Review of the Health Benefits of Greenness. *Current Epidemiology Reports*, *2*(2), 131–142. https://doi.org/10.1007/s40471-015-0043-7

Jennings, V., Browning, M. H. E. M., & Rigolon, A. (2019). Urban Green Space at the Nexus of Environmental Justice and Health Equity. In V. Jennings, M. H. E. M. Browning, & A. Rigolon, *Urban Green Spaces* (pp. 47–69). Springer International Publishing. https://doi.org/10.1007/978-3-030-10469-6_4

Jones, A., Hillsdon, M., & Coombes, E. (2009). Greenspace access, use, and physical activity: Understanding the effects of area deprivation. *Preventive Medicine*, *49*(6), 500–505. https://doi.org/10.1016/j.ypmed.2009.10.012

Kaczynski, A. T., Besenyi, G. M., Stanis, S. A. W., Koohsari, M. J., Oestman, K. B., Bergstrom, R., Potwarka, L. R., & Reis, R. S. (2014). Are park proximity and park features related to park use and park-based physical activity among adults? Variations by multiple socio-demographic characteristics. *The International Journal of Behavioral Nutrition and Physical Activity*, *11*(1), 146. https://doi.org/10.1186/s12966-014-0146-4

Kaczynski, A. T., Koohsari, J., Wilhelm Stanis, S., Bergstrom, R., & Sugiyama, T. (2014). Association of Street Connectivity and Road Traffic Speed With Park Usage and Park-Based Physical Activity. *American Journal of Health Promotion : AJHP*, *28*, 197–203. https://doi.org/10.4278/ajhp.120711-QUAN-339

Kaczynski, A. T., & Mowen, A. J. (2011). Does self-selection influence the relationship between park availability and physical activity? *Preventive Medicine*, *52*(1), 23–25. https://doi.org/10.1016/j.ypmed.2010.10.003

Kaczynski, A. T., Potwarka, L. R., & Saelens, B. E. (2008). Association of Park Size, Distance, and Features With Physical Activity in Neighborhood Parks. *American Journal of Public Health*, *98*(8), 1451–1456. https://doi.org/10.2105/AJPH.2007.129064

Khomenko, S., Cirach, M., Pereira-Barboza, E., Mueller, N., Barrera-Gómez, J., Rojas-Rueda, D., Hoogh, K. de, Hoek, G., & Nieuwenhuijsen, M. (2021). Premature mortality due to air pollution in European cities: A health impact assessment. *The Lancet Planetary Health*, *5*(3), e121–e134. https://doi.org/10.1016/S2542-5196(20)30272-2

Liang, L., & Gong, P. (2020). Urban and air pollution: A multi-city study of long-term effects of urban landscape patterns on air quality trends. *Scientific Reports*, *10*(1), Article 1. https://doi.org/10.1038/s41598-020-74524-9

Maas, J. (2006). Green space, urbanity, and health: How strong is the relation? *Journal of Epidemiology & Community Health*, *60*(7), 587–592. https://doi.org/10.1136/jech.2005.043125

Maas, J., van Dillen, S. M. E., Verheij, R. A., & Groenewegen, P. P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. *Health & Place*, *15*(2), 586–595. https://doi.org/10.1016/j.healthplace.2008.09.006

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being*. Island Press.

Mytton, O. T., Townsend, N., Rutter, H., & Foster, C. (2012). Green space and physical activity: An observational study using Health Survey for England data. *Health & Place*, *18*(5), 1034–1041. https://doi.org/10.1016/j.healthplace.2012.06.003

Office of National Statistics. (2018). *Personal well-being user guidance*. https://www.ons.gov.uk/peoplepopulationandcommunity/wellbeing/methodologies/personalwellbeingsurveyuserguide

Reis, R. S., Hino, A. A. F., Florindo, A. A., Añez, C. R. R., & Domingues, M. R. (2009). Association between physical activity in parks and perceived environment: A study with adolescents. *Journal of Physical Activity & Health*, *6*(4), 503–509. https://doi.org/10.1123/jpah.6.4.503

Rigolon, A. (2016). A complex landscape of inequity in access to urban parks: A literature review. *Landscape and Urban Planning*, *153*, 160–169. https://doi.org/10.1016/j.landurbplan.2016.05.017

Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., Salvo, D., Schipperijn, J., Smith, G., Cain, K. L., Davey, R., Kerr, J., Lai, P.-C., Mitáš, J., Reis, R., Sarmiento, O. L., Schofield, G., Troelsen, J., Van Dyck, D., … Owen, N. (2016). Physical activity in relation to urban environments in 14 cities worldwide: A cross-sectional study. *Lancet (London, England)*, *387*(10034), 2207–2217. https://doi.org/10.1016/S0140-6736(15)01284-2

Shindell, D., Zhang, Y., Scott, M., Ru, M., Stark, K., & Ebi, K. L. (2020). The Effects of Heat Exposure on Human Mortality Throughout the United States. *GeoHealth*, *4*(4), e2019GH000234. https://doi.org/10.1029/2019GH000234

Susser, M., & Susser, E. (1996). Choosing a future for epidemiology: I. Eras and paradigms. *American Journal of Public Health*, *86*(5), 668–673. https://doi.org/10.2105/ajph.86.5.668

Taylor, L., & Hochuli, D. F. (2017). Defining greenspace: Multiple uses across multiple disciplines. *Landscape and Urban Planning*, *158*, 25–38. https://doi.org/10.1016/j.landurbplan.2016.09.024

Uejio, C. K., Wilhelmi, O. V., Golden, J. S., Mills, D. M., Gulino, S. P., & Samenow, J. P. (2011). Intra-urban societal vulnerability to extreme heat: The role of heat exposure and the built environment, socioeconomics, and neighborhood stability. *Health & Place*, *17*(2), 498–507. https://doi.org/10.1016/j.healthplace.2010.12.005

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, *11*(3), 201–230. https://doi.org/10.1016/S0272-4944(05)80184-7

United Nations. (2019). *World Urbanization Prospects 2018 Highlights*. https://population.un.org/wup/Publications/Files/WUP2018-Highlights.pdf

United States Census Bureau. (2022). *Nation's Urban and Rural Populations Shift Following 2020 Census*. Census.Gov. https://www.census.gov/newsroom/press-releases/2022/urban-rural-populations.html

United States Environmental Protection Agency. (2022). *Environmental Justice* [Collections and Lists]. https://www.epa.gov/environmentaljustice

U.S. Department of Health and Human Services. (2022). *Health Equity and Health Disparities Environmental Scan*. U.S. Department of Health and Human Services, Office of the Assistant Secretary for Health, Office of Disease Prevention and Health Promotion. https://health.gov/sites/default/files/2022-04/HP2030-HealthEquityEnvironmentalScan.pdf

van den Berg, M., Wendel-Vos, W., van Poppel, M., Kemper, H., van Mechelen, W., & Maas, J. (2015). Health benefits of green spaces in the living environment: A systematic review of epidemiological studies. *Urban Forestry & Urban Greening*, *14*(4), 806–816. https://doi.org/10.1016/j.ufug.2015.07.008

Velarde, M. D., Fry, G., & Tveit, M. (2007). Health effects of viewing landscapes – Landscape types in environmental psychology. *Urban Forestry & Urban Greening*, *6*(4), 199–212. https://doi.org/10.1016/j.ufug.2007.07.001

Voelkel, J., & Shandas, V. (2017). Towards Systematic Prediction of Urban Heat Islands: Grounding Measurements, Assessing Modeling Techniques. *Climate*, *5*(2), 41. https://doi.org/10.3390/cli5020041

Watkins, S. L., & Gerrish, E. (2018). The relationship between urban forests and race: A meta-analysis. *Journal of Environmental Management*, *209*, 152–168. https://doi.org/10.1016/j.jenvman.2017.12.021

World Health Organization. (n.d.). *Social determinants of health*. Retrieved February 4, 2023, from https://www.who.int/health-topics/social-determinants-of-health

World Health Organization. (2006). *Constitution of the World Health Organization*. https://www.who.int/governance/eb/who_constitution_en.pdf

World Health Organization. (2009). *Global health risks: Mortality and burden of disease attributable to selected major risks*. https://www.who.int/publications/i/item/9789241563871

World Health Organization. (2011). *Closing the Gap: Policy into Practice on Social Determinants of Health*. https://www.who.int/publications/i/item/9789241502405

World Health Organization. (2014). *Social Determinants of Mental Health*. https://apps.who.int/iris/bitstream/handle/10665/112828/9789241506809_eng.pdf

World Health Organization. (2022a). *Global status report on physical activity 2022*. https://www.who.int/publications/i/item/9789240059153

World Health Organization. (2022b). *World mental health report: Transforming mental health for all*. https://www.who.int/publications/i/item/9789240049338

CHAPTER II

AN INTERWOVEN HISTORY OF LANDSCAPE ARCHITECTURE, URBAN PLANNING, AND PUBLIC HEALTH IN THE UNITED STATES

1. Introduction

The origins and histories of landscape architecture and urban planning in the United States are inextricably linked to public health. In the late 19th and early 20th century, park designers and sanitation officials sought to mitigate infectious disease through park planning and sanitation infrastructure. Overcrowding and unhealthy living conditions in America's inner city tenement housing gave rise to a push for social justice-oriented urban planning in the early 20th century; however, the urban planning movement was co-opted by a group of designers, planners, and engineers who favored middle-class and elite priorities, initiating slum clearance in the name of city beautification and contributing to cycles of systematic disinvestment followed by urban decay and urban renewal in predominantly Black/African American and low-income communities. As infectious disease epidemics became less prevalent with improved sanitation and medical advancement, chronic disease became the predominant public health concern in the mid-20th century. With this change came consensus that the prevalence of chronic disease and the associated risk factors were influenced by social, economic, and environmental conditions throughout an individual's life course. As such, systemic disparities in exposure to environmental harms and access to environmental benefits based on race and socioeconomic status were identified as environmental justice and healthy equity issues. Public health benefits associated with urban green space access (i.e., parks and vegetation in cities), as well as the equity of its distribution, have emerged as critical components of urban green space research, advocacy, design, and planning. However, the social and economic dynamics surrounding urban green space enhancement and expansion are complex and have led to unintended consequences such as green gentrification, underscoring the necessity for collaboration with public health professionals, affordable housing policy analysts, and social justice advocates, as well as the meaningful inclusion of marginalized communities in urban green space decision-making processes. To situate current trends in research and practice, this essay provides a historical account of connections between landscape architecture, urban planning, and public health in the United States and calls on landscape architects and urban green space planners to lead collaborative efforts to address health inequities associated with urban green space access.

2. Infectious Disease and Urban Landscapes: Origins of Urban Planning in the United States

2.1 Miasma, Sanitation, and Urban Parks

Public health was central to urban planning in the latter half of the 19th century, particularly with respect to sanitation. Two main theories for how disease was transmitted co-existed for centuries, dividing the medical field into contagionists and anti-contagionists (Ackerknecht, 2009). While the theory that disease was caused by contagious substances dates back to at least the 16th century (Nutton, 1990), miasma theory—which postulated that odorous and stagnant air resulting from decaying organic matter, poor drainage, and inadequate ventilation were the root cause of disease epidemics—pervaded as the predominant theory of disease transmission through much of the 19th century (Ackerknecht, 2009; Karamanou et al., 2012; Szczygiel & Hewitt, 2000). In an 1865 public health and hygiene report, New York City health inspectors used miasma theory to assert that environmental conditions were causally linked with public health (Carr, 2021).

> The pernicious influence of imperfect drainage and neglected or faulty sewerage, and the fatal poisons that are generated by accumulated sewage and putrefying organic materials are no longer merely matters of opinion, but…they stand related as direct causes of some of the most insidious, obstinate, and fatal diseases that afflict our city. (Citizens Association of New York, Council of Hygiene and Public Health, 1865, p. xcvi)

In some larger cities, including New York and Boston, underground stone or brick sewers were designed to convey stormwater, though most cities had no such drainage systems, and those that did were not designed for human waste disposal (Tarr et al., 1984). Instead, cesspools or privy vaults—either permeable and designed to absorb waste into the surrounding soil or impermeable, necessitating frequent waste removal—were used to dispose of human waste. Sanitation inspectors in New York City used anecdotes and statistics from England to “show how certainly and how speedily sanitary works are followed by a reduction of the death-rate and by an abeyance of fevers and infantile diseases” (Citizens Association of New York, Council of Hygiene and Public Health, 1865, p. cxvii), advocating for improved water supply and drainage, as well as elimination of cesspools in favor of in-home water closets (i.e., flush toilets). The recommendations, regulations, and infrastructural investments to address drainage, ventilation, and disposal of human waste were strongly tied to theoretical and observational connections between infectious disease prevalence and environmental conditions related to air, water, and soil (Carr, 2021).

Public health also played a critical role in the conception, design, and implementation of urban parks and park planning in the mid- to late-19th century. Prominent landscape architects and park designers framed the discourse on the importance of city parks using European urban park precedents, pastoral imagery, and concepts of environmental health.

> In the parks of London, you may imagine yourself in the depths of the country, with, apparently, its boundless space on all sides; its green turf, fresh air, and, at certain times of the day, almost its solitude and repose. And at other times, they are the healthful breathing zone of hundreds of thousands of citizens. (Downing et al., 1853, p. 485)

Andrew Jackson Downing, a landscape designer and writer, and Frederick Law Olmsted Sr., the famed American landscape architect, espoused the belief that picturesque nature in cities provided much needed fresh air, in addition to opportunities for rest and rejuvenation. With the iconic design of Central Park in 1857, Olmsted and co-designer Calvert Vaux set into motion the first American urban park movement—the “Pleasure Ground” era—characterized by large parks that simulated pastoral vistas akin to the countryside, intended to provide a respite from the chaos of urban life (Figure 2.1; Cranz, 2008). In *Trees in Streets and in Parks*, Olmsted argued that large pleasure ground parks provided subconscious, or contemplative, recreation in addition to the more active recreation benefits (1882), demonstrating his understanding of the potential physical and mental health benefits of urban parks (Eisenman, 2013). The Pleasure Ground park model was used for park designs in cities such as Boston, Philadelphia, Chicago, and San Francisco throughout the latter half of the 19th century (De Sousa, 2008).

Consistent with the perspectives in sanitation, Olmsted's urban design interventions were heavily influenced by miasma theory (Szczygiel & Hewitt, 2000). While miasma theory was later discredited in favor of germ theory (Karamanou et al., 2012), public health and sanitation professionals promoted urban parks as a means of improving air quality (Eisenman, 2013).

> The air was nearly everywhere perceptibly foul, and this to a degree often provocative, in time of epidemics, of a panicky disposition to flee the town. Where there were parks, they gave the highest assurance of safety, as well as a grateful sense of peculiarly fresh and pure air. (Olmsted, 1882, p. 589)

In large part due to his roles as general secretary and chief executive of the American Sanitary Commission during the Civil War, Olmsted advocated for urban landscape typologies that decreased stagnant water and air, such as low-density neighborhoods, large Pleasure Ground parks, and small parks connected by parkways with adequate tree cover (Fisher, 2010; Szczygiel & Hewitt, 2000). Olmsted's dedication to these urban landscape typologies was most apparent in his design of the Emerald Necklace in Boston, Massachusetts. Originally conceived in 1876, Olmsted spent the last two decades of the 19th century designing and constructing a system of parkways, canals, designed wetlands, small parks, and large pleasure parks that expanded and connected existing urban green space while simultaneously addressing noxious odors and health concerns associated with flooding from a combination of backed up raw sewage effluent, stormwater outflow, and tidal forces (Eisenman, 2013; Zube, 1995). The integration of ecological function into the planning of an organized, interconnected system of parks and parkways designed to address existing environmental health hazards made the Emerald Necklace a model for comprehensive and connected urban green space planning in the United States (O'Connell, 2016; Zube, 1995).

The connection between public health and urban green space planning was also evident in the design and development of Chicago's public park system. John Henry Rauch, a Chicago-based physician and sanitation superintendent, was, like his contemporary Frederick Law Olmsted Sr., a strong supporter of miasma theory and a leader of the public health movement (Szczygiel & Hewitt, 2000). Rauch used observation and measurements of atmospheric conditions in relation to disease and death statistics to advocate for the removal of the city's urban cemetery and the expansion of Chicago's public parks, which he argued were critical to public health. He correlated decreased mortality and improved public health with the successful addition of 2,500 acres of well-drained parkland and the planting of over one million trees. Although Rauch was not a landscape architect or designer, his advocacy for the health benefits of urban parks influenced the development and expansion of Chicago's urban parks system, underscoring the role that medical and public health professionals played in the establishment of urban green space planning.

While the early urban park and sanitation movements have been characterized by their pursuit of improved public health, these efforts were used for social control in service of middle-class values and worldviews (Taylor, 1999). Many health concerns were specifically associated with tenement housing conditions where ventilation, human waste disposal, and crowding were connected to the prevalence of disease (Carr, 2021; Citizens Association of New York, Council of Hygiene and Public Health, 1865). Although disease was thought to be caused by environmental conditions, health and sanitation officials framed the perceived social and moral ills of the immigrant and working class as critical to the spread of disease. "The worst personal causes of fatal disease not infrequently result from faulty external conditions, and they are at the same time so intimately associated with the worst moral evils and social misfortunes of the laboring classes" (Citizens Association of New York, Council of Hygiene and Public Health, 1865, p. xlix). This perspective attributed similar weight to social and environmental factors in explaining the prevalence and spread of diseases in tenement housing, thus linking health to the elite and middle-class moral ideals.

Many of the park designers advocated for park development, not solely for their health benefits, but to improve the social conditions of the working class. Though Olmsted believed in the restorative benefits of parks and advocated for their universal access, he described the potential of parks to elevate the poor and facilitate interactions between the working and middle class; in practice, however, parks were used as a means of social control (Taylor, 1999). Central Park, for example, was accessible to all classes of people, but undesirable behaviors, as determined by the middle class—from walking on the grass, picking flowers, and annoying birds to using profane language and offering items for sale—were regulated and punished through extensive monitoring and supervision. Downing also espoused the belief that parks could improve the moral character of the working class.

> The higher social and artistic elements of every man's nature lie dormant within him, and every laborer is a possible gentleman, not by the possession of money or fine clothes—but through the refining influence of intellectual and moral culture.... Plant spacious parks in your cities, and unloose their gates as wide as the gates of morning to the whole people. As there are no dark places at noon day, so education and culture—the true sunshine of the soul—will banish the plague spots of democracy. (Downing et al., 1853, p. 152)

These views demonstrate a paternalistic attitude towards urban planning, whereby those charged with planning and design for public health implicated the high prevalence of disease in tenements on the social and moral character of the working class and used parks as a form of social control to assimilate the working class to the upper- and middle-class values and morals (Carr, 2021; Taylor, 1999).

Although the early urban park movements have been heralded for their efforts to address public health through urban landscape design and planning, some park development led to displacement of already marginalized communities. Prior to becoming Central Park, the land on which the park now sits was home to a predominantly African American community called Seneca Village, established in 1825 (Carr, 2021; Meyerson, 1997; The Central Park Conservancy, 2018). By the 1850s, Seneca Village had over 250 residents, fifty homes, several churches, a school, and a cemetery (Meyerson, 1997; The Central Park Conservancy, 2018). Although many accounts portrayed the residents as squatters, Census and voting records confirmed that many residents owned property. In 1853, the land for Central Park was formally acquired by New York City through eminent domain, and while property owners were compensated, all residents were forced to relocate. This anecdote provides evidence that, even in the 19th century, private property was being appropriated from marginalized communities for the "public good", foreshadowing the policies and actions related to urban blight and urban renewal in the 20th century.

2.2 Social Justice versus City Beautiful: The Battle for Systematic Urban Planning

The character of American cities changed irrevocably throughout the latter half of the 19th and early 20th century, and this transition played an essential role in the rise of systematic urban planning. In the early 19th century, cities—except for the largest—were ethnically homogenous, and neighborhoods generally supported a diversity of economic classes (Dunn & Golding, 1978). However, following the Civil War, urban industrialization, agricultural mechanization, and the introduction of electric street cars fundamentally altered urban demographics with a massive influx of rural and foreign-born immigrant laborers to American cities. The addition of electric cars and commuter rails made it possible for cities to expand geographically, requiring the extension of municipal services and increasing demand for manufacturing, which in turn brought more people to cities seeking employment. The total urban population in the United States exploded from 6.2 million, and under 20 percent of the nation's population, in 1860 to over 30 million by the turn of the century (U.S. Census Bureau, 1993). By 1920, the urban population in the United States had grown to 54.3 million, exceeding the nation's rural population for the first time (Chudacoff, 1975; U.S. Census Bureau, 1993).

Although this period of rapid urban development lacked central organization, a distinct urban form emerged organically. In the absence of a top-down planning system, the extension of water and sewage services was constructed piecemeal, on an individual project basis (Peterson, 2009). City centers became large commercial and industrial manufacturing hubs, and housing became increasingly segregated by class and race (Dunn & Golding, 1978). More affluent residents, who had previously inhabited the city centers, fled to lower-density residential "suburbs" as unskilled laborers and immigrants poured into housing in the urban core, prompting the conversion of single-family residences to cramped multi-family tenements (Dunn & Golding, 1978; Peterson, 2009).

Squalid and insalubrious tenement housing conditions prompted a wave of expository research and social activism, which provided the momentum necessary to initiate discussions around socially just city planning. Influential work such as Jacob Riis' *How the Other Half Lives* (1890), Florence Kelley's *Hull House Maps and Papers* (1895), and the findings from the 1907-1908 Pittsburg Survey (1909) exposed the congested and unhealthy living conditions in high density immigrant and factory worker housing. The direct link between tenement housing and the spread of disease prompted public health concerns related to overcrowding, ventilation, heating, lighting, plumbing, and drainage (Garb, 2003). The diligent documentation of urban tenement housing conditions demonstrated the potential value of city planning to public health, particularly for the working poor (Greenberg et al., 1994; Peterson, 2009).

The health issues associated with overcrowded inner-city living and working conditions prompted Kelley, with the help of Mary K. Simkhovitch, to establish the Committee on Congestion of Population in 1907 in New York City, an act that would be central to the foundation of organized city planning in the United States (Peterson, 2009; Sies et al., 1996). The Committee on Congestion of Population brought on Benjamin C. Marsh to lead an exhibition on tenement overcrowding in 1908, where he pushed for an organized city planning agenda to facilitate better housing and health conditions, urging New York City to adopt districting (i.e., zoning), enforce factory siting regulations, and increase park space (Peterson, 2009). The overwhelming success of the exhibition led Marsh to plan the first National Conference on City Planning and the Problems of Congestion, held the following year in Washington D.C (Figure 2.1). This conference brought to the fore an ideological divide between the Committee on Congestion of Population's city planning agenda and the more mainstream vision for urbanization proposed by the City Beautiful Movement, which emphasized the priorities of the middle- and upper-class reformers.

The City Beautiful Movement had gained significant traction as a path towards achieving centralized urban planning in the 15 years preceding the first nationwide city planning conference. The movement was unveiled in Chicago at the World's Columbian Exposition in 1893 and displayed the potential for a city to achieve beautification and eradication of social ills through civic art placemaking (Peterson, 2009). Charles Mulford Robinson's book, *The Improvement of Towns and Cities* (1901), provided a city planning handbook for urban beautification, furthering the legitimacy of the City Beautiful Movement. The McMillan Plan for Washington D.C., finalized in 1902, marked the first implementation of the City Beautiful Movement ideals, aside from the 1893 World's Columbian Exposition, and included a comprehensive plan for parks, playgrounds, and parkways; transit and sanitation improvements; and the architectural redesign of the city's public monuments (Peterson, 2009). In the five years prior to the 1909 conference, 38 other city beautification plans were generated by Robinson, as well as a select group of architects and landscape architects, promoting the comprehensive planning approach exemplified by the McMillan Plan (Peterson, 2009).

The first National Conference on City Planning and the Problems of Congestion in 1909 served as a platform for advocates of the City Beautiful Movement's mainstream, physical-oriented approach who sought to improve efficiency, livability, and attractiveness of cities through urban planning (Peterson, 2009). At the conference, Frederick Law Olmsted, Jr.—a well-connected landscape architect who had been involved in park redesigns for the World's Columbian Exposition in Chicago, worked as Park Improvement Commissioner on the McMillan Plan, and generated numerous city beautification reports—proposed a second conference for the following year with representation from national associations of civil engineers, architects, and landscape architects, among other civic-oriented associations. Olmsted intended for the second conference to be centered around the development of city planning as a discipline, not just social reform (Figure 2.1). At the second national planning conference in 1910, Olmsted advocated for the convergence of numerous longstanding professions within city planning to form a single urban planning profession, marking the beginning of American city planning as a unified field. In the proceeding decades, the newly established urban planning profession moved away from landscape architecture, prioritizing regulation and zoning to create separation between residential and industrial land uses as a means of protecting public health (Frank, 2003).

In many ways, the foundation of urban planning and its connection to public health were established in the latter half of the 19th century by landscape architects concerned about water drainage and air quality. Although Marsh's mission for socially just urban housing reform was superseded by the coordinated agenda of the City Beautiful Movement, the social reform movement furthered the call for comprehensive urban planning with public health as a driving force. The work of Olmsted Jr. and the City Beautiful Movement leaders cemented urban planning as an independent field, leading to its divergence from landscape architecture in the decades that followed (Boults & Sullivan, 2010).

2.3 The Reform Park and Recreation Facility Eras

While the park designers of the Pleasure Ground era were enamored with the curative and restorative potential of urban parks, parks reformers began to push for increased park accessibility and active recreation opportunities, particularly in the form of playgrounds, around the turn of the century. The large pleasure ground parks of the late 19th century were located on the fringes of cities and were largely inaccessible to the working class (Figure 2.1; Cranz, 1982, 2008; Cranz & Boland, 2004). In the early 20th century, small parks were developed in immigrant and working-class neighborhoods to expand park access and provide safe play spaces for children. In his 1917 book, *The Play Movement and Its Significance*, Henry Curtis advocated for the provision of parks, specifically in low-income neighborhoods.

> There are few things that are more essential in tenement sections at present. The little children cannot go on the tenement streets with safety…. It is essential to their health that they should get much open air and exercise, and there is no way that this can be done, except by furnishing them a place within the block itself. (Curtis, 1917, p. 133)

These efforts were part of a larger movement to promote children's health through improved park and playground access. Legislation was passed in the state of Massachusetts in 1908, mandating that cities meet a specific ratio of public playgrounds per capita to promote public health, and the Health Department in Philadelphia suggested locating parks and playgrounds proximally to public schools to boost usage (Carr, 2021). As philosophies of park design and park system planning transitioned from the Pleasure Ground to the Reform Park era (Cranz, 1982), public health remained a central tenet, though the target demographic shifted from predominantly middle-class adults to immigrant and working-class children (Carr, 2021; Taylor, 1999).

From the Great Depression up until the 1960s, parks were envisioned as utilitarian spaces for recreation and oriented towards active recreation facilities such as basketball, baseball, tennis, and swimming, and new parks were constructed to provide recreational amenities for urban and suburban areas that had limited access (Cranz, 1982, 2008; Cranz & Boland, 2004). The functional, economic-oriented park planners ushered in a period of formulaic park design, typified by the installation of hard, multi-use surfaces and the removal of previously planted areas as a means of reducing maintenance and increasing useable space (Cranz, 1982). Although urban parks developed in the early to mid-20th century exemplified the philosophy that parks provided opportunities to increase leisure time recreation, the ties that bound park design and urban planning to public health had dissolved (Carr, 2021; Cranz & Boland, 2004), and their reconnection would not really reappear until the environmental movement of the 1960s.

3. Environmentalism, Racially Motivated Urban Planning, and the Rise of Chronic Disease

3.1 Environmental Movement: Ecological Approaches in Landscape Architecture and Planning

Mainstream city planning turned away from public health in favor of urban housing regulation, economic development, and suburban real estate expansion in the mid-20th century (Corburn, 2004; Laurence, 2006). While many well-known landscape architects were designing modernist private residential and commercial landscapes (Boults & Sullivan, 2010), a select group of environmentalists, landscape architects, and regional planners argued for using ecological approaches to address issues of environmental and human health. Although Patrick Geddes stressed the importance of studying the interrelationship between human activity and the regional landscape in the early 20th century and was influential in the formation of the Regional Planning Association of America in 1923, Lewis Mumford and Benton MacKaye were crucial to the inclusion of ecological thinking in regional planning (Steiner et al., 1988; Steinitz, 2008).

> Regional planning is ecology. It is *human ecology*; its concern is the relation of the human organism to its environment. The region is the unit of environment. Planning is the charting of activity therein affecting the good of the human organism; its object is the application or putting into practice of the optimum relation between the human and the region. Regional planning in short is applied human ecology. (Mackaye, 1940, p. 68)

MacKaye argued that humans are interdependent components of ecological communities that include abiotic and biotic factors (Carson, 1962; Leopold, 1949; Mackaye, 1940; McHarg & Steiner, 2014). This ecological perspective of regional planning, in conjunction with Rachel Carson's *Silent Spring* (1962) which exposed the ecological and environmental health consequences associated with pesticide use, helped bring about critical environmental regulations including the National Environmental Policy Act (1969) and the Clean Water Act (1972) and highlighted the need for planning decisions to reflect relationships and interactions between human health and their local and regional landscapes.

Ian McHarg, a prominent landscape architect, took the line of inquiry further, advocating for a new, ecology-oriented approach to urban landscape design and planning. He argued that cities of the 19th and 20th century were detrimental to human health and that their impact on human health, as well as natural cycles of soil, atmosphere, water, and climate, created utterly inhumane environments (John-Alder, 2014; McHarg & Steiner, 2014).

> The epidemiologist speaks of neuroses, lung cancer, heart and renal disease, ulcers, the stress diseases, as the badges of urban conditions. There has also arisen the specter of the effects of density and social pressure upon the incidence of disease and upon reproduction. The modern city contains other life-inhibiting aspects whose effects are present but which are difficult to measure: disorder, squalor, ugliness, noise. (McHarg & Steiner, 2014, p. 102)

The ability for the human species to create its own environment is not a uniquely human quality, but McHarg questioned whether it could be done in a way that supported human habitation perpetually (McHarg & Steiner, 2014). Recognizing the connections between human health, urbanization, and environmental quality, McHarg developed an ecological method for landscape analysis and design that, he argued, could be scaled to urban site design or to an entire region (McHarg, 2014). In his essay "An Ecological Method for Landscape Architecture" (1967) and his book, *Design with Nature* (1969), McHarg presented an analytical approach that established rules and strategies for planning and design that were responsive to the numerous environmental and societal "layers" of the local and regional landscape (Gazvoda, 2002; McHarg, 2014; Steinitz, 2008). McHarg's map-overlay approach to identify opportunities for development while preserving critical natural ecology is still commonplace in comprehensive urban planning, landscape architecture, and design practice (Ahern, 2003; Herrington, 2010; Hundt & Daniels, 2018; Steiner, 2008). While McHarg drew connections between health and urban environments and created a method for designing and planning within complex socioecological systems, neither he nor the other environmental thinkers of the mid-20th century considered how policy and planning decisions contributed to social and cultural disparities in health outcomes (Carr, 2021).

3.2 Urban Blight and Urban Renewal

Even as environmentalists and landscape architects were identifying associations between health and environment, urban planning and public health professions were complicit in exacerbating unhealthy living conditions, particularly for Black/African American and low-income communities, through segregation and systematic disinvestment followed by cycles of urban decay, declaration of urban blight, and urban renewal. A massive demographic shift took place throughout the 20th century, and by 1980, between four- and eight-million southern Black/African Americans had emigrated from states in the American south to cities in the north and west (Leibbrand et al., 2020; Tolnay, 2003). Throughout this period of intense internal migration, a series of well documented efforts were made—namely, racially-motivated comprehensive zoning, discriminatory lending practices, racial steering by real estate brokers, and racially restrictive housing covenants—to physically, socially, and economically isolate Black/African American communities (Leibbrand et al., 2020; Massey, 1993; Shertzer et al., 2022; Silver, 1997). Starting in the 1930s, redlining (i.e., the racially discriminatory practice of denying loans based on location) and the mass movement of White urbanites to the suburbs led to decreased property value, home vacancies, and systematic disinvestment in predominantly Black/African American communities (Duncan et al., 1975). This pattern of disinvestment made it exceedingly difficult for African Americans to obtain mortgages and discouraged investment in property maintenance or improvements. Although the process leading to what would become known as urban blight, and the urban renewal that followed, was impacted by numerous phenomena, the systematic segregation and disinvestment in predominantly Black/African American communities, as well as policies and practices that encouraged a White exodus from urban areas to the suburbs, likely played a significant role in the decline of urban neighborhood and housing conditions (Carr, 2021).

Disease metaphors (e.g., “blight”, “cancer”, and “contagion”) were used to describe the proliferation of deteriorating housing stock and property abandonment, and the fear of its spread—

primarily to White and middle-class suburbs—led to government action that initiated a process of urban renewal (Carr, 2021; Lopez, 2009). “Rather than fighting the causes of the urban crisis, it instead treated the symptoms with twinned strategies of quarantine and elimination” (Carr, 2021, p. 121). Federal loans and grants were offered to cities to clear slums and blighted areas, invest in comprehensive development projects, and provide housing for displaced families through the passage of the Housing Act of 1949 and 1954 (Lang & Sohmer, 2000; Lopez, 2009; McGraw, 1955). The federally funded urban renewal projects involved a coordinated effort between various professions associated with urban housing and development, including planners and public health officials (Lopez, 2009). The 1954 Housing Act mandated the reporting of blight conditions prior to redevelopment, and many cities deployed public health officials to conduct inspections of buildings and neighborhoods, tasked with documenting the existence and delineating the extent of blighted areas. To support this process, the American Public Health Association published guidelines for identifying blighted neighborhoods, lending scientific credibility to a subjective and ambiguous term. Cities then used eminent domain to seize properties for urban renewal projects, displacing and disbanding communities to build new hospitals, interstate highways, and luxury apartments. As of 1962, approximately 80% of those who were displaced were Black/African American, and by 1972, over four million people had been displaced due to urban renewal projects. With a shortage of low-income housing, federal legislation mandated housing replacement; however, less than one percent of all federal urban renewal spending was used for relocation services, and urban renewal only heightened the housing shortage (Lopez, 2009).

The built, natural, social, and economic environments have been identified as important determinants of health (Corburn, 2012; World Health Organization, 2010), and residential segregation, displacement, and urban blight have all been linked to negative health outcomes (de Leon & Schilling, 2017; Gao et al., 2022; Gibbons et al., 2020; Lim et al., 2017). A recent article found that, across nine cities, historically redlined areas had the lowest median household income and highest proportions of people of color, and significant correlations were observed between patterns of historic redlining and mental health, rates of cancer, and rates of health insurance (Nardone et al., 2020). Redlining and urban renewal, as well as those who participated in the processes, contributed to health inequities through the racist policies and actions that prompted increased segregation, urban decay, and displacement of millions of Black/African American and low-income citizens. There is an opportunity for planning and public health professions to learn from the policy, actions, and planning decisions that led to inequitable urban environmental health conditions and work with, and on behalf of, marginalized communities to address existing health inequities specifically related to the built environment.

3.3 Social Determinants of Chronic Disease and Mental Health

Following World War II, mortality from infectious diseases was surpassed by mortality of a more insidious form: chronic disease (Susser & Susser, 1996). As chronic diseases (e.g., cancer, cardiovascular disease, and diabetes) are non-communicable and are not transmitted by a pathogenic agent, epidemiologists were confronted by a suite of deadly diseases with no clear origin or means of eradication. Chronic diseases have been attributed to multiple causes including but not limited to genetics, lifestyle, socioeconomic status, discrimination, and environmental conditions (Cockerham et al., 2017). Chronic stress has been identified as a causal factor for chronic disease at the cellular level through a neuroimmune cascade whereby chemical changes in the nervous system generate an immune system response that produces chronic, low-grade inflammation (Mariotti, 2015). "The bulk of the global burden of disease and the major causes of health inequities, which are found in all countries, arise from the conditions in which people are born, grow, live, work, and age." (World Health Organization, 2011, p. 2). The strategies to address chronic disease require a departure from the approach used to control infectious diseases, necessitating consideration for the web of causal factors, termed social determinants of health. This socioecological model of relationships between chronic disease and environment—which includes the physical, social, cultural, and political context—provides a structure for characterizing, contextualizing, and addressing health inequities (Carr, 2021). The diffuse, attritional, and multi-causal nature of chronic disease suggests the need for an interdisciplinary and collaborative approach to minimize chronic disease risk factors and mitigate disparities in health outcomes.

Like chronic disease, mental health outcomes have been associated with physical, social, and economic environments. Mental health, as defined by the World Health Organization, is "a state of mental well-being that enables people to cope with the stresses of life, to realize their abilities, to learn well and work well, and to contribute to their communities" (World Health Organization, 2022, p. 8). Stressors experienced through the course of life may be accumulative and can affect mental health from the prenatal period through old age (Allen et al., 2014). Mental health is also shaped by community-level built/natural environments and healthcare settings, as well as national-scale social, political, environmental, and economic conditions (World Health Organization, 2014). Income, educational attainment, employment status, and gender have all been associated with prevalence of mental disorders (Allen et al., 2014), and structural or systematic disparities in access to healthcare, food, financial and educational resources, or political power have been identified as mechanisms that exacerbate mental health inequities (Compton & Shim, 2015). Working to address community-level disparities in chronic disease and mental health outcomes requires a fundamentally different approach from that of the sanitation era, and coordination between communities, organizations, and agencies at the local, state, and federal level is needed to identify policy and action that meaningfully improve health outcomes for marginalized communities.

3.4 Evolving Urban-"ism" Theories: Attempting to Address Environmental and Health Challenges

Although mainstream urban planning and landscape design practice shifted away from public health in the middle of the 20th century, the fields continued to evolve both in theory and practice, developing new approaches to address the negative consequences of an increasingly urbanized and suburbanized world. The urban sprawl that arose out of intentional zoning, land use regulation, and transportation investment had unintended impacts on human and environmental health (Frank & Kavage, 2008). First conceived in the 1980s, New Urbanism sought to address issues associated with urban sprawl by developing a set of principles and form-based recommendations to guide urban planning and design at scales ranging from regional to municipal, neighborhood to block, and street to building, focusing on development of compact, walkable, and transit-oriented neighborhoods and cities (*The Charter of the*

New Urbanism, 2015). The driving force behind the New Urbanist agenda was a desire to eradicate the need for automobiles (Carr, 2021). While New Urbanism has been lauded for its positive impact on public health by increasing opportunities for physical activity, reducing air pollution and traffic accidents, and improving health resource access (Iravani & Rao, 2020), urban planners contend that the pattern-based approach pushes a generalized solution without in-depth understanding of the people or place, and ecological designers argue that New Urbanism has historically been antithetical to urban design that seeks to bring nature's benefits into the city (Southworth, 2003).

> Although recognizing that the physical properties of sprawl are responsible for health, environmental, and civic crises, New Urbanists simultaneously offered a prescription for said crises while claiming to be 'only' architects and planners, therefore having plausible deniability for socioeconomic context, or effects of their work (Carr, 2021, p. 138)

New Urbanism goes beyond plausible deniability when it comes to socioeconomic context; New Urbanist founders, Andres Duany and Elizabeth Plater-Zyberk, explicitly state in their book, *Suburban Nation*, that fighting gentrification stymies revitalization projects (Duany et al., 2000). Reflecting on the social determinants of health framework and the health disparities that arose from urban renewal, New Urbanism projects failed to consider the connections between social, cultural, and environmental systems in the pursuit of a specific urban form to address sprawl.

Several theoretical approaches have responded to New Urbanism, arguing that local ecological conditions are essential to resilient and forward-looking urban landscape design. Landscape urbanism—championed by Charles Waldheim and James Corner—offered an alternative approach to conventional urban planning whereby urban landscapes are seen as dynamic and interconnected systems that include natural, cultural, political, and economic forces (Corner, 2006; Steiner, 2011; Waldheim, 2006a, 2006b). "The basic premise of landscape urbanism holds that landscape should be the fundamental building block for city design" (Steiner, 2011, p. 333). While in theory, landscape urbanism offers a compelling approach to urban design, the actual design process is difficult to define and few practical examples have been implemented (Steiner, 2008, 2011). The most influential landscape urbanism projects include James Corner's Field Operation designs of Fresh Kills and The High Line, which take complex, abandoned urban sites and adapt the designs to the underlying built and natural conditions to produce urban recreational and environmental amenities (Steiner, 2008, 2011). After its completion however, The High Line spurred a rapid increase in rent prices, putting strain on residents and businesses alike (Carr, 2021). Like landscape urbanism, ecological urbanism calls for a new approach to urban planning that innovates in the face of historic urban growth and environmental degradation, necessitating "a form of ecological design practice that does not simply take account of the fragility of the ecosystem and the limits on resources but considers such conditions the essential basis for a new form of creative imagining" (Mostafavi, 2010, p. 22). Although concepts of social and environmental justice are mentioned or discussed briefly in relation to ecological urbanism (e.g., Cohen, 2016; Fainstein, 2016; Whiston Spirn, 2012), the many examples of ecological urbanism applications presented in *Ecological Urbanism* suggest that environmental issues are of greater concern than issues of equity (Mostafavi et al., 2016). While the suite of urbanism theories proposed by planners, architects, and landscape architects have worked to address environmental and health-related challenges of an increasingly urbanized world, they largely overlook social and economic context, particularly how projects influence marginalized communities.

4. Towards Health Equity: The Role of Landscape Architecture and Urban Green Space Planning

4.1 Reconnecting Landscape Architecture, Urban Planning, and Public Health in the 21st Century

> In an era where the primary causes of mortality are from chronic, environmentally influenced illnesses…the relationships between the landscapes we inhabit, our society, and our bodies is of renewed interest to the fields of public health, design, and planning. (Carr, 2021, p. 1)

The World Health Organization defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organization, 2006, p. 1), and in the last several decades, landscape architecture and urban planning have returned to the concept of health to frame both research and practice. The establishment of the Healthy Cities and Healthy People initiatives in the late 1970s and 1980s formally recognized—at the national and international level—that physical, social, and economic environments impact physical and mental health outcomes (Tsouros, 1992;

United States Department of Health, Education, and Welfare, 1979). Physical inactivity and mental well-being have been identified as critical health challenges, and their relationships to the built environment have been central to scholarship at the cross-section of health, planning, and design in the last few decades.

Physical activity is an integral part of human health. Physical inactivity was the fourth leading risk for premature death worldwide and was considered a significant risk factor for cardiovascular disease, diabetes, and some cancers (World Health Organization, 2009). Additionally, physical inactivity has been linked to symptoms of depression and anxiety (Kandola et al., 2019; Kandola & Stubbs, 2020). With 25% of the adult population in the United States considered physically inactive (Center for Disease Control, 2022), a substantial body of research has been devoted to understanding associations between physical activity and characteristics of the built environment. Transportation and urban planning researchers have identified a suite of built environment variables that influence travel behavior (e.g., walking, bicycling, public transit, or personal vehicle), including an area's residential and commercial density, land use diversity, right-of-way design characteristics, street connectivity, distance to public transit, and destination accessibility (Ewing & Cervero, 2010). Many studies have identified associations between the built environment and physical activity, and a meta-analysis of the travel behavior literature revealed that walking was associated with the density of road intersections, the distance to the nearest store, and the jobs to housing ratio (Cao et al., 2009). These combined findings have informed urban planning strategies that seek to reduce vehicular dependence and promote non-motorized travel options such as walking and bicycling. Investigating relationships between physical activity and urban green space access, researchers have identified positive associations between physical activity outcomes and the amount of park area, number of parks, and specific park amenities (e.g., basketball courts and trails) accessible to residents (Astell-Burt et al., 2013; Coombes et al., 2010; Giles-Corti et al., 2005; Jones et al., 2009; Kaczynski, Besenyi, et al., 2014; Kaczynski et al., 2008; Mytton et al., 2012). Additionally, park-based physical activity has been tied to density of road intersections, whereby residents in areas with higher street connectivity were more likely to participate in park-based physical activity than those with low street connectivity (Kaczynski, Koohsari, et al., 2014). These findings provide direction for urban design and planning intended to maximize residents' opportunities to engage in physical activity.

Mental health has also been a central focus for researchers investigating relationships between health and the built environment. In 2021, researchers estimated that over 600 million people were living with major depressive or anxiety disorders, representing almost 8% of the global population (Santomauro et al., 2021). Much of the research on relationships between built environmental and mental well-being has focused on access and exposure to urban green space. These studies have found that various aspects of urban green space access and exposure (i.e., park access, park use, and local vegetation cover) have been associated with increased attention, positive emotional states (e.g., happiness, relaxation, serenity), and psychological well-being, as well as decreased negative feelings (e.g., stress, tension, anger, and depression) and mood disorders (Aspinall et al., 2015; Beyer et al., 2014; Bratman et al., 2012; Hartig et al., 2003; Lee, 2017; Maas et al., 2009; Nutsford et al., 2013; Roe, 2013; Velarde et al., 2007; White et al., 2017). These urban green space studies reveal potential opportunities for urban planning and design to support residents' mental well-being.

The health benefits associated with urban green space have been used frequently to obtain support for parks. As early as the mid-19th century, Rauch and Olmsted promoted green space development, citing the public health benefits as a primary factor. Today, health is presented as a critical benefit of urban green space. The Trust for Public Land—an American non-profit that advocates to transition urban and rural land to parks, greenways, and protected areas— published "The Health Benefits of Parks", describing how parks and greenways increase opportunities for physical activity and reduce air pollution, air temperature, and greenhouse gas emissions (Gies, 2018). Cities, counties, and non-profits frequently reference the health benefits of green space as a rationale for park programs, maintenance, and development (e.g., City of Eugene, 2018; Portland Parks & Recreation, 2017, 2020; San Francisco Recreation & Parks, 2021; Seattle Parks & Recreation, 2021; The Trust for Public Land, 2006). Additionally, agencies seeking to expand green space systems have conducted quantitative analyses to estimate increases in health-related benefits associated with their project or plan. For example, in a report commissioned by the East Coast Greenway Alliance, Alta Planning and Design calculated that a proposed greenway, which would connect six cities and towns, five universities, five major trail networks, and 27 parks in the Research Triangle area of North Carolina, USA, would increase physical activity by an estimated 3.6 million hours per year, reduce carbon dioxide emissions by 1.1 million tons, and save $1.5 million in annual health care costs (Alta Planning and Design, 2017a). While generalized language and estimates of urban green space health benefits have been supported by existing research and can be calculated using various tools (e.g., i-Tree and InVEST), there is a dearth of research that assesses whether the health benefits from new urban green space projects are realized, and if so, to whom the benefits are distributed.

While urban green spaces have been associated with numerous health benefits, they can also create unintended social, environmental, and health consequences. Parks or natural areas that are not well managed or well lit, lack user presence, or create opportunities for concealment may be perceived as unsafe and increase fear of crime, particularly among women (Jorgensen et al., 2013; Koskela & Pain, 2000; Lyytimäki & Sipilä, 2009). Additionally, increased nutrient runoff and invasive plant species proliferation have been identified as potential ecological challenges associated with urban green space management (Escobedo et al., 2011; Štajerová et al., 2017), and many common urban ornamental tree genera (e.g., *Quercus, Platus, Pinus, Acer, and Tilia*) produce pollen, increasing urban allergen emissions and negatively impacting lung function in people with asthma (Cariñanos et al., 2017; D'Amato, 2002). As Black/African American and Puerto Rican children under the age of 18 experienced significantly higher rates of asthma than White children (Center for Disease Control, 2007), the presence of urban trees, particularly those that produce high quantities of pollen, have potential health consequences that affect certain communities at higher rates than others.

Attention to plant selection and park design are important considerations for urban green space designers and planners; perhaps more critical, however, is that increasing the quantity or improving the quality of urban green space may initiate a process of green gentrification (Gould & Lewis, 2012). Similar to the process of urban renewal, "by simultaneously making older and typically low-income and/or industrial areas of existing cities more livable and attractive, urban greening projects can set off rounds of gentrification, dramatically altering housing opportunities and the commercial/retail infrastructure that supports lower income communities" (Wolch et al., 2014, p. 239). Park development projects and street tree planting have been associated with increases in property value, changing the socioeconomic makeup of the community and forcing those who can no longer afford to live in the area to move (Checker, 2011; Cole et al., 2017; Donovan et al., 2021; Gould & Lewis, 2012; Wolch et al., 2014). These findings demonstrate the need for careful consideration of existing socioeconomic context and potential displacement repercussions when designing and planning urban green space expansion or enhancement. The consequences associated with green gentrification warrant multi-agency collaboration to ensure residents, particularly those from marginalized communities, are not displaced or negatively impacted by urban greening efforts.

4.2 Health Equity and Environmental Justice

The environmental justice movement reoriented environmentalism towards recognizing and addressing systemic environmental health inequities based on race and income. As stated in the Constitution of the World Health Organization, "the enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, religion, political belief, economic or social condition" (World Health Organization, 2006, p. 1). This mirrors the definition of health equity proposed by Jennings et al. (2019): "health equity involves the vision that all people have the same opportunity to achieve optimal health" (p. 58). Although health inequities have existed in the United States for as long as health data have been reported (National Center for Health Statistics, 2016), the concept that disparities in health outcomes exist along racial and socioeconomic lines was first recognized by the United States government in 1985 (U.S. Department of Health and Human Services, 1985). It has been widely acknowledged that these health inequities are at least in part due to race- and income-based differences in environmental conditions (Bullard, 1983, 1990; Payne-Sturges & Gee, 2006).

The environmental justice movement originated as a response to overt environmental health inequities and sought to bring attention to disparities in environmental health hazard exposures that were disproportionately affecting communities of color and low-income communities. Momentum for the environmental justice movement was generated through the activism and legislative progress of the civil rights movement (United States Environmental Protection Agency, 2022). Though ultimately unsuccessful in its effort to stop the construction of a toxic waste disposal site in a predominantly Black/African American community, the 1982 sit-in protest in Warren County, North Carolina, USA was a seminal moment for the environmental justice movement, beginning a wave of research and activism that documented and exposed the systemic pattern of toxic disposal sites located disproportionately in predominantly Black/African American and low-income communities.

With growing evidence that environmental conditions could provide health benefits in addition to posing health risks, the environmental justice definition was broadened from the singular focus of addressing disparities in exposure to environmental burdens to include a second priority: ensuring equitable access to environmental benefits such as urban green space (Jennings et al., 2019). Numerous studies have identified disparities in urban green space access based on race/ethnicity and income. In a review of 49 urban park equity studies, Dr. Alessandro Rigolon documented varying degrees of race- and income-based inequities based on park availability, park quality, and park safety (Rigolon, 2016). Additionally, recent reviews of the urban forest literature identified significant disparities in urban tree canopy cover based on income and race, although outcomes varied by study area (Gerrish & Watkins, 2018; Watkins & Gerrish, 2018). These findings not only expose environmental injustices related to urban green space benefits but also identify multiple urban green space measures that should be considered when investigating potential environmental justice issues.

Environmental justice extends beyond the considerations of how and to whom environmental amenities and burdens are distributed (i.e., distributional justice) and encompasses inclusive decision-making processes (i.e., procedural/participatory justice) as well as the allocation of environmental amenities specific to marginalized communities' cultural values (i.e., interactional/recognition justice;

Jennings et al., 2019; Kronenberg et al., 2020). The environmental justice framework provides direction and structure for communities, organizations, and governmental agencies seeking to leverage resources to address systemic environmental injustices. In the context of urban green space planning, environmental justice encompasses much more than simply adding parks, enhancing existing parks, or planting trees in areas where distributional injustices have been identified. City-scale urban green space planning agendas should consider promoting distributional, procedural, and interactional justice simultaneously. Passive representation—that is, having representation of marginalized communities at least equal to the population—at all levels of decision-making, particularly in upper management, has been identified as an important factor in generating inclusive, socially equitable policy and action (Riccucci & Van Ryzin, 2017). Long-term, socially inclusive planning approaches inform, involve, and empower marginalized communities throughout project analysis, design, implementation, and management phases (Fors et al., 2021). Furthermore, inclusive participatory processes involve continuous evaluation to identify successes and failures, and each community may require adaptation of engagement approaches to limit barriers to involvement. Providing equitable access to urban green space that responds to a marginalized community's social, cultural, and recreational needs requires a comprehensive evaluation of distributional justice, an institutional commitment to internal representation and inclusion, and a design and planning process that meaningfully involves and responds to the lived experiences of community members.

4.3 Pursuing Health Equity: A Call to Landscape Architecture and Urban Planning

> Twenty-first-century healthful planning will require critical analyses and experimental interventions that continually ask what constitutes a healthy place; how this changes over time and varies across neighborhood, city, and region; and what strategies can address the multiple and overlapping material and social forces that continue to perpetuate urban health inequities? (Corburn, 2012, p. 410)

Building towards environmental justice and health equity in urban landscapes necessitates collaboration between landscape architects, urban planners, and public health professionals. In a 2005 editorial, Howard Frumkin—a prominent doctor and public health researcher—identified food, housing, transportation, urban green space, and unsanitary living conditions as critical areas for addressing health equity in the built environment (Frumkin, 2005). Landscape architects and urban planners may not have jurisdiction over all these arenas, but they have a responsibility to learn about, engage with, and advocate for urban environmental justice in the spaces where their professions have influence over decision-making processes. It is critical to acknowledge how those in positions of power have shaped the dominant narrative over health and landscapes and have enacted plans and policies that benefited predominantly White, middle-class, and elite populations at the expense of the health and wealth of marginalized communities. Even with health equity as the goal, marginalized communities remain vulnerable to the repeated failures of past policies and actions, such as urban renewal, if urban design and planning decisions are uncoupled from housing policy designed to protect low-income renters, collaboration with social justice-oriented organizations, and comprehensive community participation.

As part of the strategy for addressing urban environmental health inequities, public health organizations have advocated for building collaborative networks. Though evidence of public health collaboration effectiveness has been limited (Alderwick et al., 2021), fostering and coordinating multi-organizational partnerships, including those from planning, housing, and transportation, is listed as one of the ten essential public health services by the Center for Disease Control (2020). The World Health Organization and high-ranking public health officials at the United States Department of Health and Human Services have echoed the sentiment that multi-sector collaboration is necessary to address health inequities related to social determinants of health (DeSalvo et al., 2016; World Health Organization, 2011).

Multi-disciplinary collaboration has also been central to identifying priorities for urban green space planning. In 2007, The Trust for Public Land convened a group of experts from academic, non-profit, and government sectors with backgrounds in environmental management, housing, transportation, and planning to assess opportunities for synergies between urban park development and affordable housing (Harnik & Welle, 2009). The panel identified precedents where 1) states incentivized city-level affordable housing development with funding for parks, 2) cities coupled park improvement projects with a percentage of tax increment revenue (i.e., additional funds associated with real estate value increases) devoted to affordable housing, and 3) local multi-sector initiatives, such as the now shuttered Coalition for a Livable Future, promoted park and affordable housing investments. In a similar effort, the New York Restoration Project convened a task force which included government officials, non-profit leaders, landscape architects, urban planners, and one public health researcher to establish priorities for urban forestry planning (New York Restoration Project, 2011). The task force generated twelve recommendations, which included providing equitable access to urban green space amenities for low-income and minoritized racial populations, fostering public-private partnerships and regional metropolitan alliances to support urban forestry expansion and connectivity, and assembling multidisciplinary groups of practitioners and decision-makers to coordinate urban natural resource management. While various organizations have been established to coordinate local and regional urban green space planning (e.g., Intertwine Alliance), few have included public health organizations in urban green space design, planning, or evaluation. The establishment of the Colorado Public Health/Parks and Recreation Collaborative, however, represents one such example where public health and green space management professionals have worked collectively with the goal of improving health equity (Burns et al., 2017), and their collective impact strategy could serve as a model for future collaboration efforts.

As experts and decision-makers in urban green space design and planning, landscape architects and urban planners have a responsibility to initiate collaborative efforts to improve health equity. Public health organizations and urban green space professionals share a common agenda to improve health equity in cities, and both have stated the importance of multidisciplinary collaboration. Yet, public health professionals have had extremely limited roles in urban green space planning, to-date, even though urban green space design, planning, and management decisions impact health through complex interactions between social, environmental, and economic systems. If landscape architects and urban green space planners wish to use health as an impetus for urban park and forestry development, then public health professionals need to be included in urban green space decision-making. Furthermore, the histories of landscape architecture and urban planning suggest that health has been used as a rationale for policy and planning that negatively impacted the health of marginalized communities. “The impulse to improve urban landscapes in the name of health or abandon ‘unhealthy’ landscapes for healthier ones almost always disadvantages the poor, minorities, and immigrants, even if through a series of unintended or even well-meaning decisions” (Carr, 2021, p. 165). As such, all urban green space project planning and design work should include input from experts in affordable housing policy and social justice advocacy, in addition to the continuous and authentic inclusion of marginalized community members in each step of urban green space decision-making processes. Lastly, frequent evaluation of planning, design, implementation, and management processes can provide longitudinal data and possible insight into successes and failures from each stage of urban green space projects. These recommendations are intended to guide and encourage landscape architects and urban green space planners to act as facilitators and advocates for the design and planning of urban green space for environmental justice and health equity in the 21st century.

Bridge

The analysis presented in this chapter, identifies the shared histories of landscape architecture, urban planning, and public health in the United States, providing critical context for the empirical urban green space research presented in the following chapters. In the subsequent chapter, I use the social determinants of health framework to investigate relationships between urban green space, physical activity, and mental well-being in Portland, Oregon.

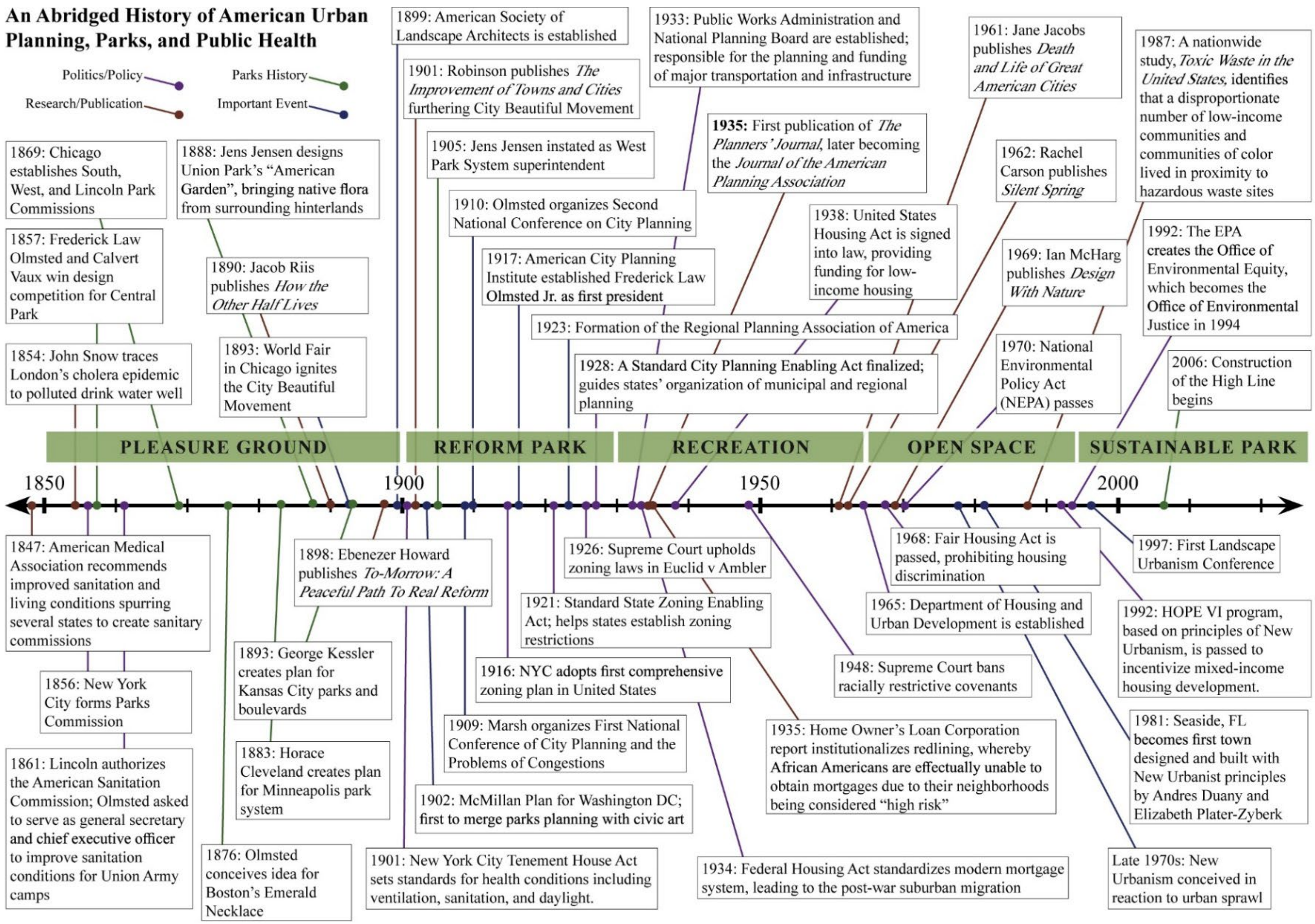

Figure 2.1. A timeline of influential events (blue line), publications (maroon line), policies (purple line), and urban park plans/movements (green line/boxes) at the intersection of urban planning, landscape architecture, and public health in the United States (American Planning Association, 2020; Campbell, 2019; Cranz, 1982; Cranz & Boland, 2004; United States Environmental Protection Agency, 2022; Zube, 1995).

References Cited

Ackerknecht, E. H. (2009). Anticontagionism between 1821 and 1867: The Fielding H. Garrison Lecture. *International Journal of Epidemiology*, *38*(1), 7–21. https://doi.org/10.1093/ije/dyn254

Ahern, J. (2003). Greenways in the USA: theory, trends and prospects. In R. H. Jongman & G. Pungetti (Eds.), *Ecological networks and greenways: Concept, design, implementation* (pp. 34–55). Cambridge University Press.

Alderwick, H., Hutchings, A., Briggs, A., & Mays, N. (2021). The impacts of collaboration between local health care and non-health care organizations and factors shaping how they work: A systematic review of reviews. *BMC Public Health*, *21*(1), 753. https://doi.org/10.1186/s12889-021-10630-1

Allen, J., Balfour, R., Bell, R., & Marmot, M. (2014). Social determinants of mental health. *International Review of Psychiatry (Abingdon, England)*, *26*(4), 392–407. https://doi.org/10.3109/09540261.2014.928270

Alta Planning and Design. (2017a). The Impact of Greenways in the Triangle: How the East Coast Greenway Benefits the Health and Economy of North Carolina's Triangle Region. https://www.greenway.org/uploads/attachments/cjgqs3ffg03yyp8qitykwkvz8-triangle-impact-report.pdf

American Planning Association. (2020). *Planning History Timeline*. https://www.planning.org/timeline/

Aspinall, P., Mavros, P., Coyne, R., & Roe, J. (2015). The urban brain: Analysing outdoor physical activity with mobile EEG. *British Journal of Sports Medicine*, *49*(4), 272–276. https://doi.org/10.1136/bjsports-2012-091877

Astell-Burt, T., Feng, X., & Kolt, G. S. (2013). Mental health benefits of neighbourhood green space are stronger among physically active adults in middle-to-older age: Evidence from 260,061 Australians. *Preventive Medicine*, *57*(5), 601–606. https://doi.org/10.1016/j.ypmed.2013.08.017

Beyer, K., Kaltenbach, A., Szabo, A., Bogar, S., Nieto, F., & Malecki, K. (2014). Exposure to Neighborhood Green Space and Mental Health: Evidence from the Survey of the Health of Wisconsin. *International Journal of Environmental Research and Public Health*, *11*(3), 3453–3472. https://doi.org/10.3390/ijerph110303453

Boults, E., & Sullivan, C. (2010). *Illustrated history of landscape design*. J. Wiley.

Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health: Nature experience, cognitive function, and mental health. *Annals of the New York Academy of Sciences*, *1249*(1), 118–136. https://doi.org/10.1111/j.1749-6632.2011.06400.x

Bullard, R. D. (1983). Solid Waste Sites and the Black Houston Community*. *Sociological Inquiry*, *53*(2–3), 273–288. https://doi.org/10.1111/j.1475-682X.1983.tb00037.x

Bullard, R. D. (1990). Dumping in dixie: Race, class, and environmental quality. 3.

Burns, J., Joyce, B., Visconti, V., & Kates, B. (2017). The Colorado Public Health/Parks and Recreation Collaborative: A Model for Bringing Together Multi-Sectoral Professionals. *Recreation, Parks, and Tourism in Public Health*, *1*, 37. https://doi.org/10.2979/rptph.1.1.04

Campbell, S. (2019). *A Selected Chronology of Urban Planning History*. http://www-personal.umich.edu/~sdcamp/timeline.html

Cao, X., Mokhtarian, P. L., & Handy, S. L. (2009). The relationship between the built environment and nonwork travel: A case study of Northern California. *Transportation Research Part A: Policy and Practice*, *43*(5), 548–559. https://doi.org/10.1016/j.tra.2009.02.001

Cariñanos, P., Calaza-Martínez, P., O'Brien, L., & Calfapietra, C. (2017). The Cost of Greening: Disservices of Urban Trees. In D. Pearlmutter, C. Calfapietra, R. Samson, L. O'Brien, S. Krajter Ostoić, G. Sanesi, & R. Alonso del Amo (Eds.), *The Urban Forest* (Vol. 7, pp. 79–87). Springer International Publishing. https://doi.org/10.1007/978-3-319-50280-9_9

Carr, S. J. (2021). The topography of wellness: How health and disease shaped the American landscape. University of Virginia Press.

Carson, R. (1962). *Silent spring*. Boston : Houghton Mifflin Company.

Center for Disease Control. (2007). QuickStats: Percentage of children aged <18 years who currently have asthma by race/ethnicity and poverty status, National Health Interview Survey—United States, 2003–2005. https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5605a5.htm

Center for Disease Control. (2020). *The 10 Essential Public Health Services*. https://www.cdc.gov/publichealthgateway/publichealthservices/essentialhealthservices.html

Center for Disease Control. (2022). *Adult Physical Inactivity Prevalence Maps*. Centers for Disease Control and Prevention. https://www.cdc.gov/physicalactivity/data/inactivity-prevalence-maps/index.html

Checker, M. (2011). Wiped Out by the "Greenwave": Environmental Gentrification and the Paradoxical Politics of Urban Sustainability. *City & Society*, *23*(2), 210–229. https://doi.org/10.1111/j.1548-744X.2011.01063.x

Chudacoff, H. P. (1975). *The evolution of American urban society*. Prentice-Hall.

Citizens Association of New York, Council of Hygiene and Public Health. (1865). Report of the Council of Hygiene and Public Health of the Citizens' Association of New York upon the Sanitary Condition of the City. https://collections.nlm.nih.gov/catalog/nlm:nlmuid-63120960R-bk

City of Eugene. (2018). Picture. Plan. Play. A Vision and Implementation Plan for Eugene's Parks and Recreation System. https://www.eugene-or.gov/2885/System-Plan

Cockerham, W. C., Hamby, B. W., & Oates, G. R. (2017). The Social Determinants of Chronic Disease. *American Journal of Preventive Medicine*, *52*(1 Suppl 1), S5–S12. https://doi.org/10.1016/j.amepre.2016.09.010

Cohen, L. (2016). Black and White in Green Cities. In M. Mostafavi & G. Doherty (Eds.), *Ecological Urbanism* (pp. 134–135).

Cole, H. V. S., Garcia Lamarca, M., Connolly, J. J. T., & Anguelovski, I. (2017). Are green cities healthy and equitable? Unpacking the relationship between health, green space and gentrification. *Journal of Epidemiology and Community Health*, *71*(11), 1118.

Compton, M. T., & Shim, R. S. (2015). The Social Determinants of Mental Health. *FOCUS*, *13*(4), 419–425. https://doi.org/10.1176/appi.focus.20150017

Coombes, E., Jones, A. P., & Hillsdon, M. (2010). The relationship of physical activity and overweight to objectively measured green space accessibility and use. *Social Science & Medicine*, *70*(6), 816–822. https://doi.org/10.1016/j.socscimed.2009.11.020

Corburn, J. (2004). Confronting the Challenges in Reconnecting Urban Planning and Public Health. *American Journal of Public Health*, *94*(4), 541–546. https://doi.org/10.2105/AJPH.94.4.541

Corburn, J. (2012). Reconnecting Urban Planning and Public Health. In R. Crane & R. Weber (Eds.), *The Oxford Handbook of Urban Planning* (pp. 391–417). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195374995.013.0020

Corner, J. (2006). Terra Fluxus. In C. Waldheim (Ed.), *Landscape Urbanism Reader*. Princeton Architectural Press. http://ebookcentral.proquest.com/lib/uoregon/detail.action?docID=3387326

Cranz, G. (1982). The politics of park design: A history of urban parks in America. MIT Press.

Cranz, G. (2008). *Urban Parks of the Past and Future* [Project for Public Spaces]. https://www.pps.org/article/futureparks

Cranz, G., & Boland, M. (2004). Defining the Sustainable Park: A Fifth Model for Urban Parks. *Landscape Journal*, *23*, 102–120. https://doi.org/10.3368/lj.23.2.102

Curtis, H. S. (Henry S. (1917). *The play movement and its significance*. New York : The Macmillan company. http://archive.org/details/playmovementitss00curt

D'Amato, G. (2002). Environmental urban factors (air pollution and allergens) and the rising trends in allergic respiratory diseases. *Allergy*, *57*(s72), 30–33. https://doi.org/10.1034/j.1398-9995.57.s72.5.x

de Leon, E., & Schilling, J. (2017). *Urban Blight and Public Health Addressing the Impact of Substandard Housing, Abandoned Buildings, and Vacant Lots*. The Urban Institute. https://www.urban.org/sites/default/files/publication/89491/2017.04.03_urban_blight_and_public_health_vprn_report_finalized.pdf

De Sousa, C. A. (2008). Brownfields redevelopment and the quest for sustainability. Elsevier.

DeSalvo, K. B., O'Carroll, P. W., Koo, D., Auerbach, J. M., & Monroe, J. A. (2016). Public Health 3.0: Time for an Upgrade. *American Journal of Public Health*, *106*(4), 621–622. https://doi.org/10.2105/AJPH.2016.303063

Donovan, G. H., Prestemon, J. P., Butry, D. T., Kaminski, A. R., & Monleon, V. J. (2021). The politics of urban trees: Tree planting is associated with gentrification in Portland, Oregon. *Forest Policy and Economics. 124: 102387.*, *124*, 102387. https://doi.org/10.1016/j.forpol.2020.102387

Downing, A. J. (Andrew J., Curtis, G. W., & Bremer, F. (1853). *Rural essays*. New York : George P. Putman and Company, 10 Park Place. http://archive.org/details/ruralessays00down

Duany, A., Plater-Zyberk, E., & Speck, J. (2000). *Suburban nation: The rise of sprawl and the decline of the American Dream* (1st ed.). North Point Press.

Duncan, M., Hood, E. T., & Neet, J. L. (1975). Redlining Practices, Racial Resegregation, and Urban Decay: Neighborhood Housing Services as a Viable Alternative. *Urban Lawyer*, *7*(3), 510–539.

Dunn, J. F., & Golding, P. A. (1978). *The Progressive Origins of Modern City Planning*. https://digitalcommons.uri.edu/theses/379

Eisenman, T. S. (2013). Frederick Law Olmsted, Green Infrastructure, and the Evolving City. *Journal of Planning History*, *12*(4), 287–311. https://doi.org/10.1177/1538513212474227

Escobedo, F. J., Kroeger, T., & Wagner, J. E. (2011). Urban forests and pollution mitigation: Analyzing ecosystem services and disservices. *Environmental Pollution*, *159*(8–9), 2078–2087. https://doi.org/10.1016/j.envpol.2011.01.010

Ewing, R., & Cervero, R. (2010). Travel and the Built Environment: A Meta-Analysis. *Journal of the American Planning Association*, *76*(3), 265–294. https://doi.org/10.1080/01944361003766766

Fainstein, S. S. (2016). Social Justice and Ecological Urbanism. In M. Mostafavi & G. Doherty (Eds.), *Ecological Urbanism* (pp. 300–301).

Fisher, T. (2010). Frederick Law Olmsted and the Campaign for Public Health. *Places Journal*, *2010*. https://doi.org/10.22269/101115

Fors, H., Hagemann, F. A., Sang, Å. O., & Randrup, T. B. (2021). Striving for Inclusion—A Systematic Review of Long-Term Participation in Strategic Management of Urban Green Spaces. *Frontiers in Sustainable Cities*, *3*. https://www.frontiersin.org/articles/10.3389/frsc.2021.572423

Frank, L. D. (2003). Health and community design: The impact of the built environment on physical activity. Washington, DC : Island Press.

Frank, L. D., & Kavage, S. (2008). Urban planning and public health: A story of separation and reconnection. *Journal of Public Health Management and Practice: JPHMP*, *14*(3), 214–220. https://doi.org/10.1097/01.PHH.0000316478.42264.a7

Frumkin, H. (2005). Guest Editorial: Health, Equity, and the Built Environment. *Environmental Health Perspectives*, *113*(5), A290–A291. https://doi.org/10.1289/ehp.113-a290

Gao, X., Kershaw, K. N., Barber, S., Schreiner, P. J., Do, D. P., Diez Roux, A. V., & Mujahid, M. S. (2022). Associations Between Residential Segregation and Incident Hypertension: The Multi-Ethnic Study of Atherosclerosis. *Journal of the American Heart Association*, *11*(3), e023084. https://doi.org/10.1161/JAHA.121.023084

Garb, M. (2003). Health, Morality, and Housing: The "Tenement Problem" in Chicago. *American Journal of Public Health*, *93*(9), 1420–1430.

Gazvoda, D. (2002). Characteristics of modern landscape architecture and its education. *Landscape and Urban Planning*, *60*(2), 117–133. https://doi.org/10.1016/S0169-2046(02)00064-6

Gerrish, E., & Watkins, S. L. (2018). The relationship between urban forests and income: A meta-analysis. *Landscape and Urban Planning*, *170*, 293–308. https://doi.org/10.1016/j.landurbplan.2017.09.005

Gibbons, J., Yang, T.-C., Brault, E., & Barton, M. (2020). Evaluating Residential Segregation's Relation to the Clustering of Poor Health across American Cities. *International Journal of Environmental Research and Public Health*, *17*(11), 3910. https://doi.org/10.3390/ijerph17113910

Gies, E. (2018). The Health Benefits of Parks: How Parks Help Keep Americans And Their Communities Fit And Healthy. The Trustfor Public Land.

Giles-Corti, B., Broomhall, M. H., Knuiman, M., Collins, C., Douglas, K., Ng, K., Lange, A., & Donovan, R. J. (2005). Increasing walking: How important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine*, *28*(2), 169–176. https://doi.org/10.1016/j.amepre.2004.10.018

Gould, K. A., & Lewis, T. L. (2012). The environmental injustice of green gentrification: The case of Brooklyn's Prospect Park. In J. N. DeSena & T. Shortell (Eds.), *The world in Brooklyn: Gentrification, immigration, and ethnic politics in a global city* (pp. 113–146). Lexington Books.

Greenberg, M., Popper, F., West, B., & Krueckeberg, D. (1994). Linking City Planning and Public Health in the United States. *Journal of Planning Literature*, *8*(3), 235–239. https://doi.org/10.1177/088541229400800301

Harnik, P., & Welle, B. (2009). *Smart Collaboration: How Urban Parks Can Support Affordable Housing*. The Trust for Public Land. https://www.tpl.org/wp-content/uploads/2013/12/ccpe_SmartCollaboration.pdf

Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S., & Gärling, T. (2003). Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology*, *23*(2), 109–123. https://doi.org/10.1016/S0272-4944(02)00109-3

Herrington, S. (2010). The Nature of Ian McHarg's Science. *Landscape Journal*, *29*(1), 1–20. JSTOR.

Hull-House maps and papers a presentation of nationalities and wages in a congested district of Chicago, together with comments and essays on problems growing out of the social conditions. (1895). T.Y. Crowell.

Hundt, G., & Daniels, T. L. (2018). The Plan for the Valleys: Assessing the Vision of Ian McHarg and David Wallace. *Journal of Planning History*, *17*(1), 3–19. https://doi.org/10.1177/1538513216681586

Iravani, H., & Rao, V. (2020). The effects of New Urbanism on public health. *Journal of Urban Design*, *25*(2), 218–235. https://doi.org/10.1080/13574809.2018.1554997

Jennings, V., Browning, M. H. E. M., & Rigolon, A. (2019). Urban Green Space at the Nexus of Environmental Justice and Health Equity. In V. Jennings, M. H. E. M. Browning, & A. Rigolon, *Urban Green Spaces* (pp. 47–69). Springer International Publishing. https://doi.org/10.1007/978-3-030-10469-6_4

John-Alder, K. L. (2014). Toward a New Landscape: Modern Courtyard Housing and Ian McHarg's Urbanism. *Journal of Planning History*, *13*(3), 187–206. https://doi.org/10.1177/1538513213510895

Jones, A., Hillsdon, M., & Coombes, E. (2009). Greenspace access, use, and physical activity: Understanding the effects of area deprivation. *Preventive Medicine*, *49*(6), 500–505. https://doi.org/10.1016/j.ypmed.2009.10.012

Jorgensen, L. J., Ellis, G. D., & Ruddell, E. (2013). Fear Perceptions in Public Parks: Interactions of Environmental Concealment, the Presence of People Recreating, and Gender. *Environment and Behavior*, *45*(7), 803–820. https://doi.org/10.1177/0013916512446334

Kaczynski, A. T., Besenyi, G. M., Stanis, S. A. W., Koohsari, M. J., Oestman, K. B., Bergstrom, R., Potwarka, L. R., & Reis, R. S. (2014). Are park proximity and park features related to park use and park-based physical activity among adults? Variations by multiple socio-demographic characteristics. *The International Journal of Behavioral Nutrition and Physical Activity*, *11*(1), 146. https://doi.org/10.1186/s12966-014-0146-4

Kaczynski, A. T., Koohsari, J., Wilhelm Stanis, S., Bergstrom, R., & Sugiyama, T. (2014). Association of Street Connectivity and Road Traffic Speed With Park Usage and Park-Based Physical Activity. *American Journal of Health Promotion : AJHP*, *28*, 197–203. https://doi.org/10.4278/ajhp.120711-QUAN-339

Kaczynski, A. T., Potwarka, L. R., & Saelens, B. E. (2008). Association of Park Size, Distance, and Features With Physical Activity in Neighborhood Parks. *American Journal of Public Health*, *98*(8), 1451–1456. https://doi.org/10.2105/AJPH.2007.129064

Kandola, A., Ashdown-Franks, G., Hendrikse, J., Sabiston, C. M., & Stubbs, B. (2019). Physical activity and depression: Towards understanding the antidepressant mechanisms of physical activity. *Neuroscience and Biobehavioral Reviews*, *107*, 525–539. https://doi.org/10.1016/j.neubiorev.2019.09.040

Kandola, A., & Stubbs, B. (2020). Exercise and Anxiety. *Advances in Experimental Medicine and Biology*, *1228*, 345–352. https://doi.org/10.1007/978-981-15-1792-1_23

Karamanou, M., Panayiotakopoulos, G., Tsoucalas, G., Kousoulis, A. A., & Androutsos, G. (2012). From miasmas to germs: A historical approach to theories of infectious disease transmission. *Le Infezioni in Medicina*, *20*(1), 58–62. PRIME.

Koskela, H., & Pain, R. (2000). Revisiting fear and place: Women’s fear of attack and the built environment. *Geoforum*, *31*(2), 269–280. https://doi.org/10.1016/S0016-7185(99)00033-0

Kronenberg, J., Haase, A., Łaszkiewicz, E., Antal, A., Baravikova, A., Biernacka, M., Dushkova, D., Filčak, R., Haase, D., Ignatieva, M., Khmara, Y., Niţă, M. R., & Onose, D. A. (2020). Environmental justice in the context of urban green space availability, accessibility, and attractiveness in postsocialist cities. *Cities*, *106*, 102862. https://doi.org/10.1016/j.cities.2020.102862

Lang, R. E., & Sohmer, R. R. (2000). Legacy of the Housing Act of 1949: The Past, Present, and Future of Federal Housing and Urban Policy. *Housing Policy Debate*, *11*(2), 291–298. https://doi.org/10.1080/10511482.2000.9521369

Laurence, P. L. (2006). The Death and Life of Urban Design: Jane Jacobs, The Rockefeller Foundation and the New Research in Urbanism, 1955–1965. *Journal of Urban Design*, *11*(2), 145–172. https://doi.org/10.1080/13574800600644001

Lee, J. (2017). Experimental Study on the Health Benefits of Garden Landscape. *International Journal of Environmental Research and Public Health*, *14*(7), 829. https://doi.org/10.3390/ijerph14070829

Leibbrand, C., Massey, C., Alexander, J. T., Genadek, K. R., & Tolnay, S. (2020). The Great Migration and Residential Segregation in American Cities during the Twentieth Century. *Social Science History*, *44*(1), 19–55. https://doi.org/10.1017/ssh.2019.46

Leopold, A. (1949). *A Sand County almanac, and Sketches here and there*. New York, Oxford Univ. Press.

Lim, S., Chan, P. Y., Walters, S., Culp, G., Huynh, M., & Gould, L. H. (2017). Impact of residential displacement on healthcare access and mental health among original residents of gentrifying neighborhoods in New York City. *PLoS ONE*, *12*(12), e0190139. https://doi.org/10.1371/journal.pone.0190139

Lopez, R. P. (2009). Public Health, the APHA, and Urban Renewal. *American Journal of Public Health*, *99*(9), 1603–1611. https://doi.org/10.2105/AJPH.2008.150136

Lyytimäki, J., & Sipilä, M. (2009). Hopping on one leg – The challenge of ecosystem disservices for urban green management. *Urban Forestry & Urban Greening*, *8*(4), 309–315. https://doi.org/10.1016/j.ufug.2009.09.003

Maas, J., van Dillen, S. M. E., Verheij, R. A., & Groenewegen, P. P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. *Health & Place*, *15*(2), 586–595. https://doi.org/10.1016/j.healthplace.2008.09.006

Mackaye, B. (1940). Regional Planning and Ecology. *Ecological Monographs*, *10*(3), 349–353. https://doi.org/10.2307/1948509

Mariotti, A. (2015). The effects of chronic stress on health: New insights into the molecular mechanisms of brain–body communication. *Future Science OA*, *1*(3), FSO23. https://doi.org/10.4155/fso.15.21

Massey, D. S. (1993). American apartheid: Segregation and the making of the underclass. Harvard University Press.

McGraw, B. T. (1955). The Housing Act of 1954 and Implications for Minorities. *Phylon (1940-1956)*, *16*(2), 171–182. https://doi.org/10.2307/272718

McHarg, I. L. (2014). An Ecological Method for Landscape Architecture; Landscape Architecture (1967). In F. O. Ndubisi (Ed.), *The Ecological Design and Planning Reader* (pp. 341–347). Island Press/Center for Resource Economics. https://doi.org/10.5822/978-1-61091-491-8_29

McHarg, I. L., & Steiner, F. (2014). Man and the Environment; The Urban Condition (1963). In F. O. Ndubisi (Ed.), *The Ecological Design and Planning Reader* (pp. 97–107). Island Press/Center for Resource Economics. https://doi.org/10.5822/978-1-61091-491-8_11

Meyerson, A. (1997). Review of Before Central Park: The Life and Death of Seneca Village [Review of *Review of Before Central Park: The Life and Death of Seneca Village*, by C. R. Copeland & G. Turner]. *The Public Historian*, *19*(4), 100–102. https://doi.org/10.2307/3379512

Mostafavi, M. (2010). Why Ecological Urbanism? Why Now. In M. Mostafavi & G. Doherty (Eds.), *Ecological urbanism*. Lars Muller Publishers.

Mostafavi, M., Doherty, G., Koolhaas, R., Oma, Amo, R., Haskoningdhv, B., Associates, H., Advisors, Bhabha, H., Raven-Ellison, D., Askins, K., Branzi, A., Textor, R., One, T., Latour, B., Bruno, G., Cohen, L., Cohen, P., Cott, L., & Tolaas, S. (2016). *Ecological Urbanism, revised edition (2016)*.

Mytton, O. T., Townsend, N., Rutter, H., & Foster, C. (2012). Green space and physical activity: An observational study using Health Survey for England data. *Health & Place*, *18*(5), 1034–1041. https://doi.org/10.1016/j.healthplace.2012.06.003

Nardone, A., Chiang, J., & Corburn, J. (2020). Historic Redlining and Urban Health Today in U.S. Cities. *Environmental Justice*, *13*(4), 109–119. https://doi.org/10.1089/env.2020.0011

National Center for Health Statistics. (2016). *Health, United States, 2015: With Special Feature on Racial and Ethnic Health Disparities.* National Center for Health Statistics (US). https://www.ncbi.nlm.nih.gov/books/NBK367640/

New York Restoration Project. (2011). *Vibrant Cities & Urban Forests*.

Nutsford, D., Pearson, A. L., & Kingham, S. (2013). An ecological study investigating the association between access to urban green space and mental health. *Public Health*, *127*(11), 1005–1011. https://doi.org/10.1016/j.puhe.2013.08.016

Nutton, V. (1990). The Reception of Fracastoro's Theory of Contagion: The Seed That Fell among Thorns? *Osiris*, *6*, 196–234.

O'Connell, J. (2016). The Legacy of Frederick Law Olmsted's Emerald Necklace in Contemporary Boston. *Proceedings of the Fábos Conference on Landscape and Greenway Planning*, *5*(1). https://scholarworks.umass.edu/fabos/vol5/iss1/23

Olmsted, F. L. (1882). Trees in Streets and in Parks.

Payne-Sturges, D., & Gee, G. C. (2006). National environmental health measures for minority and low-income populations: Tracking social disparities in environmental health. *Environmental Research*, *102*(2), 154–171. https://doi.org/10.1016/j.envres.2006.05.014

Peterson, J. A. (2009). The Birth of Organized City Planning in the United States, 1909–1910. *Journal of the American Planning Association*, *75*(2), 123–133. https://doi.org/10.1080/01944360802608484

Portland Parks & Recreation. (2017). 2017-2020 Portland Parks & Recreation Strategic Plan.

Portland Parks & Recreation. (2020). *Urban Forest Action Plan 2019 Implementation Update*. https://www.portland.gov/trees/documents/2019-urban-forest-action-plan-implementation-update/download

Riccucci, N. M., & Van Ryzin, G. G. (2017). Representative Bureaucracy: A Lever to Enhance Social Equity, Coproduction, and Democracy. *Public Administration Review*, *77*(1), 21–30. https://doi.org/10.1111/puar.12649

Rigolon, A. (2016). A complex landscape of inequity in access to urban parks: A literature review. *Landscape and Urban Planning*, *153*, 160–169. https://doi.org/10.1016/j.landurbplan.2016.05.017

Riis, J. (1890). *How the Other Half Live*. https://mashable.com/2016/04/13/new-york-tenement-photos/

Robinson, C. M. (1901). The improvement of towns and cities, or, The practical basis of civic aesthetics. G.P. Putnam's Sons.

Roe, J. (2013). Engaging the brain: The impact of natural versus urban scenes using novel EEG methods in an experimental setting. https://doi.org/10.12988/es.2013.3109

San Francisco Recreation & Parks. (2021). *Strategic Plan: 2021-2025 Update*. https://sfrecpark.org/DocumentCenter/View/17451/Strategic-Plan-Update-2021

Santomauro, D. F., Herrera, A. M. M., Shadid, J., Zheng, P., Ashbaugh, C., Pigott, D. M., Abbafati, C., Adolph, C., Amlag, J. O., Aravkin, A. Y., Bang-Jensen, B. L., Bertolacci, G. J., Bloom, S. S., Castellano, R., Castro, E., Chakrabarti, S., Chattopadhyay, J., Cogen, R. M., Collins, J. K., … Ferrari, A. J. (2021). Global prevalence and burden of depressive and anxiety disorders in 204 countries and territories in 2020 due to the COVID-19 pandemic. *The Lancet*, *398*(10312), 1700–1712. https://doi.org/10.1016/S0140-6736(21)02143-7

Seattle Parks & Recreation. (2021). *2021 Strategic Plan Implementation*. https://www.seattle.gov/documents/Departments/ParksAndRecreation/PoliciesPlanning/SPR%20Strategic%20Plan%20Implementation_2Page.pdf

Shertzer, A., Twinam, T., & Walsh, R. P. (2022). Zoning and segregation in urban economic history. *Regional Science and Urban Economics*, *94*, 103652. https://doi.org/10.1016/j.regsciurbeco.2021.103652

Sies, M. C., Silver, C., & Silver, P. C. (1996). *Planning the Twentieth-century American City*. JHU Press.

Silver, C. (1997). The racial origins of zoning in American Cities. In J. Manning Thomas & M. Ritzdorf (Eds.), *Urban Planning and the African American Community: In the Shadows* (Vol. 6, pp. 189–205). Sage Publications. https://eportfolios.macaulay.cuny.edu/goldwyn17/files/2017/01/silver-racialoriginsofzoning.pdf

Southworth, M. (2003). New Urbanism and the American Metropolis. *Built Environment (1978-)*, *29*(3), 210–226. JSTOR.

Štajerová, K., Šmilauer, P., Brůna, J., & Pyšek, P. (2017). Distribution of invasive plants in urban environment is strongly spatially structured. *Landscape Ecology*, *32*(3), 681–692. https://doi.org/10.1007/s10980-016-0480-9

Steiner, F. (2008). The Ghost of Ian McHarg. *Log*, *13/14*, 147–151. JSTOR.

Steiner, F. (2011). Landscape ecological urbanism: Origins and trajectories. *Landscape and Urban Planning*, *100*(4), 333–337. https://doi.org/10.1016/j.landurbplan.2011.01.020

Steiner, F., Young, G., & Zube, E. (1988). Ecological Planning: Retrospect and Prospect. *Landscape Journal*, *7*(1), 31–39. JSTOR.

Steinitz, C. (2008). Landscape planning: A brief history of influential ideas. *Journal of Landscape Architecture*, *3*(1), 68–74. https://doi.org/10.1080/18626033.2008.9723397

Susser, M., & Susser, E. (1996). Choosing a future for epidemiology: I. Eras and paradigms. *American Journal of Public Health*, *86*(5), 668–673. https://doi.org/10.2105/ajph.86.5.668

Szczygiel, B., & Hewitt, R. (2000). Nineteenth-Century Medical Landscapes: John H. Rauch, Frederick Law Olmsted, and the Search for Salubrity. *Bulletin of the History of Medicine*, *74*(4), 708–734. JSTOR.

Tarr, J. A., McCurley, J., McMichael, F. C., & Yosie, T. (1984). Water and Wastes: A Retrospective Assessment of Wastewater Technology in the United States, 1800-1932. *Technology and Culture*, *25*(2), 226–263. https://doi.org/10.2307/3104713

Taylor, D. E. (1999). Central Park as a Model for Social Control: Urban Parks, Social Class and Leisure Behavior in Nineteenth-Century America. *Journal of Leisure Research*, *31*(4), 420–477. https://doi.org/10.1080/00222216.1999.11949875

The Central Park Conservancy. (2018). *Before Central Park: The Story of Seneca Village*. Central Park Conservancy. https://www.centralparknyc.org/articles/seneca-village

The Charter of the New Urbanism. (2015, April 20). CNU. https://www.cnu.org/who-we-are/charter-new-urbanism

The Pittsburgh Survey ... (1909). Charity Organization Society of the City of New York.

The Trust for Public Land. (2006). *The Health Benefits of Parks*. https://www.tpl.org/wp-content/uploads/2014/03/benefits_HealthBenefitsReport.pdf

Tolnay, S. E. (2003). The African American "Great Migration" and Beyond. *Annual Review of Sociology*, *29*, 209–232.

Tsouros, A. D. (Ed.). (1992). *World Health Organization Healthy Cities Project: A Project Becomes a Movement*. World Health Organization, Regional Office for Europe. https://www.euro.who.int/__data/assets/pdf_file/0016/101446/WA_380.pdf

United States Department of Health, Education, and Welfare. (1979). *Healthy People: The Surgeon General's Report on Health Promotion and Disease Prevention*. https://profiles.nlm.nih.gov/101584932X92

United States Environmental Protection Agency. (2022). *Environmental Justice* [Collections and Lists]. https://www.epa.gov/environmentaljustice

U.S. Census Bureau. (1993). *Population: 1790 to 1990*. https://www.census.gov/population/censusdata/table-4.pdf

U.S. Department of Health and Human Services. (1985). *Report of the Secretary's Task Force on Black and Minority Health: Volume I: Executive Summary*. GPO. http://archive.org/details/reportofsecretar00usde

Velarde, M. D., Fry, G., & Tveit, M. (2007). Health effects of viewing landscapes – Landscape types in environmental psychology. *Urban Forestry & Urban Greening*, *6*(4), 199–212. https://doi.org/10.1016/j.ufug.2007.07.001

Waldheim, C. (2006a). A Reference Manifesto. In *Landscape Urbanism Reader* (pp. 13–20). Princeton Architectural Press. http://ebookcentral.proquest.com/lib/uoregon/detail.action?docID=3387326

Waldheim, C. (2006b). Landscape as Urbanism. In *Landscape Urbanism Reader* (pp. 13–20). Princeton Architectural Press. http://ebookcentral.proquest.com/lib/uoregon/detail.action?docID=3387326

Watkins, S. L., & Gerrish, E. (2018). The relationship between urban forests and race: A meta-analysis. *Journal of Environmental Management*, *209*, 152–168. https://doi.org/10.1016/j.jenvman.2017.12.021

Whiston Spirn, A. (2012). *Ecological Urbanism: A Framework for the Design of Resilient Cities*. https://annewhistonspirn.com/sharefiles/Spirn-EcoUrbanism-2012.pdf

White, M. P., Pahl, S., Wheeler, B. W., Depledge, M. H., & Fleming, L. E. (2017). Natural environments and subjective wellbeing: Different types of exposure are associated with different aspects of wellbeing. *Health & Place*, *45*, 77–84. https://doi.org/10.1016/j.healthplace.2017.03.008

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough.' *Landscape and Urban Planning*, *125*, 234–244. https://doi.org/10.1016/j.landurbplan.2014.01.017

World Health Organization. (2006). *Constitution of the World Health Organization*. https://www.who.int/governance/eb/who_constitution_en.pdf

World Health Organization. (2009). *Global health risks: Mortality and burden of disease attributable to selected major risks*. https://www.who.int/publications/i/item/9789241563871

World Health Organization. (2010). *Hidden cities: Unmasking and overcoming health inequities in urban settings.* http://apps.who.int/iris/bitstream/handle/10665/44439/9789241548038_eng.pdf?sequence=1

World Health Organization. (2011). *Closing the Gap: Policy into Practice on Social Determinants of Health*. https://www.who.int/publications/i/item/9789241502405

World Health Organization. (2014). *Social Determinants of Mental Health*. https://apps.who.int/iris/bitstream/handle/10665/112828/9789241506809_eng.pdf

World Health Organization. (2022). *World mental health report: Transforming mental health for all*. https://www.who.int/publications/i/item/9789240049338

Zube, E. H. (1995). Greenways and the US National Park system. *Landscape and Urban Planning*, *33*(1–3), 17–25. https://doi.org/10.1016/0169-2046(94)02011-4

CHAPTER III

A NEW FRONTIER IN HEALTH EQUITY PLANNING: MODELLING COMPLEX RELATIONSHIPS BETWEEN PHYSICAL ACTIVITY, MENTAL WELL-BEING, AND URBAN GREEN SPACE

1. Introduction

The rapid rate of urban development and population growth in the latter half of the 20th century and the early 21st century pose community health challenges for urban designers and planners today. Specifically, urban land use and land cover patterns have implications for human health, defined as a combination of physical and mental health, as well as social well-being (Barr, 2014; World Health Organization, 2006). Access and exposure to urban green space, which includes all vegetated land cover (e.g., trees, grass, shrubs, and woodlands), as well as any land uses with publicly available recreational amenities (e.g., parks, schoolyards, university campuses, and conservation areas) located within a city's geographic boundary, have been linked to positive physical and mental health outcomes (Bratman et al., 2019; James et al., 2015; Kondo et al., 2018; Velarde et al., 2007), providing an opportunity for designers, planners, and public health officials to mitigate the negative health consequences associated with urban environments.

1.1 Urban Green Space and Mental Health

Interdisciplinary research over the past 40 years has found that access and exposure to green space contributes directly to mental health, defined as "the absence of mental illness and the presence of psychological well-being" (Bratman et al., 2019, p. 2). The associations between nature and health have been investigated extensively, dating back to Ulrich's 1984 study in which post-surgery recovery times for patients with a window view of trees were significantly shorter than for patients with a window view of a brick wall (Ulrich, 1984), and a recent review found mounting evidence that exposure to nature improves psychological well-being and reduces risk of some mental illnesses (Bratman et al., 2019). Myriad mental health benefits have been linked to spending time in nature or looking at green landscapes, including increased happy, relaxed, and meditative states as well as reduced levels of stress, tension, anger, and depression (Aspinall et al., 2015; Hartig et al., 2003; J. Lee, 2017; Roe, 2013; Velarde et al., 2007). White et al. (2017) found that urban residents who visited a natural area (e.g., park, woodland, or coast) self-reported being happier the day after their visit compared to those who had not visited a natural area on the preceding day, and those who reported spending time in nature at least once per month had significantly higher eudemonic well-being (i.e., finding one's life activities meaningful) compared to those who spent less than one day per month in nature. Two central theories have emerged from these investigations: stress reduction theory and attention restoration theory, positing that interacting with nature reduces stress levels and replenish one's ability to focus, respectively (Bratman et al., 2012).

A growing body of research has investigated the spatial relationship between green space access and mental health, comparing various green space metrics (e.g., number of parks, park area, park amenities, and total green space) with results from mental health surveys and clinical diagnoses. Engemann et al. (2019) found that children living in the least green areas—defined by cumulative normalized difference vegetation index (NDVI) within 210 m of their place of residence—were at greater risk to develop psychiatric disorders compared to those living in the greenest areas. Beyer et al. (2014) identified that residents living in greener areas—those with higher cumulative NDVI and/or percent tree canopy cover at the Census tract level—reported significantly lower levels of stress, anxiety, and depression. In addition, Nutsford et al. (2013) found that increased access to total green space (i.e., sum of areas greater than 500 m^2) within three kilometers of place of residence was associated with significantly lower levels of anxiety and mood disorders, and Maas et al. (2009) found that residents with greater total green space access (i.e., green land uses within 1 and 3 km) reported fewer feelings of loneliness and better overall psychological well-being. These studies provide evidence to support the theory that access and exposure to urban green cover influence both clinical and self-reported mental health outcomes.

Researchers have also worked to identify how specific green space elements influence mental health, and results from these studies indicate that increased quantities of various types of urban green space correspond with improved mental health outcomes. People with access to a greater number of parks and more total park area reported better mental health perceptions than those with poorer park access

(Sturm & Cohen, 2014; Wood et al., 2017). While access to large parks had a stronger correlation with better mental health outcomes, access to smaller pocket parks had a statistically significant positive relationship as well (Wood et al., 2017). Although streetscape greenery has not been a primary source of investigation in other studies, Van Dillen et al. (2012) and de Vries et al. (2013) found that high quality streetscape vegetation was associated with better mental health outcomes, and Taylor et al. (2015) found a negative correlation between number of street trees and rates of antidepressant prescriptions, indicating that individuals living in areas with more street trees had lower levels of clinically diagnosed and medicated depression. These findings provide further evidence tying mental health outcomes to urban green space with increasing levels of specificity.

1.2 Urban Green Space and Physical Activity

While mental health benefits may be obtained from contact with nature, access to urban green spaces contributes to health outcomes by creating opportunities for physical activity. Parks provide opportunities for a variety of leisure-time physical activities (e.g., walking, jogging, cycling, soccer, volleyball, and tennis), and numerous studies have identified positive associations between park access (i.e., total park area and/or number of parks) and physical activity (Astell-Burt et al., 2013; Coombes et al., 2010; Giles-Corti et al., 2005; Jones et al., 2009; Mytton et al., 2012). In addition, specific urban green space qualities have been identified as influential to rates of park use and physical activity. Individuals with access to large and attractive parks and open spaces were twice as likely to visit those spaces (Giles-Corti et al., 2005), and residents' park-based physical activity has been positively associated with the access to a playground, splash pad, basketball court, tennis court, fitness station, or skatepark within 1-mile road distance of place of residence (Kaczynski, Besenyi, et al., 2014). Kaczynski et al. (2008) found that the presence of paved trails and the total number of park facilities (i.e., features the directly enable physical activity such as trails, basketball courts, and open spaces) were the most important factors for determining park use for physical activity, even when park size, aesthetics, and perceived safety were included in the models. These findings support the notion that greater access to large, ecologically diverse urban green spaces with an abundance of park features increases the likelihood that residents will engage in physical activity.

1.3 Problem Statement, Research Questions, and Conceptual Framework

While the influences of urban green space access and exposure on physical activity and mental well-being have been investigated extensively, the precise nature of these relationships remains unclear. Researchers have developed numerous measures of urban green space access, exposure, and quality (Ekkel & de Vries, 2017; Gidlow et al., 2018; Rigolon, 2016; van den Berg et al., 2015) and have found that, in general, access to parks and recreational activity areas increases the likelihood that residents will participate in physical activities and meet physical activity guidelines (Astell-Burt et al., 2013; Coombes et al., 2010; James et al., 2015; Kaczynski, Besenyi, et al., 2014; Mytton et al., 2012), and exposure to urban green cover improves psychological well-being and reduces risk of some mental illnesses (Bratman et al., 2012, 2019; Engemann et al., 2019; Maas et al., 2009; van den Berg et al., 2015). However, the use of disparate urban green space metrics has led to incongruous analyses that overlook potentially influential green space characteristics, making it difficult to identify direct links between specific green space components, physical activity, and mental well-being. Numerous factors—sociodemographic characteristics, individual health history, lifestyle choices, resident self-selection, perceptions of neighborhood environment, and neighborhood walkability—have been identified as potential mediating forces in the relationships between green space access and exposure, physical activity, and mental well-being (Cerin et al., 2008; Frank et al., 2005; Huang et al., 2020; Jones et al., 2009; Kaczynski, Besenyi, et al., 2014; Kaczynski et al., 2008; Kaczynski, Koohsari, et al., 2014; Kaczynski & Mowen, 2011; Reis et al., 2009). Consequently, it is necessary to factor in, and distinguish between, the effects from these factors. Yet, no studies, to my knowledge have sought to include all these factors into one comprehensive analysis. Though not meeting criteria for causal inference, disentangling effects of these potentially mediating factors from urban green space characteristics would move closer to understanding causation in cross-sectional studies that assess relationships between urban green space access/exposure, physical activity, and mental well-being (Frank et al., 2007). To this end, I take an ecological approach—one that factors in a diverse suite of individual and contextual factors (McLaren & Hawe, 2005)—to identify which urban green space access and exposure characteristics have the strongest relationships with park use, neighborhood-based physical activity, and mental well-being (Figure 3.1).

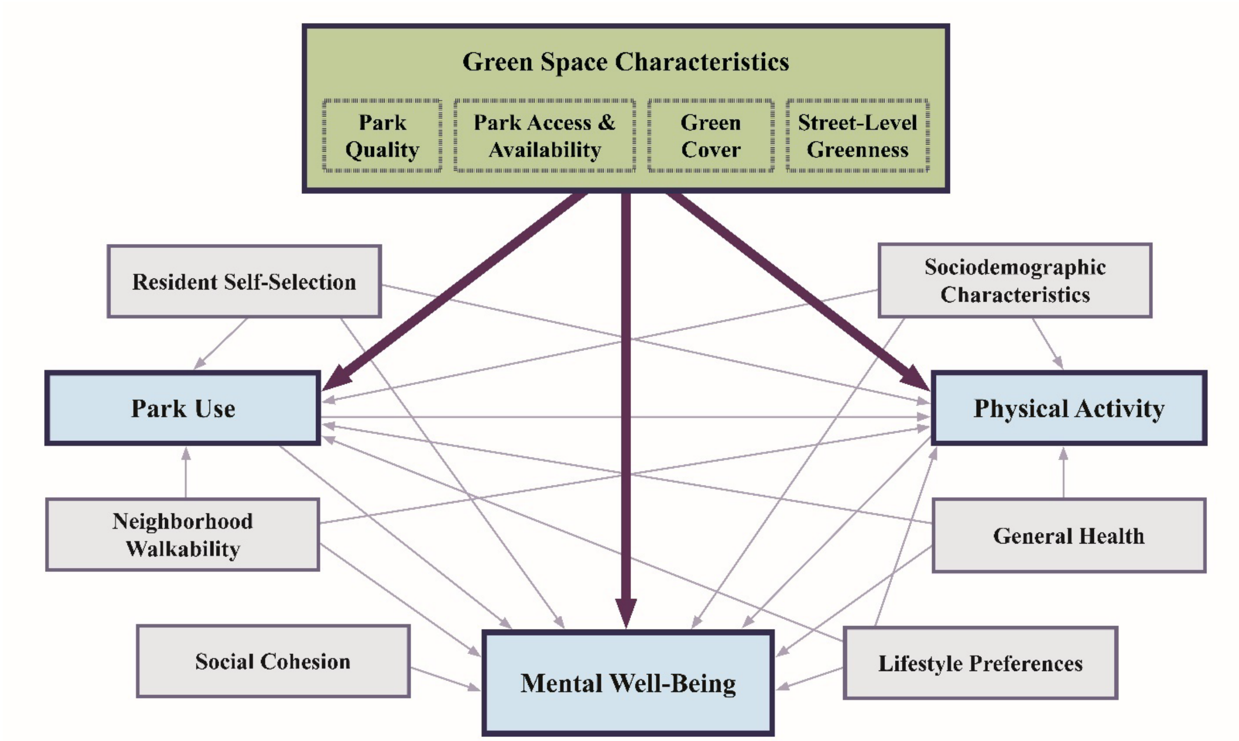

Figure 3.1. Conceptual model depicting relationships between model response variables (i.e., park use, physical activity, and mental well-being), explanatory variables (i.e., green space characteristics), and control variable groups. Relationships between explanatory variables (green box) to response variables (blue boxes) are represented by thick purple arrows; relationships between control variables (gray boxes) and response variables are represented by thin gray arrows.

2. Methods

2.1 Site Context

This study was conducted in Portland, the largest city in Oregon, USA with an estimated population of 641,162 in 2021 (Figure 3.2; U.S. Census Bureau, 2022). Portland's population has an estimated median household income of $73,7159 and is approximately 69.5% non-Hispanic, White (U.S. Census Bureau, 2022). Portland residents' commuting behavior suggests an active populace; the American Community Survey 5-year estimate (2008-2012) found that Portland had the highest rate of bicycle commuters among large U.S. cities, with 6.1% biking to work and an additional 5.7% of the population walking to work (McKenzie, 2014). Portland is well known as an environmentally conscious city and has three bureaus or departments—Environmental Services, Planning and Sustainability, and Parks & Recreation—that are primarily responsible for the planning and management of Portland's public urban green space and environmental health. The City of Portland contains over 500 parks and natural areas and had a citywide canopy cover of 30.7% as of 2015 (Oregon Metro RLIS, 2020a; Portland Parks & Recreation, 2017c). Recent publications by Portland's Parks & Recreation department, including the *2017-2020 Portland Parks & Recreation Strategic Plan* and *Five-Year Racial Equity Plan*, indicate a strong commitment to improving the equity of urban green space resources for Portland's low-income and ethnically diverse communities (Portland Parks & Recreation, 2017b, 2017a). As such, Portland provides an excellent opportunity for urban green space health equity research.

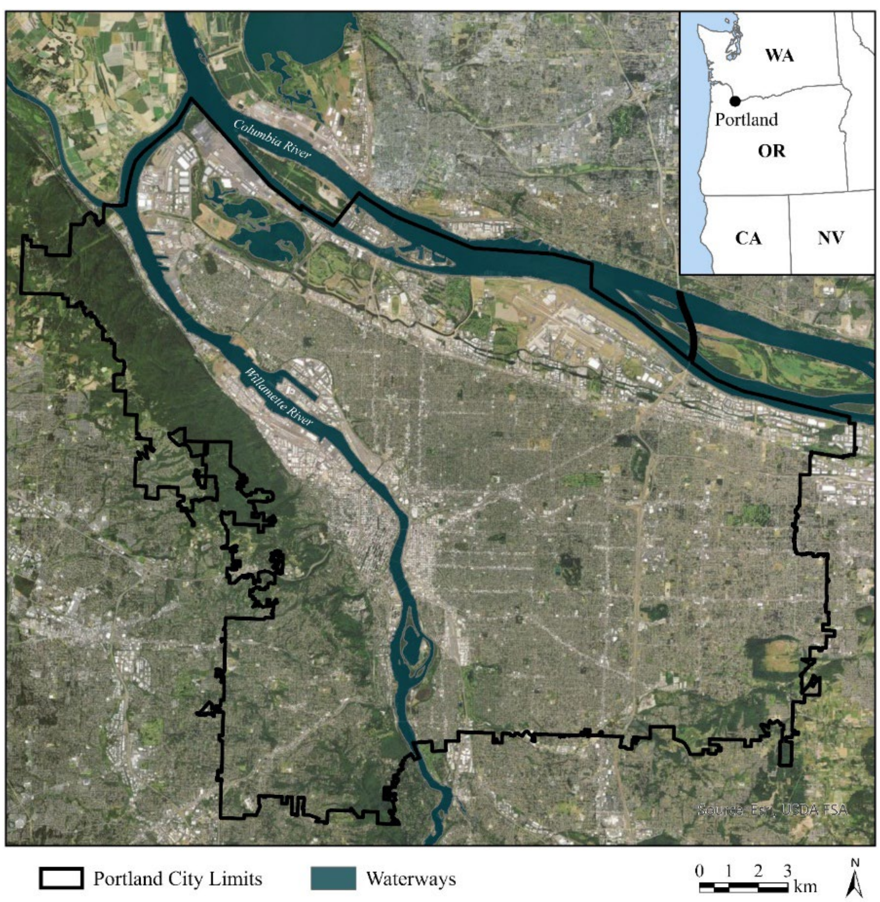

Figure 3.2. Map of the Portland, Oregon with 2016 aerial photograph (United States Department of Agriculture, 2016).

2.2 Survey Data

Survey data were collected from July through October 2021 using a non-probability sample, administered via an online research panel through Qualtrics, which provided the survey platform and recruited participants for the study. Research using online panels to collect survey data has become increasingly common across multiple disciplines (Baker et al., 2013; Hays et al., 2015; Porter et al., 2018; Riley et al., 2014; Walter et al., 2019), allowing researchers to recruit large samples of specific populations at a relatively low cost (Hays et al., 2015; Walter et al., 2019). To protect respondent anonymity while collecting spatial data on place of residence, respondents were asked to place a marker on a map within a block radius of their place of residence and provide the name of the street they live on and the nearest cross streets. Latitudinal and longitudinal coordinates of the marker were used for resident location. If the marker was placed outside of Portland city limits or if the respondent noted that they were not able to properly use the map, points were created at the intersection of respondents' street of residence and nearest cross street. Survey data were inspected for response quality during and after data collection, and samples that did not meet response quality criteria were removed prior to statistical analysis (Appendix B, Section B2.5). All components of this study involving human subjects were approved by the University of Oregon Internal Review Board (STUDY00000093), and survey participant informed consent was obtained electronically.

2.2.1 Physical Activity, Mental Well-being, and Park Use

Surveys have been used extensively to obtain self-reported physical activity data (e.g., Baar et al., 2015; Cerin et al., 2008; De Bourdeaudhuij et al., 2003; Frank et al., 2006; Kaczynski, Besenyi, et al., 2014; Kaczynski, Koohsari, et al., 2014; Mackenbach et al., 2018; R. Zhang et al., 2019). I used the Neighborhood Physical Activity Questionnaire (Giles-Corti et al., 2006) to assess neighborhood-based physical activity and the International Physical Activity Questionnaire (IPAQ) short form (*International Physical Activity Questionnaire*, 2002) to assess total physical activity (Appendix A). Total physical activity was determined as metabolic equivalent minutes per week (MET-m/week), calculated based on the number of minutes engaged in walking, moderate, and vigorous physical activity (*Guidelines for Data*

Processing and Analysis of the International Physical Activity Questionnaire (IPAQ), 2005). Neighborhood-based physical activity was separated into two categories: low and moderate/high (Dadvand et al., 2016). The thresholds for moderate weekly physical activity were 1) at least three days of ≥ 20 minutes of vigorous-intensity physical activity, 2) at least five days of ≥ 30 minutes of moderate-intensity physical activity, or 3) at least five days of combined walking, moderate-intensity, or vigorous-intensity physical activity and ≥ 600 MET-m/wk (*Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ)*, 2005).

Self-reported mental well-being was assessed using the WHO-5 Well-Being Index questionnaire (World Health Organization, 1998) and four personal well-being questions from the United Kingdom's Office of National Statistics (ONS; Office of National Statistics, 2018). The WHO-5 questionnaire contains five questions, each scored on a 0-5 scale, that are summed and multiplied by four to obtain a percentage score ranging from 0 to 100 (Appendix A). The ONS well-being questions capture different aspects of well-being—evaluative well-being (i.e., life satisfaction), eudemonic well-being (i.e., life worthwhile), positive experiential well-being (i.e., happiness), and negative experiential well-being (i.e., anxiety)—and are scored on a 0-10 scale. Consistent with ONS recommendations, scores greater than five for negative experiential well-being and scores greater than six for evaluative, eudemonic, and positive experiential well-being were rated "high", and these values were used as a threshold for binomial classification (Office of National Statistics, 2018).

Park use was assessed by asking respondents how many times they had visited any park and how many times they had visited a park in their neighborhood (i.e., 10–15-minute walk) in the past month (Appendix A). Responses were coded into two categories: at least one park visit per week and less than one park visit per week.

2.2.2 Lifestyle Preferences, Neighborhood Perceptions, General Health, and Sociodemographic Factors

There are numerous factors that potentially mediate relationships between urban green space access/exposure and residents' physical activity and mental well-being (Alcock et al., 2014; Cerin et al., 2008; Chong et al., 2019; de Jong et al., 2012; Engemann et al., 2019; Frank et al., 2007; Giles-Corti et al., 2005; Jones et al., 2009; Maas et al., 2009; Mytton et al., 2012; van Dillen et al., 2012). Frank et al. (2007) assert that, to move from identifying correlation closer to understanding causation in cross-sectional studies, it is necessary to factor in, and distinguish between, the effects from resident preferences, characteristics of the built environment, and pertinent individual health history. In addition to self-reported physical activity, mental well-being, and park use, I asked survey respondents about their sociodemographic characteristics, general health, neighborhood perceptions, and lifestyle preferences (Appendix A; Table B1). I collected respondents' age, gender, race, ethnicity, income, and educational attainment, as well as their homeownership, car ownership, and employment status. I asked respondents to rate their general health and report their height and weight (converted to metric body mass index), nightly sleep quantity, physical activity limitations, and previous mental illness diagnoses. As perceptions of neighborhood green space and walkability vary from objective measures (Gebel et al., 2009; Jones et al., 2009; Leslie et al., 2010), I created a subjective neighborhood walkability index to assess residents' perceptions of their neighborhoods' land use mix, walkability, aesthetics, and safety by taking a sum of z-scores from seven abbreviated Neighborhood Environment Walkability Scale (NEWS-A) subscales (α=0.58; Table B1; Cerin et al., 2006). Neighborhood social cohesion was assessed by taking the average of four items from the Perceived Neighborhood Social Cohesion questionnaire, scored on a 7-point Likert scale that measure each respondent's sense of belonging as well as their perceptions of neighbor friendliness, trustworthiness, and helpfulness (α=0.84; Dupuis et al., 2016; Kim & Kawachi, 2017).

Review articles from transportation and urban planning literature have identified numerous examples where, to varying degrees, resident self-selection—the theory that people's lifestyle preferences determine where they live—influences rates of active transportation, and thus physical activity (Bohte et al., 2009; Cao et al., 2009). As such, I included a question asking residents to identify important considerations when they were moving to their current housing (Appendix A). Five binary variables were created from this question to distinguish residents who selected their place of residence with consideration to ease of walking, ease of cycling, proximity to parks or natural areas, presence/quality of street trees, and access to private outdoor space (Table B1). I included several additional lifestyle-related questions, asking survey respondents if they owned a dog and if they identified as a smoker (Appendix A).

2.3 Green Space Variables

Researchers have used various measures to investigate the distribution of green space and the accompanying health benefits, and there is no clear consensus regarding the appropriate metrics for analysis. As recommended by Bratman et al. (2019), I obtained a combination of green space metrics across four categories—park quality, park access and availability, green cover, and street level greenness—to identify characteristics of urban green space associated with physical activity and mental health outcomes.

2.3.1 Park Quality

Urban green space quality has been identified as pertinent to park use (Fongar et al., 2019; Giles-Corti et al., 2005), physical activity (Giles-Corti et al., 2005; Hoffimann et al., 2017), and mental health (de Vries et al., 2003; van Dillen et al., 2012). I used the Natural Environment Scoring Tool (NEST), a 47-item questionnaire, to obtain overall park quality scores and scores based on seven domains: accessibility, amenities, incivilities/safety, natural and non-natural aesthetics, recreation facilities, and usability (Gidlow et al., 2018). In addition, I used a section of the Community Park Audit Tool (CPAT) to inventory specific park activity areas (Kaczynski et al., 2012). I visited every park, natural area, cemetery, golf course, and public schoolyard within the city limits of Portland (n=634; Oregon Metro RLIS, 2020a, 2020b) and audited all those that were accessible, and did not require payment to enter (n=406; Appendix B, Section B2.2, Figure B3). I calculated average NEST scores—for each domain and overall—and counted the number parks/schoolyards with each CPAT activity area for all parks/schoolyards accessible within 400 and 800 m road distance from each survey participant's place of residence (Table 3.1, Figure B4).

2.3.2 Park Access & Availability

Park accessibility (i.e., distance to nearest park) and availability (i.e., number or area of parks within a defined distance) are important considerations when analyzing urban green space distribution.

Researchers have not reached a consensus for the appropriate distance to or minimum size of green space when analyzing availability (Ekkel & de Vries, 2017), and as such, I adopted several commonly used distances (e.g., Coombes et al., 2010; Crawford et al., 2008; Hoffimann et al., 2017; Jones et al., 2009; Kaczynski, Besenyi, et al., 2014; Rigolon, 2016). I measured accessibility as the road distance from each participant's place of residence to the nearest audited park, natural area, cemetery, golf course, and public schoolyard (n=406) using ArcGIS Network Analyst (Figure B1; ESRI, 2019). I defined availability as the presence, number, and area of audited parks, natural areas, cemeteries, golf courses, and public schoolyards within 400 and 800 m road distance from each survey participant's place of residence (Table 3.1; Figure B2).

2.3.3 Green Cover

Exposure to green cover, or greenness generally, may provide critical health benefits, and various metrics have been used to calculate exposure to vegetated land cover (Ekkel & de Vries, 2017). Cumulative NDVI, or the average NDVI within a given Euclidean buffer, is commonly used as an indicator of living vegetation identified from multi-band satellite or aerial imagery (Beyer et al., 2014; Ekkel & de Vries, 2017; Nesbitt et al., 2019; Smith et al., 2017). I calculated cumulative NDVI within 400 and 800 m Euclidean buffers surrounding survey participants' places of residence using National Agriculture Imagery Program (NAIP) four-band aerial imagery from 2016 (Table 3.1; Figure B7; United States Department of Agriculture, 2022). In addition, I used one-meter resolution urban land cover data for Portland from the United States' Environmental Protection Agency EnviroAtlas (US EPA, 2017) to calculate green cover (i.e., all vegetation cover types) and tree canopy cover by percent area within 400 and 800 m Euclidean buffers of each survey participant's residence location (Table 3.1; Figure B6). I further subdivided green cover by land use type to identify percent of green cover and tree canopy cover on right-of-way, park/schoolyard, and private land (i.e., not right-of-way or park) within 400 and 800 m Euclidean buffers of each survey participant's place of residence Figure 3.3).

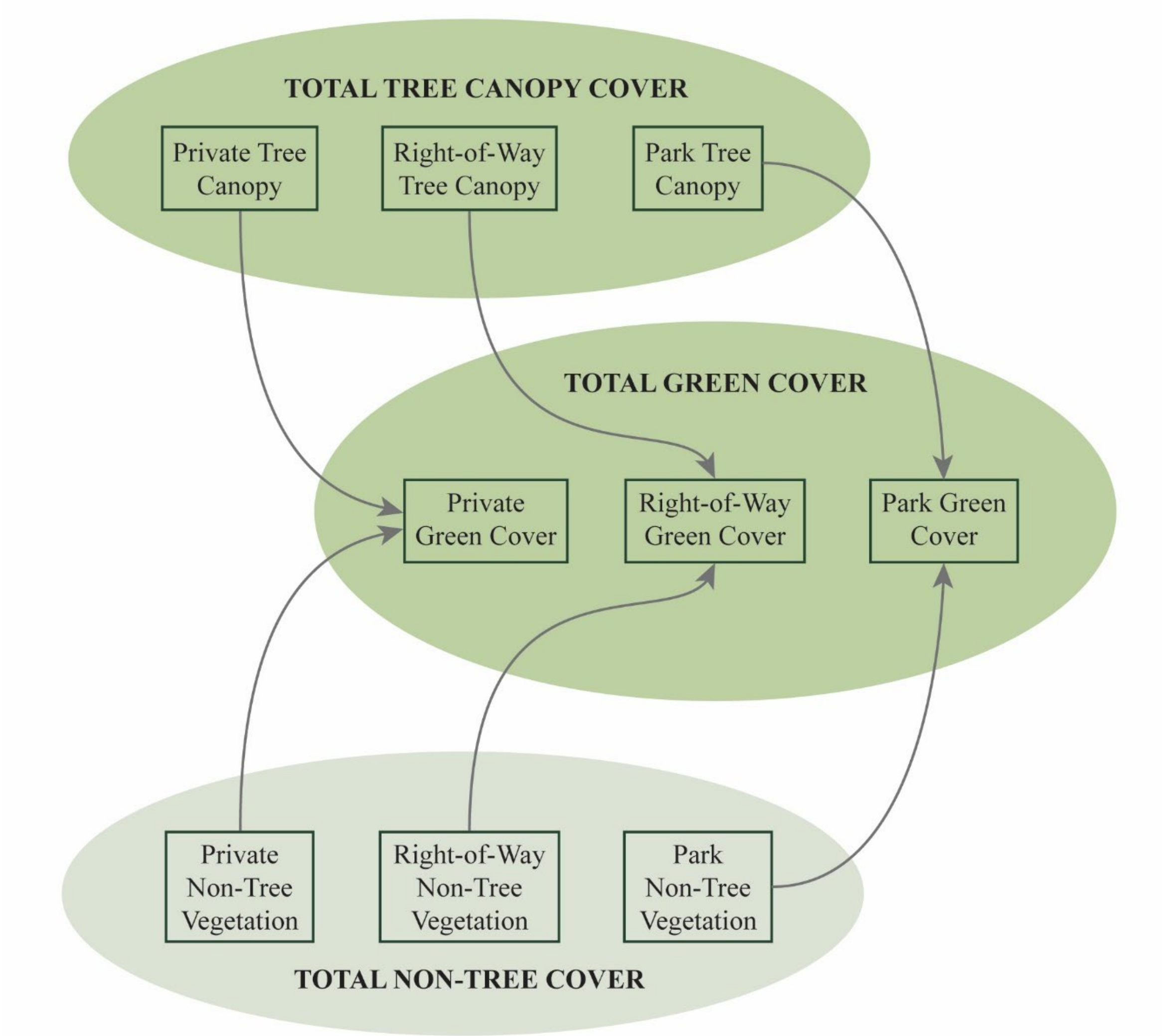

Figure 3.3. Green cover variables are distinguished by land use type (i.e., private, right-of-way, and park), as well as cover type (tree canopy, non-tree vegetation, and green cover). Green cover variables include tree canopy and non-tree canopy cover. Only tree canopy and green cover variables were used in modeling (i.e., non-tree vegetation cover was only used to calculate green cover variables).

2.3.4 Street-Level Greenness

To more accurately represent greenness as experienced from the human perspective, I calculated a modified Green View Index (GVI), a metric that quantifies greenness as seen from the right-of-way, by taking the sum of all green pixels in street-level imagery and dividing by the total number of pixels using *NumPy* and *PyMeanShift* Python packages (Harris et al., 2020; Jean, 2012) and modified open source code (Li et al., 2017, 2018/2020; Li, Zhang, Li, Kuzovkina, et al., 2015; Li, Zhang, Li, Ricard, et al., 2015; Yang et al., 2009). I adapted the modified GVI proposed by Li et al. (2015) to create panoramas with three Google Street View images at each location (120° horizontal field of view and 0° pitch; Figure B8-B9). I generated points 50 m apart across the entire road network within Portland city limits and used the Google Street View Static API to download images (Google, 2020). Images taken during leaf-off period (October-April) were removed from the dataset and replaced with the most recent historical Google Street View images taken during leaf-on period (May-September), if available. The final GVI shapefile contained 148,086 total points across 49,362 locations. Average GVI was calculated for 400 and 800 m Euclidean buffers surrounding each survey participant's place of residence (Figure B10).

Table 3.1. Urban green space metrics, measured for each survey respondent, used to model park use, neighborhood-based physical activity, and mental well-being.

Green Space Variable	Variable Category	Data Type
Road distance to nearest park (m)	Park Accessibility	Continuous
Presence of park [a]	Park Availability	Binary
Number of parks [a]	Park Availability	Count
Park area (ha) [a]	Park Availability	Continuous
Park quality score (domain and overall scores) [a]	Park Quality	Continuous
Park Facilities [a c]	Park Quality	Count/Binary
Cumulative NDVI [b]	Green Cover	Continuous
Vegetation cover – total, park/open space, private, and right-of way (percent) [b]	Green Cover	Continuous
Tree canopy cover – total, park/open space, private, and right-of way (percent) [b]	Green Cover	Continuous
Green View Index (average) [a]	Street-level Greenness	Continuous

NDVI – normalized difference vegetation index

[a] within 400 and 800 m road distance of residence location

[b] within 400m and 800m Euclidean buffer from residence location

[c] Park facilities data were only used in park use models.

2.4 Neighborhood Walkability

Transportation and urban planning researchers have identified a suite of built environment variables that influence physical activity (Ewing & Cervero, 2010; Sallis et al., 2016), and these variables should be considered as potential confounding variables when investigating relationships between urban green space and health. To reduce potential for multicollinearity among built environment variables, Frank et al. (2005, 2006, 2007) proposed a walkability index to compare residence locations by taking a sum of the z-scores of residential density, land use heterogeneity, and intersection density within a one-kilometer road-network service area. Frank et al. (2005) explained that, in addition, "measures of urban form that capture the presence of sidewalks and bike paths will also advance the ability to assess the linkages between the built environment and physical activity" (p. 120). As several studies have found that sidewalks and bike infrastructure increase the likelihood of walking, cycling, or physical activity (e.g., Ding et al., 2013; C. Lee & Moudon, 2008; McCormack et al., 2012), I generated an objective neighborhood walkability index, similar to the one proposed by Frank et al. (2007), by taking the sum of z-scores for residential density, street connectivity, land use mix, sidewalk-to-road-length ratio, and bike-infrastructure-to-road-length ratio within a one-kilometer road-network from each survey participant's place of residence (Table 3.2).

Table 3.2. Neighborhood walkability index factors, adapted from Frank et al. (2005, 2006, 2007) with added sidewalk and bike lane accessibility measures.

Measure	**Definition**	**Data source**
Resident density	Residential units/acres in residential land use	RLIS – Multifamily Housing Inventory; Taxlots
Street Connectivity	Number of intersections/km^2	RLIS – Streets
Land Use Mix +	Measure of evenness of distribution of residential, commercial, and educational buildings	RLIS – Taxlots; Building Footprint Database
Sidewalk Accessibility	Length of sidewalks/total street length	RLIS – Sidewalks – Beta; Streets
Bike Infrastructure Accessibility	Street length with bike lane infrastructure/total street length	RLIS – Bike Routes; Streets

+ Land Use Mix = A/ln(N) where:

A = (b1/a)*ln(b1/a) + (b2/a)*ln(b2/a) + (b3/a)*ln(b3/a) + (b4/a)*ln(b4/a) + (b5/a)*ln(b5/a)

a = total area (ft2) of land in single- and multi-family residential, commercial, mixed, and educational land uses

b1 = building footprint area (ft2) in single-family residential uses

b2 = building footprint area (ft2) in multi-family residential uses

b3 = building footprint area (ft2) in commercial uses

b4 = building footprint area (ft2) in mixed uses (i.e., combination of residential and commercial land uses)

b5 = building footprint area (ft2) in educational uses

N = number of land uses

2.5 Statistical Analysis

Statistical analysis was conducted with response variables in three categories—park use (any park and neighborhood park), neighborhood-based physical activity, and mental well-being—to identify relationships with urban green space. I built multiple regression models in R (R Core Team, 2022) to investigate relationships between urban green space access/availability/exposure and park use, neighborhood-based physical activity, and mental well-being while accounting for a suite of potentially mediating environment, lifestyle, health, and sociodemographic variables (Table B1; Figure 3.1). The type of regression model selected depended upon the response variable; ordinary least squares (OLS) multiple linear regression was used for WHO-5 well-being index models (i.e., continuous response variable), and binomial logistic regression was used for ONS personal well-being, neighborhood-based physical activity, and park use models (i.e., binary response variables).

Baseline models were generated (i.e., control/confounding variables only) for each response variable, and models were then generated by adding one green space variable at a time to the baseline model, iterating through all green space variables (see Table 3.1). A summary table was created for all models where the added green space variable was significant ($\alpha = 0.05$) and improved the adjusted-R^2 (for OLS regression models) or decreased the Akaike information criterion (AIC; for binomial logistic regression models) from the baseline model. Ordinary least squares regression models were removed if they violated homoscedasticity or residual normality assumptions (Breusch-Pagan and Shapiro-Wilk test $p < 0.05$, respectively), contained multicollinearity (variance inflation factor ≥ 2), or the green space variable estimated coefficient changed sign from simple regression. This process was the repeated with two green space variables included in the model, and models were selected if both green space variables were significant ($\alpha = 0.05$) and adjusted-R^2 increased (for linear regression) or AIC decreased (for binomial logistic regression) from the best-fit model with one green space variable.

3. Results

3.1 Survey Descriptive Statistics

I obtained a response rate of 37.6%, based on total completed responses, and 422 survey responses met data quality standards required for spatial and statistical analyses (Appendix B, Section B4). The survey population's racial, ethnic (i.e., Hispanic, non-Hispanic), and household size demographic data were comparable to American Community Survey (ACS) estimates for the City of Portland, while the survey population was more female, lower income, and less educated than citywide ACS estimates (Table 3.3; U.S. Census Bureau, 2022).

Table 3.3. Descriptive statistics for survey respondents (n=422) with demographic data compared to American Community Survey 5-year estimates for Portland, OR (U.S. Census Bureau, 2022).

	Survey	**Census** [a]
Median Household Income	$40,000 – 49,999 [b]	$73,159 [c]
Race, White alone	73.9%	75.3 %
Race, Black or African American alone	6.2%	5.9%
Race, Asian alone	5.0%	8.7%
Race, American Indian or Alaska Native alone	1.2%	0.8%
Race, Native Hawaiian or Pacific Islander alone	0.5%	0.7%
Race, two or more	9.5%	6.4%
Gender, Female	57.6%	50.4%
Hispanic (any race)	9.5%	9.8%
Mean Household Size	2.3 [d]	2.29
Education, Bachelor's degree or higher (25 years old and above)	40.0%	51.0% [e]
Park Use (any park, weekly)	49.5%	NA
Park Use (neighborhood park, weekly)	38.2%	NA
Neighborhood-based Physical Activity (moderate/high)	50.2%	NA
Neighborhood-based Physical Activity as percent of Total Physical Activity (mean)	29.5%	
WHO-5 Well-Being Index (median)	44	NA
Distance to Nearest Park (median)	407 m	NA
No Park Access within 400 m	35.1%	NA
Park Count (median; within 800 m)	3	NA
Total Vegetation Cover (mean, 800 m)	43.6%	NA
Total Tree Cover (mean, 800 m)	22.3%	NA
Green View Index (mean, 800 m)	15.4	NA

[a] U.S. Census data from 2016-2020 American Community Survey (ACS) 5-year estimates, except for education data, which were from 2015-2019 ACS 5-year estimates.

[b] Median household income was reported within $10,000 range.

[c] Per capita income reported as $43,811.

[d] ACS education level is reported for respondents over 25 years old only.

[e] Mean household size may be a slight underestimate as seven respondents reported household size of "7+".

3.2 Park Use

Nearly 50% of survey respondents reported visiting any park at least once per week, while 38.2% reported visiting a neighborhood park on a weekly basis (Table 3.3). Of all the models generated with one green space predictor added to the baseline model, 18 neighborhood park use models had a significant green space predictor ($p < 0.05$) and performed better (i.e., lower AIC) than the baseline model (Table B3). In the best-fit model (i.e., lowest AIC), residents with access to at least one park within 400 m of their place of residence were 3.9 times as likely to visit a neighborhood park and 2.4 times more likely to visit any park on a weekly basis compared to those without a park within 400 m (Table 3.4). Survey respondents with higher perceived neighborhood environment walkability were more likely to use both neighborhood and any parks, and those who reported considering park access in their home selection process were 3.4 and 2.7 times more likely to visit a neighborhood park or any park on a weekly basis, respectively. Residents who reported ease of walking as an important factor in home selection were 1.8 times more likely to use a neighborhood park, while those who reported ease of biking as an important consideration were 2.3 times more likely to use any park. In addition, respondents with access to a car were approximately twice as likely to use a park (neighborhood park or any park) on a weekly basis compared to those without car access.

Table 3.4. Best-fit binomial logistic regression models for neighborhood park use (weekly) and any park use (weekly) with one green space predictor and all control variables (n=422).

Predictor Variable	**Weekly Park Use (Neighborhood Park) Odds Ratio [95% CI]**	**Weekly Park Use (Any Park) Odds Ratio [95% CI]**
(Intercept)	**0.028 [0.01 - 0.13] *****	**0.10 [0.02 - 0.4] ****
Park access within 400 m (yes=1)	**3.92 [2.28 - 6.94] *****	**2.39 [1.47 - 3.95] *****
Smoker (yes=1)	**3.85 [2.13 - 7.1] *****	**2.35 [1.35 - 4.15] ****
Resident self-selection, park access (yes=1)	**3.42 [1.94 - 6.14] *****	**2.71 [1.56 - 4.77] *****
Neighborhood walkability index, subjective	**1.09 [1.01 - 1.18] ***	**1.10 [1.02 - 1.18] ***
Resident self-selection, walkability (yes=1)	**1.79 [1.05 - 3.06] ***	1.54 [0.92 - 2.59]
Car access (yes=1)	**1.94 [1.01 - 3.78] ***	**2.07 [1.12 - 3.87] ***
Dog ownership (yes=1)	1.54 [0.92 - 2.59]	**2.13 [1.29 - 3.54] ****
Resident self-selection, bikeability (yes=1)	1.64 [0.8 - 3.4]	**2.33 [1.11 - 5.11] ***
Mental illness, diagnosed (yes=1)	0.62 [0.37 - 1.03]	**0.61 [0.38 - 0.99] ***

Table 3.4 Continued

Age [a]	0.84 [0.69 - 1.01]	0.91 [0.76 - 1.08]
Resident self-selection, street trees (yes=1)	1.58 [0.85 - 2.94]	1.38 [0.75 - 2.55]
Body Mass Index (BMI)	1.02 [0.99 - 1.06]	1.01 [0.98 - 1.04]
Employment status (unemployed=1)	0.62 [0.3 - 1.23]	0.78 [0.4 - 1.51]
General health [a]	1.22 [0.92 - 1.63]	1.23 [0.94 - 1.62]
Resident self-selection, private yard (yes=1)	0.73 [0.39 - 1.33]	1.05 [0.59 - 1.86]
Ethnicity (Hispanic/Latinx=1)	0.68 [0.3 - 1.49]	0.50 [0.23 - 1.09]
Vigorous physical activity limitation (yes=1)	0.77 [0.42 - 1.38]	0.72 [0.41 - 1.25]
Neighborhood walkability index, objective	1.03 [0.96 - 1.11]	1.01 [0.94 - 1.09]
Gender (male=1)	0.82 [0.48 - 1.4]	0.66 [0.39 - 1.1]
Education (postsecondary degree=1)	0.82 [0.46 - 1.45]	1.16 [0.68 - 1.99]
Home ownership (yes=1)	1.22 [0.65 - 2.28]	0.65 [0.35 - 1.19]
Sleep (less than 7 hours=1)	1.11 [0.68 - 1.81]	0.90 [0.57 - 1.43]
Race (not White alone=1)	1.12 [0.64 - 1.92]	1.19 [0.7 - 2]
Household income [a]	1.01 [0.92 - 1.11]	1.04 [0.95 - 1.14]

* p<0.05; ** p<0.01; *** p<0.001

[a] ordinal variable (see Table B1 for recoding details)

3.3. Neighborhood-based Physical Activity Model

On average, survey respondents completed 29.5% of their physical activity in their neighborhoods, and 212 of the 422 survey respondents (50.2%) met the criteria for moderate or high weekly neighborhood-based physical activity (Table 3.3). In the baseline model, objective neighborhood walkability, weekly park use, and respondents' perceptions of their general health had the strongest associations with neighborhood-based physical activity (Table 3.5). Those who reported using a neighborhood park on a weekly basis were more than two times as likely to exceed the threshold for moderate neighborhood-based physical activity compared with those who reported to visit a neighborhood park less than once per week. In addition, respondents without a four-year college degree were 1.78 times more likely to meet the moderate neighborhood-based physical activity threshold than those with such a degree.

In total, nine binomial logistic regression models satisfied modeling parameters with one green space predictor and all control variables; however, none of the significant green space variables—all relating to park quality, park accessibility, or park availability variables—had positive associations with neighborhood-based physical activity (Table B4).

Table 3.5. Baseline binomial logistic regression model for moderate/high weekly neighborhood-based physical activity with all control variables and no green space predictors (n=422; AIC = 548.9).

Predictor Variable	Odds Ratio [95% CI]
(Intercept)	0.77 [0.20 - 2.99]
Neighborhood walkability index, objective	1.12 [1.04 - 1.2]**
Neighborhood park use, weekly (yes=1)	2.12 [1.31 - 3.45]**
General health [a]	1.44 [1.11 - 1.88]**
Education (no postsecondary degree=1)	1.78 [1.06 - 3.02]*
Dog ownership (yes=1)	1.54 [0.96 - 2.47]
Body Mass Index (BMI)	0.98 [0.95 – 1.00]
Car access (yes=1)	0.64 [0.36 - 1.15]
Home ownership (yes=1)	1.55 [0.87 - 2.78]
Age [a]	0.88 [0.75 - 1.04]
Race (not White alone=1)	1.42 [0.85 - 2.37]
Smoker (yes=1)	1.43 [0.82 - 2.51]
Gender (male=1)	1.35 [0.83 - 2.19]
Vigorous physical activity limitation (yes=1)	0.73 [0.43 - 1.24]
Sleep (less than 7 hours=1)	0.77 [0.50 - 1.21]
Resident self-selection, park access (yes=1)	1.37 [0.79 - 2.36]
Resident self-selection, bikeability (yes=1)	1.47 [0.75 - 2.94]
Mental illness, diagnosed (yes=1)	1.23 [0.78 - 1.97]
Resident self-selection, street trees (yes=1)	0.81 [0.45 - 1.44]
Household income [a]	1.02 [0.94 - 1.12]
Neighborhood walkability index, subjective	0.98 [0.92 - 1.05]
Employment status (unemployed=1)	0.89 [0.47 - 1.65]
Resident self-selection, private yard (yes=1)	1.09 [0.63 - 1.89]
Resident self-selection, walkability (yes=1)	0.95 [0.57 - 1.57]
Ethnicity (Hispanic/Latinx=1)	1.03 [0.48 - 2.22]

* p<0.05; ** p<0.01; *** p<0.001

[a] ordinal variable (see Table B1 for recoding details)

3.4 Mental Well-being

In modeling WHO-5 well-being, I found strong multicollinearity (VIF > 3) between the objective neighborhood walkability index and several green cover variables (e.g., total green cover and NDVI within 800 m). As the objective neighborhood walkability index was not significant in simple regression or the baseline WHO-5 well-being model, I removed it from all well-being models (Table B5). I identified 18 WHO-5 well-being models that met modeling parameters when adding one green space predictor to the baseline model, 13 of which included a green cover variable (Table B6). An additional 37 models were generated with two green space variables added to the baseline model while satisfying modeling criteria, all of which contained one green cover variable (e.g., NDVI, total green cover/tree canopy, private green cover/tree canopy, and right-of-way green cover) and one park-related variable (e.g., number of parks, park area, park green cover/tree canopy, total park quality, and park amenities; Table B7). While residents' self-reported general health, sleep quantity, and presence of a diagnosed mental illness were the most influential predictors of mental well-being, total green cover within 800 m of respondents' homes was a stronger predictor of mental well-being than total weekly physical activity or any other sociodemographic, economic, lifestyle, or built environment variable (Table 3.6). A 10% increase in total green cover within an 800 m area was associated with a 2-point increase in WHO-5 well-being score (B=0.20). The number of parks within 800 m of respondents' places of residence and respondents' age were also positively associated with self-reported mental well-being, where each additional park corresponded with 1.23-point increase in WHO-5 well-being score.

Thirteen significant green space predictors improved upon the baseline negative experiential well-being model (i.e., ONS anxiety model), twelve of which were green cover variables (i.e., NDVI and total, private, and park green/tree cover; Table B8). A 1% increase in total green cover within 800 m decreased residents' likelihood of having high anxiety scores by 3% (Table 3.7). Positive perceptions of neighborhood environment walkability also decreased the likelihood of high anxiety, and respondents who reported smoking, sleeping fewer than 7 hours per night, or having been diagnosed with a mental illness were approximately two times more likely to feel highly anxious and nearly half as likely to report high happiness levels. Additionally, Hispanic survey respondents were more than three times as likely to report feeling highly anxious compared to non-Hispanic respondents. No green space predictors were significantly associated with experiential well-being (i.e., happiness), evaluative well-being, and eudemonic well-being; however, the strongest predictors included employment status (eudemonic and evaluative well-being only), sleep, self-reported general health, and perceptions of neighborhood social cohesion.

Table 3.6. Ordinary least squares (OLS) regression model for self-reported well-being (WHO-5 well-being index) with all control variables, two green space predictors ($p < 0.5$), and a higher adjusted-R^2 than the best fit model with one green space predictor and all control variables (n=422; adjusted-$R^2 = 0.40$) [a].

Predictor Variable	Estimated Coefficient	Standardized Coefficient (β)	Standard Error
(Intercept)	10.48	NA	6.69
General health [b]	7.76***	0.35	1.04
Sleep (less than 7 hours=1)	-7.39***	-0.17	1.74
Mental illness, diagnosed (yes=1)	-6.3***	-0.14	1.83
Total green cover within 800 m	0.20**	0.13	0.07
Physical activity, total (kMET-m/wk)	0.68**	0.13	0.23
Number of parks within 800 m	1.23**	0.13	0.4
Age [b]	1.42*	0.1	0.65
Employment status (unemployed=1)	-5.25*	-0.08	2.49
Education (postsecondary degree=1)	3.99	0.09	2.04
Neighborhood social cohesion	1.43	0.09	0.77
Gender (male=1)	3.62	0.08	1.91
Dog ownership (yes=1)	-3.36	-0.08	1.89
Smoker (yes=1)	-3.23	-0.06	2.14
Neighborhood walkability index, subjective	0.38	0.06	0.29
Resident self-selection, bikeability (yes=1)	3.93	0.06	2.63
Park use, weekly (yes=1)	-2.68	-0.06	1.9
Car access (yes=1)	-2.98	-0.06	2.3
Resident self-selection, street trees (yes=1)	2.9	0.05	2.25
Household income [b]	-0.32	-0.05	0.34
Ethnicity (Hispanic/Latinx=1)	-3.11	-0.04	2.95
Home ownership (yes=1)	1.9	0.04	2.3
Body Mass Index (BMI)	0.07	0.03	0.11
Resident self-selection, walkability (yes=1)	-0.85	-0.02	1.96
Race (not White alone=1)	0.93	0.02	1.98
Resident self-selection, private yard (yes=1)	0.66	0.01	2.15
Resident self-selection, park access (yes=1)	-0.15	0.00	2.14

* p<0.05; ** p<0.01; *** p<0.001

[a] Model with NDVI had slightly higher adjusted-R2; however, as NDVI and total green cover within 800 m are extremely strongly correlated (r=0.97) and the correlation coefficient for total green cover provides are more intuitive.

[b] ordinal variable (see Table B1 for recoding details)

Table 3.7. Binomial logistic regression models based on Office of National Statistics (ONS) personal well-being questions for negative experiential well-being (i.e., "ONS Anxiety"), positive experiential well-being (i.e., "ONS Happiness"), evaluative well-being (i.e., "ONS Life Satisfaction"), and eudemonic well-being (i.e., "ONS Life Worthwhile").

Predictor Variable [a]	**ONS Anxiety Odds Ratio [95% CI]**	**ONS Happiness Odds Ratio [95% CI]**	**ONS Life Satisfaction Odds Ratio [95% CI]**	**ONS Life Worthwhile Odds Ratio [95% CI]**
(Intercept)	0.35 [0.07 - 1.87]	**0.09 [0.02 - 0.43] ****	**0.09 [0.02 - 0.48] ****	**0.12 [0.02 - 0.6] ***
Neighborhood walkability index, subjective	**0.85 [0.78 - 0.92] *****	0.98 [0.91 - 1.05]	1.01 [0.93 - 1.09]	1 [0.93 - 1.07]
Age [b]	**0.71 [0.59 - 0.85] *****	1.14 [0.96 - 1.36]	1.12 [0.94 - 1.34]	1.16 [0.98 - 1.38]
Total green cover within 800 m	**0.97 [0.95 - 0.99] *****	NA	NA	NA
Mental illness, diagnosed (yes=1)	**2.07 [1.29 - 3.33] ****	**0.57 [0.35 - 0.91] ***	0.62 [0.38 - 1.02]	**0.61 [0.38 - 0.97] ***
Ethnicity (Hispanic/Latinx=1)	**3.32 [1.51 - 7.63] ****	0.76 [0.34 - 1.67]	0.79 [0.35 - 1.76]	1.2 [0.56 - 2.62]
Smoker (yes=1)	**2.32 [1.32 - 4.14] ****	**0.51 [0.28 - 0.9] ***	**0.44 [0.24 - 0.82] ***	0.58 [0.33 - 1.02]
Resident self-selection, walkability (yes=1)	**2.07 [1.23 - 3.52] ****	1.12 [0.66 - 1.91]	0.8 [0.46 - 1.39]	1.11 [0.66 - 1.87]
Sleep (less than 7 hours=1)	**1.87 [1.18 - 2.98] ****	**0.49 [0.31 - 0.77] ****	**0.43 [0.27 - 0.7] *****	**0.47 [0.29 - 0.74] ****
Car access (yes=1)	**2.17 [1.17 - 4.07] ***	1.77 [0.96 - 3.29]	0.99 [0.51 - 1.9]	1.28 [0.69 - 2.37]
General health [b]	0.94 [0.72 - 1.23]	**1.62 [1.23 - 2.16] *****	**2.03 [1.51 - 2.77] *****	**1.92 [1.45 - 2.58] *****
Neighborhood social cohesion	1.17 [0.95 - 1.44]	**1.33 [1.09 - 1.64] ****	**1.34 [1.08 - 1.66] ****	**1.25 [1.02 - 1.53] ***
Employment status (unemployed=1)	1.24 [0.65 - 2.38]	0.59 [0.29 - 1.17]	**0.3 [0.13 - 0.64] ****	**0.37 [0.18 - 0.72] ****
Resident self-selection, private yard (yes=1)	0.68 [0.38 - 1.2]	**2.63 [1.47 - 4.82] ****	**2.23 [1.23 - 4.1] ****	1.37 [0.77 - 2.43]

* p<0.05; ** p<0.01; *** p<0.001

[a] Park use, total physical activity (MET-m/wk), body mass index, income, education, race, gender, homeownership, dog ownership, and resident self-selection (for street trees, easy biking, and park access) were used as control variables and were not significant in any of the ONS personal well-being models.

[b] ordinal variable (see Table B1 for recoding details)

4. Discussion

This study explored relationships between place-of-residence built environment characteristics, park use, neighborhood-based physical activity, and mental well-being to inform urban planning and design decision making.

4.1 Park Use

While previous studies have found positive relationships between park access (Giles-Corti et al., 2005), park availability (Kaczynski, Besenyi, et al., 2014), park size (Cohen et al., 2010; S. Zhang & Zhou, 2018) and diversity of available recreational facilities (Donahue et al., 2018; Kaczynski, Besenyi, et al., 2014), I identified access to any public park, natural area, or schoolyard within 400 m of home as the strongest green space predictor of weekly neighborhood park use even when factoring in resident self-selection for park access (Table 3.4; Figure 3.4). In independent models, I also found positive, but weaker, associations between neighborhood park use and percent of park area within 400 m with green cover or tree canopy cover, as well as specific park qualities (i.e., parks with basketball courts, playgrounds, or at least three paths/trails), park access domain scores (i.e., based on number of entry points and walking/cycling paths), park useability domain scores (i.e., based on the diversity of potential uses including sports, informal games, walking/running, cycling, children's play, conservation, aesthetic appreciation, socializing, and relaxation), and overall park quality scores for parks within 800 m. These findings offer a clear set of planning priorities. First, identify locations for park development in areas without park access within 400m of residences. A road-network service area analysis revealed that nearly half the area of Portland (48.2%) lacks such access to a public park or schoolyard (Figure B5). Independent models suggest promoting park usage by increasing green cover and tree canopy cover, as well as accessibility and useability through development of additional trails, basketball courts, and playgrounds within existing parks, natural areas, and schoolyards. In addition, the significance of perceived neighborhood walkability—consistent with findings by Richardson et al. (2020) that streetscape walkability, aesthetics, and amenities increased likelihood of park use—offers an avenue for further study.

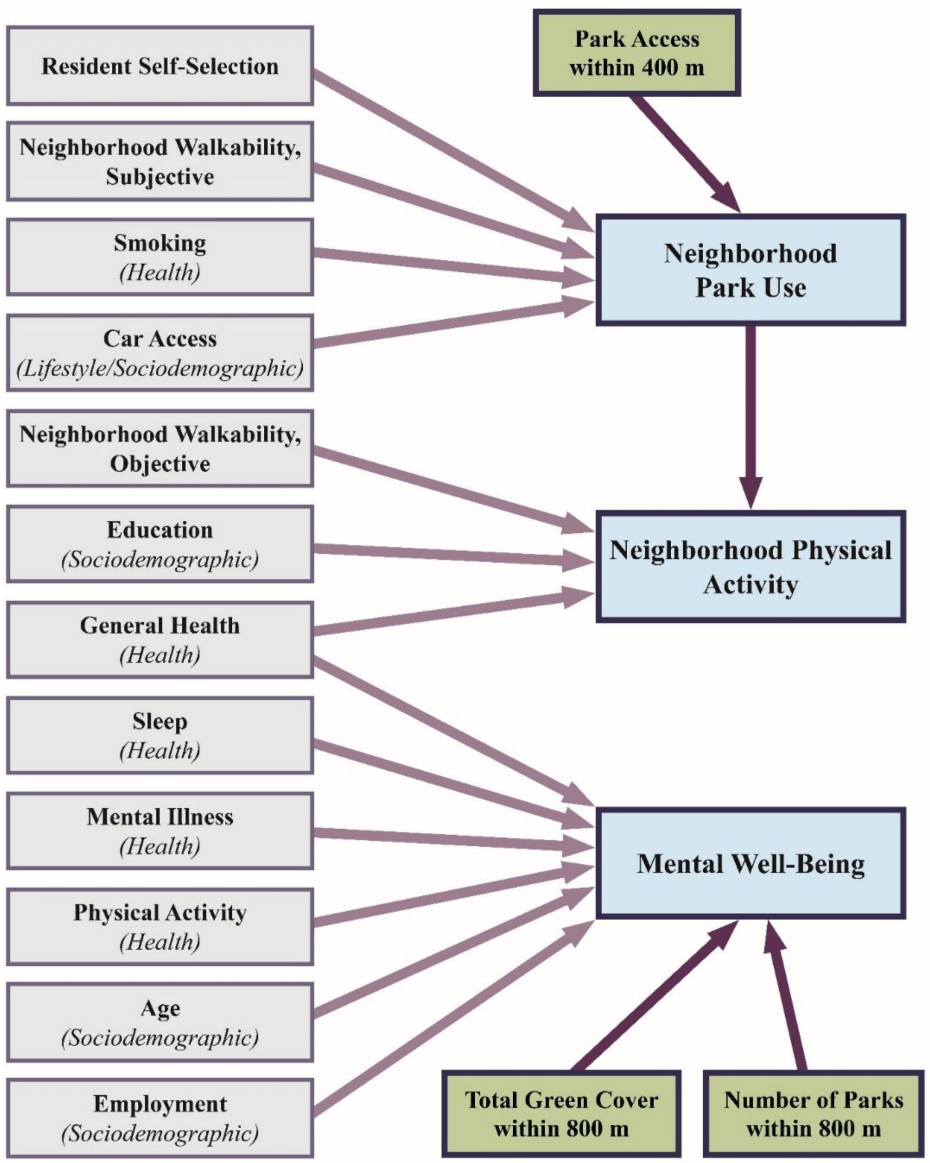

Figure 3.4. Schematic diagram of significant relationships in neighborhood park use, neighborhood physical activity, and overall mental well-being models. Significant relationships between urban green space variables (green boxes) and response variables (blue boxes) are represented with dark purple arrows, while significant relationships between control/moderating variables (gray boxes) and response variables are represented with light purple arrows.

4.2 Neighborhood-based Physical Activity

Previous built environment and urban green space studies have focused predominantly on moderate-to-vigorous intensity physical activity (e.g., Sallis et al., 2016), leisure-time physical activity (e.g., Kajosaari & Laatikainen, 2020), park-based physical activity (e.g., Kaczynski & Mowen, 2011; Wang et al., 2019) and active travel behavior (e.g., Frank et al., 2006). Contrary to the findings from previous studies that identified significant relationships between physical activity and park access/availability (Astell-Burt et al., 2013; Coombes et al., 2010; Giles-Corti et al., 2005; Jones et al., 2009; Mytton et al., 2012) or park quality (Giles-Corti et al., 2005; Kaczynski, Besenyi, et al., 2014; Kaczynski et al., 2008; Schipperijn et al., 2013), I found no direct associations between urban green space characteristics and likelihood that residents would meet the moderate to high neighborhood-based physical activity threshold (Table 3.5, Table B4). Instead, objectively derived neighborhood walkability and weekly park use were the strongest predictors of neighborhood-based physical activity. These findings indicate that characteristics of the built environment may influence physical activity, which is consistent with results from Kaczynski, Koohsari, et al. (2014), where park-based physical was positively associated with road intersection density. Additionally, neighborhood-based physical activity may be indirectly affected by park access, as access to one or more parks within 400m of home increased the likelihood of neighborhood park use which in turn increased the likelihood of neighborhood-based physical activity (Figure 3.4; Table 3.5). And, while Cerin et al. (2008) and Kaczynski and Mowen (2011) found resident self-selection for neighborhood walkability and park access attenuated relationships between green space access and leisure-time walking and park-based physical activity, respectively, resident self-selection was not a significant factor in predicting neighborhood-based physical activity outcomes in Portland (Table 3.5). However, my models suggest that resident self-selection may have an indirect effect on neighborhood-based physical activity, as both self-selection for walkability and park access were significant in park use models (Table 3.4-3.5; Figure 3.4). These findings align with the vast travel behavior literature linking neighborhood design for active transport (i.e., combination of land use mix and residential, intersection, sidewalk, and bike lane density) to physical activity outcomes and generally support urban planning initiatives that increase sidewalk and bicycle infrastructure, residential density, and land use heterogeneity (McCormack, 2017; McCormack & Shiell, 2011). It is important to note that upzoning practices aimed at increasing residential density have been linked to gentrification (Davis, 2021), and wholistic and inclusive housing policy should accompany any zoning changes that target increased densification for walkability.

4.3 Mental Wellbeing Well-being

The quantity of green cover within 800m of residents' homes corresponded with better overall mental well-being (Table 3.6; Figure 3.4), as well as reduced likelihood of anxiety (Table 3.7), suggesting that mental health benefits of green space may be realized through passive exposure to green cover in the landscape surrounding people's homes, as identified by Tsurumi et al. (2018) and Zhang and Tan (2019), and are not necessarily associated with visits to parks or natural areas as identified in previous studies (e.g., Coldwell & Evans, 2018; Dallimer et al., 2014; Mitchell, 2013; Payne et al., 2005; White et al., 2017). With all else being equal, an individual in the 10^{th} percentile for total green cover within 800 m (20.5%) is predicted to have a nearly eight-point lower WHO-5 well-being index score and is more than 3 times as likely to have a high anxiety score compared to an individual in the 90^{th} percentile for total green cover (59.1%; Table 3.6-3.7). Exposure to green cover and tree canopy cover located on specific land use types— in parks, on the right-of-way, and on private property—also significantly improved overall mental well-being and decreased the likelihood of high anxiety in independent models (Table B6-B7). These results provide broad yet illuminating direction for urban green space planners and policy makers: promote green cover on all urban land uses, particularly in areas of low vegetation cover, to maximize mental health benefits. While outside the purview of this study, it is imperative to coordinate urban greening policy and planning with appropriate affordable housing policy to protect against potential gentrification associated with improved urban environmental conditions (Jennings et al., 2019; Wolch et al., 2014).

It is interesting to further consider the relationship between total green cover and neighborhood walkability. As mentioned previously, total green cover is strongly and negatively correlated with neighborhood walkability index (r=-0.84), illuminating a tradeoff in existing urban planning: areas that are better for mental well-being tend to be less conducive for neighborhood-based physical activity. Acknowledging this tradeoff allows planners and researchers to consider creative solutions that may allow for increased green cover exposure in highly walkable but sparsely vegetated neighborhoods, including the use of vegetation wall paneling, potted perennial trees and shrubs, and dedicated space for tree wells and stormwater planters.

Although mental health outcomes were not significantly different based on race, education, or household income, Hispanic/Latinx respondents were more than three times as likely to report high levels of anxiety (Table 3.7). The Hispanic/Latinx population has historically had lower prevalence of anxiety disorders (Asnaani et al., 2010); however, a study looking at racial and ethnic disparities in mental health during the COVID-19 pandemic found that, relative to non-Hispanic White respondents, Hispanic/Latinx respondents reported higher levels of anxiety and/or depression during the pandemic, even though pre-pandemic levels were lower (Thomeer et al., 2022). Further investigation is necessary to understand potential explanations for the disparity in anxiety levels between Hispanic/Latinx and non-Hispanic/Latinx respondents observed in this study.

4.4 Study Strengths and Limitations

This study contributes to a more nuanced understanding of relationships between health and the built environment. There is a paucity of research that includes park quality measures in studies investigating relationships between urban green space and physical activity (Koohsari et al., 2015). Although park qualities were not identified as significant factors, this study provides an example methodology for future researchers to include park quality variables alongside a suite of other urban green space metrics. As physical and mental health outcomes are influenced by a complex network of social, environmental, and economic circumstances (World Health Organization, 2011, 2014), the ecological approach used in this study provides a clearer understanding of relationships between urban green space access/exposure and health outcomes. Finally, the associations between environmental characteristics and health outcomes observed in this study, particularly with respect to mental well-being, support the need to consider urban green space access/exposure as an environmental justice and health equity issue, underscoring the importance of citywide urban green space equity assessments.

While the methodology for this study was built on recommendations from past research, there are several notable limitations. I conducted a cross-sectional analysis, and as such, this study does not meet the criteria for making causal inferences. By using Qualtrics Panels to recruit participants, I obtained a non-probability sample. Although my sample was representative of the Portland population based on race (i.e., percent White, alone) and ethnicity (i.e., percent Hispanic/Latinx), my findings may be subject to sample bias as I oversampled females, people with household incomes lower than the median, and people without postsecondary education. Additionally, Cronbach's alpha values for the subjective neighborhood walkability scale were below the commonly accepted threshold of 0.7, meaning that the NEWS-A subscales are not internally consistent and may not accurately represent subjective walkability. Finally, while I controlled for race and ethnicity in models, I was unable to conduct separate analyses based on race or ethnicity due to sample size limitations. As the population of my sample was predominantly White and non-Hispanic/Latinx (Table 3.1), my findings, while racially and ethnically representative of Portland, do not necessarily reflect relationships between park use, neighborhood-based physical activity, and mental well-being urban green space for minoritized races or ethnicities. Future studies should obtain large enough samples for respondents of minoritized races and ethnicities to be able to accurately identify health inequities based on urban green space access/exposure.

5. Conclusion

This study sought to build upon previous studies by taking a more wholistic approach to assess relationships between urban green space and health. I was able to determine the strongest relationships between urban green space access/exposure and park use, neighborhood-based physical activity, and mental well-being through iterative modeling with a variety of green cover, street-level greenness, park access/availability, and park quality variables. Models identified the importance of park access for park use, regardless of park size or quality, demonstrating the value of targeted park system expansion in areas that maximize the number of residents with public park access within 400 m of their homes. Both park use and improved neighborhood walkability—the combination of factors including residential and intersection density, walking and cycling infrastructure, and land use mix—increase the likelihood that residents partake in moderate to high levels of neighborhood-based physical activity. And, overall mental well-being and anxiety were linked to various vegetation exposure metrics, the most significant being the quantity of total green cover within the 800 m surrounding residents' homes. Additionally, the significance of health, sociodemographic, and built environment variables to physical activity and mental well-being outcomes highlights the importance of taking an ecological approach to investigate relationships between urban green space and health.

Bridge

The empirical analyses presented in this chapter lend support to the concept that urban green space provides mental and physical health benefits. Based on this research, as well as the supporting literature, I conclude that the distribution of urban green space should be considered a health equity issue, reinforcing the importance of the following chapter. In the next chapter, I build upon this premise to develop a methodology for identifying disparities in urban green space access and exposure based on race, ethnicity, income, and education. I then apply the methodology in a case study of Portland, Oregon to establish priority areas for urban green space investment.

References Cited

Alcock, I., White, M. P., Wheeler, B. W., Fleming, L. E., & Depledge, M. H. (2014). Longitudinal Effects on Mental Health of Moving to Greener and Less Green Urban Areas. *Environmental Science & Technology*, *48*(2), 1247–1255. https://doi.org/10.1021/es403688w

Asnaani, A., Richey, J. A., Dimaite, R., Hinton, D. E., & Hofmann, S. G. (2010). A Cross-Ethnic Comparison of Lifetime Prevalence Rates of Anxiety Disorders. *The Journal of Nervous and Mental Disease*, *198*(8), 551–555. https://doi.org/10.1097/NMD.0b013e3181ea169f

Aspinall, P., Mavros, P., Coyne, R., & Roe, J. (2015). The urban brain: Analysing outdoor physical activity with mobile EEG. *British Journal of Sports Medicine*, *49*(4), 272–276. https://doi.org/10.1136/bjsports-2012-091877

Astell-Burt, T., Feng, X., & Kolt, G. S. (2013). Mental health benefits of neighbourhood green space are stronger among physically active adults in middle-to-older age: Evidence from 260,061 Australians. *Preventive Medicine*, *57*(5), 601–606. https://doi.org/10.1016/j.ypmed.2013.08.017

Baar, J., Romppel, M., Igel, U., Brähler, E., & Grande, G. (2015). The independent relations of both residential self-selection and the environment to physical activity. *International Journal of Environmental Health Research*, *25*(3), 288–298. https://doi.org/10.1080/09603123.2014.938029

Baker, R., Brick, J. M., Bates, N. A., Battaglia, M., Couper, M. P., Dever, J. A., Gile, K. J., & Tourangeau, R. (2013). Summary Report of the AAPOR Task Force on Non-probability Sampling. *Journal of Survey Statistics and Methodology*, *1*(2), 90–143. https://doi.org/10.1093/jssam/smt008

Barr, D. A. (2014). Health disparities in the United States: Social class, race, ethnicity, and health (Second edition.). Johns Hopkins University Press.

Beyer, K., Kaltenbach, A., Szabo, A., Bogar, S., Nieto, F., & Malecki, K. (2014). Exposure to Neighborhood Green Space and Mental Health: Evidence from the Survey of the Health of Wisconsin. *International Journal of Environmental Research and Public Health*, *11*(3), 3453–3472. https://doi.org/10.3390/ijerph110303453

Bohte, W., Maat, K., & van Wee, B. (2009). Measuring Attitudes in Research on Residential Self-Selection and Travel Behaviour: A Review of Theories and Empirical Research. *Transport Reviews*, *29*(3), 325–357. https://doi.org/10.1080/01441640902808441

Bratman, G. N., Anderson, C. B., Berman, M. G., Cochran, B., de Vries, S., Flanders, J., Folke, C., Frumkin, H., Gross, J. J., Hartig, T., Kahn, P. H., Kuo, M., Lawler, J. J., Levin, P. S., Lindahl, T., Meyer-Lindenberg, A., Mitchell, R., Ouyang, Z., Roe, J., … Daily, G. C. (2019). Nature and mental health: An ecosystem service perspective. *Science Advances*, *5*(7), eaax0903. https://doi.org/10.1126/sciadv.aax0903

Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health: Nature experience, cognitive function, and mental health. *Annals of the New York Academy of Sciences*, *1249*(1), 118–136. https://doi.org/10.1111/j.1749-6632.2011.06400.x

Cao, X., Mokhtarian, P. L., & Handy, S. L. (2009). Examining the Impacts of Residential Self-Selection on Travel Behaviour: A Focus on Empirical Findings. *Transport Reviews*, *29*(3), 359–395. https://doi.org/10.1080/01441640802539195

Cerin, E., Saelens, B. E., Sallis, J. F., & Frank, L. D. (2006). Neighborhood Environment Walkability Scale: Validity and development of a short form. *Medicine and Science in Sports and Exercise*, *38*(9), 1682–1691. https://doi.org/10.1249/01.mss.0000227639.83607.4d

Cerin, E., Vandelanotte, C., Leslie, E., & Merom, D. (2008). Recreational facilities and leisure-time physical activity: An analysis of moderators and self-efficacy as a mediator. *Health Psychology*, *27*(2, Suppl), S126–S135. https://doi.org/10.1037/0278-6133.27.2(Suppl.).S126

Chong, S., Mazumdar, S., Ding, D., Morgan, G., Comino, E. J., Bauman, A., & Jalaludin, B. (2019). Neighbourhood greenspace and physical activity and sedentary behaviour among older adults with a recent diagnosis of type 2 diabetes: A prospective analysis. *BMJ Open*, *9*(11), e028947. https://doi.org/10.1136/bmjopen-2019-028947

Cohen, D. A., Marsh, T., Williamson, S., Derose, K. P., Martinez, H., Setodji, C., & McKenzie, T. L. (2010). Parks and physical activity: Why are some parks used more than others? *Preventive Medicine*, *50*, S9–S12. https://doi.org/10.1016/j.ypmed.2009.08.020

Coldwell, D. F., & Evans, K. L. (2018). Visits to urban green-space and the countryside associate with different components of mental well-being and are better predictors than perceived or actual local urbanisation intensity. *Landscape and Urban Planning*, *175*, 114–122. https://doi.org/10.1016/j.landurbplan.2018.02.007

Coombes, E., Jones, A. P., & Hillsdon, M. (2010). The relationship of physical activity and overweight to objectively measured green space accessibility and use. *Social Science & Medicine*, *70*(6), 816–822. https://doi.org/10.1016/j.socscimed.2009.11.020

Crawford, D., Timperio, A., Giles-Corti, B., Ball, K., Hume, C., Roberts, R., Andrianopoulos, N., & Salmon, J. (2008). Do features of public open spaces vary according to neighbourhood socio-economic status? *Health & Place*, *14*(4), 889–893. https://doi.org/10.1016/j.healthplace.2007.11.002

Dadvand, P., Bartoll, X., Basagaña, X., Dalmau-Bueno, A., Martinez, D., Ambros, A., Cirach, M., Triguero-Mas, M., Gascon, M., Borrell, C., & Nieuwenhuijsen, M. J. (2016). Green spaces and General Health: Roles of mental health status, social support, and physical activity. *Environment International*, *91*, 161–167. https://doi.org/10.1016/j.envint.2016.02.029

Dallimer, M., Davies, Z. G., Irvine, K. N., Maltby, L., Warren, P. H., Gaston, K. J., & Armsworth, P. R. (2014). What personal and environmental factors determine frequency of urban greenspace use? *International Journal of Environmental Research and Public Health*, *11*(8), 7977–7992. https://doi.org/10.3390/ijerph110807977

Davis, J. (2021). How do upzonings impact neighborhood demographic change? Examining the link between land use policy and gentrification in New York City. *Land Use Policy*, *103*, 105347. https://doi.org/10.1016/j.landusepol.2021.105347

De Bourdeaudhuij, I., Sallis, J. F., & Saelens, B. E. (2003). Environmental Correlates of Physical Activity in a Sample of Belgian Adults. *American Journal of Health Promotion*, *18*(1), 83–92. https://doi.org/10.4278/0890-1171-18.1.83

de Jong, K., Albin, M., Skärbäck, E., Grahn, P., & Björk, J. (2012). Perceived green qualities were associated with neighborhood satisfaction, physical activity, and general health: Results from a cross-sectional study in suburban and rural Scania, southern Sweden. *Health & Place*, *18*(6), 1374–1380. https://doi.org/10.1016/j.healthplace.2012.07.001

de Vries, S., van Dillen, S. M. E., Groenewegen, P. P., & Spreeuwenberg, P. (2013). Streetscape greenery and health: Stress, social cohesion and physical activity as mediators. *Social Science & Medicine*, *94*, 26–33. https://doi.org/10.1016/j.socscimed.2013.06.030

de Vries, S., Verheij, R. A., Groenewegen, P. P., & Spreeuwenberg, P. (2003). Natural Environments—Healthy Environments? An Exploratory Analysis of the Relationship between Greenspace and Health. *Environment and Planning A: Economy and Space*, *35*(10), 1717–1731. https://doi.org/10.1068/a35111

Ding, D., Adams, M. A., Sallis, J. F., Norman, G. J., Hovell, M. F., Chambers, C. D., Hofstetter, C. R., Bowles, H. R., Hagströmer, M., Craig, C. L., Gomez, L. F., Bourdeaudhuij, I. D., Macfarlane, D. J., Ainsworth, B. E., Bergman, P., Bull, F. C., Carr, H., Klasson-Heggebo, L., Inoue, S., … Bauman, A. E. (2013). Perceived neighborhood environment and physical activity in 11 countries: Do associations differ by country? *International Journal of Behavioral Nutrition and Physical Activity*, *10*(1), 57. https://doi.org/10.1186/1479-5868-10-57

Donahue, M. L., Keeler, B. L., Wood, S. A., Fisher, D. M., Hamstead, Z. A., & McPhearson, T. (2018). Using social media to understand drivers of urban park visitation in the Twin Cities, MN. *Landscape and Urban Planning*, *175*, 1–10. https://doi.org/10.1016/j.landurbplan.2018.02.006

Dupuis, M., Studer, J., Henchoz, Y., Deline, S., Baggio, S., N'Goran, A., Mohler-Kuo, M., & Gmel, G. (2016). Validation of French and German versions of a Perceived Neighborhood Social Cohesion Questionnaire among young Swiss males, and its relationship with substance use. *Journal of Health Psychology*, *21*(2), 171–182. https://doi.org/10.1177/1359105314524010

Ekkel, E. D., & de Vries, S. (2017). Nearby green space and human health: Evaluating accessibility metrics. *Landscape and Urban Planning*, *157*, 214–220. https://doi.org/10.1016/j.landurbplan.2016.06.008

Engemann, K., Pedersen, C. B., Arge, L., Tsirogiannis, C., Mortensen, P. B., & Svenning, J.-C. (2019). Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. *Proceedings of the National Academy of Sciences*, 201807504. https://doi.org/10.1073/pnas.1807504116

ESRI. (2019). *ArcMap 10.7*. Environmental Systems Research Institute.

Ewing, R., & Cervero, R. (2010). Travel and the Built Environment: A Meta-Analysis. *Journal of the American Planning Association*, *76*(3), 265–294. https://doi.org/10.1080/01944361003766766

Fongar, Aamodt, Randrup, & Solfjeld. (2019). Does Perceived Green Space Quality Matter? Linking Norwegian Adult Perspectives on Perceived Quality to Motivation and Frequency of Visits. *International Journal of Environmental Research and Public Health*, *16*(13), 2327. https://doi.org/10.3390/ijerph16132327

Frank, L. D., Saelens, B. E., Powell, K. E., & Chapman, J. E. (2007). Stepping towards causation: Do built environments or neighborhood and travel preferences explain physical activity, driving, and obesity? *Social Science & Medicine*, *65*(9), 1898–1914. https://doi.org/10.1016/j.socscimed.2007.05.053

Frank, L. D., Sallis, J. F., Conway, T. L., Chapman, J. E., Saelens, B. E., & Bachman, W. (2006). Many Pathways from Land Use to Health: Associations between Neighborhood Walkability and Active Transportation, Body Mass Index, and Air Quality. *Journal of the American Planning Association*, *72*(1), 75–87. https://doi.org/10.1080/01944360608976725

Frank, L. D., Schmid, T. L., Sallis, J. F., Chapman, J., & Saelens, B. E. (2005). Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ. *American Journal of Preventive Medicine*, *28*(2, Supplement 2), 117–125. https://doi.org/10.1016/j.amepre.2004.11.001

Gebel, K., Bauman, A., & Owen, N. (2009). Correlates of Non-Concordance between Perceived and Objective Measures of Walkability. *Annals of Behavioral Medicine*, *37*(2), 228–238. https://doi.org/10.1007/s12160-009-9098-3

Gidlow, C., van Kempen, E., Smith, G., Triguero-Mas, M., Kruize, H., Gražulevičienė, R., Ellis, N., Hurst, G., Masterson, D., Cirach, M., van den Berg, M., Smart, W., Dėdelė, A., Maas, J., & Nieuwenhuijsen, M. J. (2018). Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening*, *29*, 322–333. https://doi.org/10.1016/j.ufug.2017.12.007

Giles-Corti, B., Broomhall, M. H., Knuiman, M., Collins, C., Douglas, K., Ng, K., Lange, A., & Donovan, R. J. (2005). Increasing walking: How important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine*, *28*(2), 169–176. https://doi.org/10.1016/j.amepre.2004.10.018

Google. (2020). *Street View Static API overview*. Google Developers. https://developers.google.com/maps/documentation/streetview/overview

Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ). (2005). IPAQ. https://www.researchgate.net/file.PostFileLoader.html?id=5641f4c36143250eac8b45b7&assetKey=AS%3A294237418606593%401447163075131#:~:text=Total%20physical%20activity%20MET%2Dminutes,MET%2Dminutes%2Fweek%20scores.

Harris, C. R., Millman, K. J., van der Walt, S. J., Gommers, R., Virtanen, P., Cournapeau, D., Wieser, E., Taylor, J., Berg, S., Smith, N. J., Kern, R., Picus, M., Hoyer, S., van Kerkwijk, M. H., Brett, M., Haldane, A., Fernández del Río, J., Wiebe, M., Peterson, P., … Oliphant, T. E. (2020). Array programming with NumPy. *Nature*, *585*, 357–362. https://doi.org/10.1038/s41586-020-2649-2

Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S., & Gärling, T. (2003). Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology*, *23*(2), 109–123. https://doi.org/10.1016/S0272-4944(02)00109-3

Hays, R. D., Liu, H., & Kapteyn, A. (2015). Use of Internet panels to conduct surveys. *Behavior Research Methods*, *47*(3), 685–690. https://doi.org/10.3758/s13428-015-0617-9

Hoffimann, E., Barros, H., & Ribeiro, A. (2017). Socioeconomic Inequalities in Green Space Quality and Accessibility—Evidence from a Southern European City. *International Journal of Environmental Research and Public Health*, *14*(8), 916. https://doi.org/10.3390/ijerph14080916

Huang, J.-H., Hipp, J. A., Marquet, O., Alberico, C., Fry, D., Mazak, E., Lovasi, G. S., Robinson, W. R., & Floyd, M. F. (2020). Neighborhood characteristics associated with park use and park-based physical activity among children in low-income diverse neighborhoods in New York City. *Preventive Medicine*, *131*, 105948. https://doi.org/10.1016/j.ypmed.2019.105948

International Physical Activity Questionnaire. (2002). https://sites.google.com/site/theipaq/questionnaire_links

James, P., Banay, R. F., Hart, J. E., & Laden, F. (2015). A Review of the Health Benefits of Greenness. *Current Epidemiology Reports*, *2*(2), 131–142. https://doi.org/10.1007/s40471-015-0043-7

Jean, F. (2012). *PyMeanShift*. https://github.com/clememic/pymeanshift/blob/master/pymeanshift.py

Jennings, V., Browning, M. H. E. M., & Rigolon, A. (2019). Friend or Foe? An Overview of the Services and Disservices from Urban Green Spaces. In V. Jennings, M. H. E. M. Browning, & A. Rigolon, *Urban Green Spaces* (pp. 7–30). Springer International Publishing. https://doi.org/10.1007/978-3-030-10469-6_2

Jones, A., Hillsdon, M., & Coombes, E. (2009). Greenspace access, use, and physical activity: Understanding the effects of area deprivation. *Preventive Medicine*, *49*(6), 500–505. https://doi.org/10.1016/j.ypmed.2009.10.012

Kaczynski, A. T., Besenyi, G. M., Stanis, S. A. W., Koohsari, M. J., Oestman, K. B., Bergstrom, R., Potwarka, L. R., & Reis, R. S. (2014). Are park proximity and park features related to park use and park-based physical activity among adults? Variations by multiple socio-demographic characteristics. *The International Journal of Behavioral Nutrition and Physical Activity*, *11*(1), 146. https://doi.org/10.1186/s12966-014-0146-4

Kaczynski, A. T., Koohsari, J., Wilhelm Stanis, S., Bergstrom, R., & Sugiyama, T. (2014). Association of Street Connectivity and Road Traffic Speed With Park Usage and Park-Based Physical Activity. *American Journal of Health Promotion : AJHP*, *28*, 197–203. https://doi.org/10.4278/ajhp.120711-QUAN-339

Kaczynski, A. T., & Mowen, A. J. (2011). Does self-selection influence the relationship between park availability and physical activity? *Preventive Medicine*, *52*(1), 23–25. https://doi.org/10.1016/j.ypmed.2010.10.003

Kaczynski, A. T., Potwarka, L. R., & Saelens, B. E. (2008). Association of Park Size, Distance, and Features With Physical Activity in Neighborhood Parks. *American Journal of Public Health*, *98*(8), 1451–1456. https://doi.org/10.2105/AJPH.2007.129064

Kaczynski, A. T., Wilhelm Stanis, S. A., & Besenyi, G. M. (2012). Development and Testing of a Community Stakeholder Park Audit Tool. *American Journal of Preventive Medicine*, *42*(3), 242–249. https://doi.org/10.1016/j.amepre.2011.10.018

Kajosaari, A., & Laatikainen, T. E. (2020). Adults' leisure-time physical activity and the neighborhood built environment: A contextual perspective. *International Journal of Health Geographics*, *19*(1), 35. https://doi.org/10.1186/s12942-020-00227-z

Kim, E. S., & Kawachi, I. (2017). Perceived Neighborhood Social Cohesion and Preventive Healthcare Use. *American Journal of Preventive Medicine*, *53*(2), e35–e40. https://doi.org/10.1016/j.amepre.2017.01.007

Kondo, M. C., Fluehr, J. M., McKeon, T., & Branas, C. C. (2018). Urban Green Space and Its Impact on Human Health. *International Journal of Environmental Research and Public Health*, *15*(3), 445. https://doi.org/10.3390/ijerph15030445

Koohsari, M. J., Mavoa, S., Villanueva, K., Sugiyama, T., Badland, H., Kaczynski, A. T., Owen, N., & Giles-Corti, B. (2015). Public open space, physical activity, urban design and public health: Concepts, methods and research agenda. *Health & Place*, *33*, 75–82. https://doi.org/10.1016/j.healthplace.2015.02.009

Lee, C., & Moudon, A. V. (2008). Neighbourhood design and physical activity. *Building Research & Information*, *36*(5), 395–411. https://doi.org/10.1080/09613210802045547

Lee, J. (2017). Experimental Study on the Health Benefits of Garden Landscape. *International Journal of Environmental Research and Public Health*, *14*(7), 829. https://doi.org/10.3390/ijerph14070829

Leslie, E., Sugiyama, T., Ierodiaconou, D., & Kremer, P. (2010). Perceived and objectively measured greenness of neighbourhoods: Are they measuring the same thing? *Landscape and Urban Planning*, *95*(1), 28–33. https://doi.org/10.1016/j.landurbplan.2009.11.002

Li, X., Ratti, C., & Seiferling, I. (2017). Mapping Urban Landscapes Along Streets Using Google Street View. In M. P. Peterson (Ed.), *Advances in Cartography and GIScience* (pp. 341–356). Springer International Publishing. https://doi.org/10.1007/978-3-319-57336-6_24

Li, X., Seiferling, I., Cai, B., Abdulhai, M., & So, W. (2020). *Mittrees/Treepedia_Public* [Python]. https://github.com/mittrees/Treepedia_Public (Original work published 2018)

Li, X., Zhang, C., Li, W., Kuzovkina, Y. A., & Weiner, D. (2015). Who lives in greener neighborhoods? The distribution of street greenery and its association with residents' socioeconomic conditions in Hartford, Connecticut, USA. *Urban Forestry & Urban Greening*, *14*(4), 751–759. https://doi.org/10.1016/j.ufug.2015.07.006

Li, X., Zhang, C., Li, W., Ricard, R., Meng, Q., & Zhang, W. (2015). Assessing street-level urban greenery using Google Street View and a modified green view index. *Urban Forestry & Urban Greening*, *14*(3), 675–685. https://doi.org/10.1016/j.ufug.2015.06.006

Maas, J., van Dillen, S. M. E., Verheij, R. A., & Groenewegen, P. P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. *Health & Place*, *15*(2), 586–595. https://doi.org/10.1016/j.healthplace.2008.09.006

Mackenbach, J. D., Matias de Pinho, M. G., Faber, E., Braver, N. den, de Groot, R., Charreire, H., Oppert, J.-M., Bardos, H., Rutter, H., Compernolle, S., De Bourdeaudhuij, I., & Lakerveld, J. (2018). Exploring the cross-sectional association between outdoor recreational facilities and leisure-time physical activity: The role of usage and residential self-selection. *International Journal of Behavioral Nutrition and Physical Activity*, *15*(1), 55. https://doi.org/10.1186/s12966-018-0689-x

McCormack, G. R. (2017). Neighbourhood built environment characteristics associated with different types of physical activity in Canadian adults. *Health Promotion and Chronic Disease Prevention in Canada*, *37*(6), 175–185. https://doi.org/10.24095/hpcdp.37.6.01

McCormack, G. R., & Shiell, A. (2011). In search of causality: A systematic review of the relationship between the built environment and physical activity among adults. *The International Journal of Behavioral Nutrition and Physical Activity*, *8*, 125. https://doi.org/10.1186/1479-5868-8-125

McCormack, G. R., Shiell, A., Giles-Corti, B., Begg, S., Veerman, J. L., Geelhoed, E., Amarasinghe, A., & Emery, J. H. (2012). The association between sidewalk length and walking for different purposes in established neighborhoods. *International Journal of Behavioral Nutrition and Physical Activity*, *9*(1), 92. https://doi.org/10.1186/1479-5868-9-92

McKenzie, B. (2014). Modes Less Traveled—Bicycling and Walking to Work in the United States: 2008–2012. U.S. Census Bureau.

McLaren, L., & Hawe, P. (2005). Ecological perspectives in health research. *Journal of Epidemiology and Community Health*, *59*(1), 6–14. https://doi.org/10.1136/jech.2003.018044

Mitchell, R. (2013). Is physical activity in natural environments better for mental health than physical activity in other environments? *Social Science & Medicine*, *91*, 130–134. https://doi.org/10.1016/j.socscimed.2012.04.012

Mytton, O. T., Townsend, N., Rutter, H., & Foster, C. (2012). Green space and physical activity: An observational study using Health Survey for England data. *Health & Place*, *18*(5), 1034–1041. https://doi.org/10.1016/j.healthplace.2012.06.003

Nesbitt, L., Meitner, M. J., Girling, C., Sheppard, S. R. J., & Lu, Y. (2019). Who has access to urban vegetation? A spatial analysis of distributional green equity in 10 US cities. *Landscape and Urban Planning*, *181*, 51–79. https://doi.org/10.1016/j.landurbplan.2018.08.007

Nutsford, D., Pearson, A. L., & Kingham, S. (2013). An ecological study investigating the association between access to urban green space and mental health. *Public Health*, *127*(11), 1005–1011. https://doi.org/10.1016/j.puhe.2013.08.016

Office of National Statistics. (2018). *Personal well-being user guidance*. https://www.ons.gov.uk/peoplepopulationandcommunity/wellbeing/methodologies/personalwellbeingsurveyuserguide

Oregon Metro RLIS. (2020a). *ORCA Sites* [Map]. https://rlisdiscovery.oregonmetro.gov/

Oregon Metro RLIS. (2020b). *Schools* [Map]. https://rlisdiscovery.oregonmetro.gov/

Payne, L. L., Orsega-Smith, E., Roy, M., & Godbey, G. C. (2005). Local Park Use and Personal Health Among Older Adults: An Exploratory Study. *Journal of Park & Recreation Administration*, *23*(2), 1–20.

Porter, C. O. L. H., Outlaw, R., Gale, J. P., & Cho, T. S. (2018). The Use of Online Panel Data in Management Research: A Review and Recommendations: *Journal of Management*. https://doi.org/10.1177/0149206318811569

Portland Parks & Recreation. (2017a). 2017-2020 Portland Parks & Recreation Strategic Plan.

Portland Parks & Recreation. (2017b). *Five-Year Racial Equity Plan*.

Portland Parks & Recreation. (2017c). Tree Canopy Monitoring: Protocol and Monitoring from 2000-2015.

R Core Team. (2022). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Reis, R. S., Hino, A. A. F., Florindo, A. A., Añez, C. R. R., & Domingues, M. R. (2009). Association between physical activity in parks and perceived environment: A study with adolescents. *Journal of Physical Activity & Health*, *6*(4), 503–509. https://doi.org/10.1123/jpah.6.4.503

Richardson, A. S., Ghosh-Dastidar, M., Collins, R. L., Hunter, G. P., Troxel, W. M., Colabianchi, N., Cohen, D. A., & Dubowitz, T. (2020). Improved Street Walkability, Incivilities, and Esthetics Are Associated with Greater Park Use in Two Low-Income Neighborhoods. *Journal of Urban Health*, *97*(2), 204–212. https://doi.org/10.1007/s11524-019-00416-7

Rigolon, A. (2016). A complex landscape of inequity in access to urban parks: A literature review. *Landscape and Urban Planning*, *153*, 160–169. https://doi.org/10.1016/j.landurbplan.2016.05.017

Riley, W., Hays, R. D., Kaplan, R. M., & Cella, D. (2014). *Sources of Comparability Between Probability Sample Estimates and Nonprobability Web Sample Estimate*. Proceedings of the 2013 Federal Committee on Statistical Methodology (FCSM) Research Conference.

Roe, J. (2013). Engaging the brain: The impact of natural versus urban scenes using novel EEG methods in an experimental setting. https://doi.org/10.12988/es.2013.3109

Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., Salvo, D., Schipperijn, J., Smith, G., Cain, K. L., Davey, R., Kerr, J., Lai, P.-C., Mitáš, J., Reis, R., Sarmiento, O. L., Schofield, G., Troelsen, J., Van Dyck, D., … Owen, N. (2016). Physical activity in relation to urban environments in 14 cities worldwide: A cross-sectional study. *Lancet (London, England)*, *387*(10034), 2207–2217. https://doi.org/10.1016/S0140-6736(15)01284-2

Schipperijn, J., Bentsen, P., Troelsen, J., Toftager, M., & Stigsdotter, U. K. (2013). Associations between physical activity and characteristics of urban green space. *Urban Forestry & Urban Greening*, *12*(1), 109–116. https://doi.org/10.1016/j.ufug.2012.12.002

Smith, G., Cirach, M., Swart, W., Dėdelė, A., Gidlow, C., van Kempen, E., Kruize, H., Gražulevičienė, R., & Nieuwenhuijsen, M. J. (2017). Characterisation of the natural environment: Quantitative indicators across Europe. *International Journal of Health Geographics*, *16*(1), 16. https://doi.org/10.1186/s12942-017-0090-z

Sturm, R., & Cohen, D. (2014). Proximity to urban parks and mental health. *The Journal of Mental Health Policy and Economics*, *17*(1), 19–24.

Taylor, M. S., Wheeler, B. W., White, M. P., Economou, T., & Osborne, N. J. (2015). Research note: Urban street tree density and antidepressant prescription rates—A cross-sectional study in London, UK. *Landscape and Urban Planning*, *136*, 174–179. https://doi.org/10.1016/j.landurbplan.2014.12.005

Thomeer, M. B., Moody, M. D., & Yahirun, J. (2022). Racial and Ethnic Disparities in Mental Health and Mental Health Care During The COVID-19 Pandemic. *Journal of Racial and Ethnic Health Disparities*. https://doi.org/10.1007/s40615-022-01284-9

Tsurumi, T., Imauji, A., & Managi, S. (2018). Greenery and Subjective Well-being: Assessing the Monetary Value of Greenery by Type. *Ecological Economics*, *148*, 152–169. https://doi.org/10.1016/j.ecolecon.2018.02.014

Ulrich, R. (1984). View through a window may influence recovery from surgery. *Science*, *224*(4647), 420–421. https://doi.org/10.1126/science.6143402

United States Department of Agriculture. (2016). *NAIP Imagery* [Page]. https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/index

United States Department of Agriculture. (2022). *NAIP GeoHub*. https://naip-usdaonline.hub.arcgis.com/

U.S. Census Bureau. (2022). *QuickFacts: Portland city, Oregon*. https://www.census.gov/quickfacts/portlandcityoregon

US EPA. (2017). *EnviroAtlas Data Download: Step 2* [Data and Tools]. https://www.epa.gov/enviroatlas/data-download-step-2 van den Berg, M., Wendel-Vos, W., van Poppel, M., Kemper, H., van Mechelen, W., & Maas, J. (2015). Health benefits of green spaces in the living environment: A systematic review of epidemiological studies. *Urban Forestry & Urban Greening*, *14*(4), 806–816. https://doi.org/10.1016/j.ufug.2015.07.008

van Dillen, S. M. E., de Vries, S., Groenewegen, P. P., & Spreeuwenberg, P. (2012). Greenspace in urban neighbourhoods and residents' health: Adding quality to quantity. *Journal of Epidemiology and Community Health*, *66*(6), e8–e8. https://doi.org/10.1136/jech.2009.104695

Velarde, M. D., Fry, G., & Tveit, M. (2007). Health effects of viewing landscapes – Landscape types in environmental psychology. *Urban Forestry & Urban Greening*, *6*(4), 199–212. https://doi.org/10.1016/j.ufug.2007.07.001

Walter, S. L., Seibert, S. E., Goering, D., & O'Boyle, E. H. (2019). A Tale of Two Sample Sources: Do Results from Online Panel Data and Conventional Data Converge? *Journal of Business and Psychology*, *34*(4), 425–452. https://doi.org/10.1007/s10869-018-9552-y

Wang, H., Dai, X., Wu, J., Wu, X., & Nie, X. (2019). Influence of urban green open space on residents' physical activity in China. *BMC Public Health*, *19*(1), 1093. https://doi.org/10.1186/s12889-019-7416-7

White, M. P., Pahl, S., Wheeler, B. W., Depledge, M. H., & Fleming, L. E. (2017). Natural environments and subjective wellbeing: Different types of exposure are associated with different aspects of wellbeing. *Health & Place*, *45*, 77–84. https://doi.org/10.1016/j.healthplace.2017.03.008

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough.' *Landscape and Urban Planning*, *125*, 234–244. https://doi.org/10.1016/j.landurbplan.2014.01.017

Wood, L., Hooper, P., Foster, S., & Bull, F. (2017). Public green spaces and positive mental health – investigating the relationship between access, quantity and types of parks and mental wellbeing. *Health & Place*, *48*, 63–71. https://doi.org/10.1016/j.healthplace.2017.09.002

World Health Organization. (1998). *WHO-5 Well-Being Index*. Psychiatric Research Unit.

World Health Organization. (2006). *Constitution of the World Health Organization*. https://www.who.int/governance/eb/who_constitution_en.pdf

World Health Organization. (2011). *Closing the Gap: Policy into Practice on Social Determinants of Health*. https://www.who.int/publications/i/item/9789241502405

World Health Organization. (2014). *Social Determinants of Mental Helth*.

Yang, J., Zhao, L., Mcbride, J., & Gong, P. (2009). Can you see green? Assessing the visibility of urban forests in cities. *Landscape and Urban Planning*, *91*(2), 97–104. https://doi.org/10.1016/j.landurbplan.2008.12.004

Zhang, L., & Tan, P. (2019). Associations between Urban Green Spaces and Health are Dependent on the Analytical Scale and How Urban Green Spaces are Measured. *International Journal of Environmental Research and Public Health*, *16*(4), 578. https://doi.org/10.3390/ijerph16040578

Zhang, R., Wulff, H., Duan, Y., & Wagner, P. (2019). Associations between the physical environment and park-based physical activity: A systematic review. *Journal of Sport and Health Science*, *8*(5), 412–421. https://doi.org/10.1016/j.jshs.2018.11.002

Zhang, S., & Zhou, W. (2018). Recreational visits to urban parks and factors affecting park visits: Evidence from geotagged social media data. *Landscape and Urban Planning*, *180*, 27–35. https://doi.org/10.1016/j.landurbplan.2018.08.004

CHAPTER IV

EVALUATING URBAN GREEN SPACE INEQUITY TO PROMOTE DISTRIBUTIONAL JUSTICE IN PORTLAND, OREGON

1. Introduction

> *The enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, religion, political belief, economic or social condition.* (World Health Organization, 2006, p. 1)

As urban areas are now home to a majority of the world's population and are projected to continue increasing in proportion of the global population through at least 2050 (United Nations, 2019), researchers have sought to understand how these landscapes affect human health. Land use and land cover changes associated with urban development have altered hydrological and biogeochemical cycles, climate, and biodiversity across local, regional, and global scales (Grimm et al., 2008). These changes correspond with a reduction in the availability of ecosystem services—the benefits humans obtain from ecosystems. Characteristics of urban environments have been linked to increased air pollution concentrations (Liang & Gong, 2020), extreme heat (Uejio et al., 2011; Voelkel & Shandas, 2017), mental health outcomes (Alcock et al., 2014; Bailey et al., 2018; Maas, 2006), and physical inactivity (Frank et al., 2005; Sallis et al., 2016), all of which are risk factors for premature mortality (Hockey et al., 2022; Khomenko et al., 2021; Shindell et al., 2020; World Health Organization, 2009). Yet, urban green spaces, which include parks, natural areas, right-of-way plantings (e.g., street trees and planting strips), green cover (i.e., trees and all other vegetation), and private yards, provide numerous ecosystem services, including surface and air temperature regulation (Marando et al., 2019; Mohajerani et al., 2017; Murage et al., 2020), flood mitigation (Bai et al., 2018; Kadaverugu et al., 2021), and air pollution reduction (Nowak et al., 2014; Nowak & Dwyer, 2007), as well as attention restoration and stress reduction (Bailey et al., 2018; Huang et al., 2021; Wolf et al., 2020), and opportunities for physical activity (Hunter et al., 2015). As such, the design, planning, and distribution of urban green spaces are important public health considerations.

The distribution of urban green space, and the localized benefits derived from these spaces, varies from city to city; however, studies have repeatedly identified inequitable access to green cover based on race and income. In an assessment of urban areas across Oregon and Washington state, median household income was correlated with tree canopy cover (Mills et al., 2016), and individuals from Wisconsin in the lowest income bracket—those making less than $20,000 per year—had the highest likelihood of living in neighborhoods with less than 10% tree canopy (Beyer et al., 2014). An investigation of urban green space equity in Montreal, Canada revealed that neighborhoods with greater low-income and minoritized racial populations had significantly less total green cover and tree canopy cover, as well as right-of-way green cover and tree canopy cover (Pham et al., 2012). Recent meta-analyses of the urban forest equity literature identified significant inequities in urban forest cover based on both race and income, though the association between urban tree canopy cover and income was nearly twice as strong as the association between urban tree canopy cover and race (Gerrish & Watkins, 2018; Watkins & Gerrish, 2018). These findings present clear evidence of disparities in total green cover, as well as tree canopy, cover across various land uses based on race and income.

Although park equity studies have yielded mixed results, there are consistent patterns of race-, ethnicity-, and income-based disparities in park access. In a nationwide study of park access, Wen et al. (2013) discovered that while census tracts with higher poverty rates and higher Black/African American and Hispanic/Latinx populations were associated with shorter distances to parks, they had access to less total park area. Another study, looking at the distribution of parkland in Australia's five largest cities, established that lower-income communities had significantly less access to parkland across all five study areas (Astell-Burt et al., 2014). A review of the urban park equity literature found that in eighteen of twenty papers, non-Latinx White people had the greatest park access, determined by number of parks and park area, both total and per person, and that all studies conducted at the national scale in the United States reported people of color with low socioeconomic status having access to fewer parks and less total park area than White and higher income demographics (Rigolon, 2016). Though park inequities have been identified consistently, the variability of park access between cities demonstrates the importance of considering park access equity for each city independently.

Given that both park quality and quantity may influence park use and physical activity (A. T. Kaczynski et al., 2008, 2014; A. T. Kaczynski & Henderson, 2007), it is critical to assess the distributional equity of park quality in addition to park quantity. More affluent communities, and those with higher proportions of non-Latinx White residents, frequently have access to better quality parks than communities with higher proportions of people with low-incomes and people of color (Rigolon, 2016). In Porto, Portugal, the most economically deprived neighborhoods had more safety concerns and lacked infrastructure to engage in physical and leisure activities (Hoffimann et al., 2017). Engelberg et al. (2016) found significant negative relationships between median household income and sports facilities and overall park amenities in Seattle, Washington, USA, while in Baltimore, Maryland, USA they found that areas with higher White populations had higher overall open space quality scores. Rigolon (2016) identified several common inequalities, including park safety, park maintenance, and diversity of park amenities (e.g., trails and playgrounds). These factors may all influence park perception, park usage, and park-based physical activity with the potential to exacerbate existing race- and income-based health disparities.

Improved health outcomes have been closely linked to green space exposure, particularly for vulnerable populations. One study identified that green space only had statistically significant health benefits for people with the least education (de Vries et al., 2003). In another study, health perceptions for all people were significantly associated with green space availability, but the elderly (i.e., age 65 or older), youth (i.e., age 0-24), and least educated populations benefited most from living near green space (Maas, 2006). Additionally, a recent systematic review found that access to public green space had a stronger association with health outcomes for people with lower socioeconomic status than those with higher socioeconomic status, although no difference in health outcomes was detected based on race or ethnicity (Rigolon et al., 2021). These findings support the concept that living proximal to urban green space may positively impact health outcomes, particularly for marginalized populations.

Access to environmental benefits and exposure to environmental burdens have been focal points for the environmental justice movement since its inception in the late 1960s. There is a long history of health outcome disparities based on race and socioeconomic status in the United States (Barr, 2014), and the environmental justice movement was borne out of the understanding that hazardous waste sites were disproportionately located in communities comprised predominantly of people of color and people with low incomes (Heckler, 1985; Jennings et al., 2019; National Center for Health Statistics, 2012). Revelations regarding the health benefits of urban green space have coincided with a shift in environmental justice literature, and research focusing on distributional justice—the inequitable access to environmental benefits—has been increasingly incorporated into the environmental justice discourse (Anguelovski, 2016; Jennings et al., 2012, 2019; Jennings & Gaither, 2015; Rigolon, 2016; Walker et al., 2009). While environmental justice encompasses much more than just distributional justice concerns, continuing to build on previous work to develop methods by which to identify and expose unjust distributions of urban green space may serve to improve equity of urban green space planning, decision-making, and health outcomes.

Although numerous studies have investigated equity concerns related to urban green cover and others have evaluated park access or park quality disparities, few, to my knowledge, have sought to include park and green cover assessments into a unified methodology to assess urban green space equity (see Nesbitt et al., 2019). And, while numerous city- and national-scale assessments have consistently found evidence of urban green space inequity, they stop short of providing data-informed, spatially explicit recommendations for addressing existing disparities. To address these gaps, this study builds on previous urban green space equity research to identify environmental justice concerns based on the distributions of multiple urban green space measures. I propose a multi-step process including 1) measurement of green space characteristics (i.e., park quality, park availability, green cover, and street-level greenness); 2) bivariate analyses comparing urban green space access/exposure based on sociodemographic characteristics of Census block groups; 3) multivariate characterizations of urban green space distribution based on block group sociodemographic characteristics (i.e., race, ethnicity, income, and education), landscape controls (i.e., elevation and urban form), and spatial clustering (Figure 4.1); and 4) recommendations for urban green space planning priorities. In this study, I developed and implemented a suite of methods for identifying and characterizing urban green space distributional justice concerns to inform policy and planning decisions that promote urban green space equity in Portland, Oregon, USA.

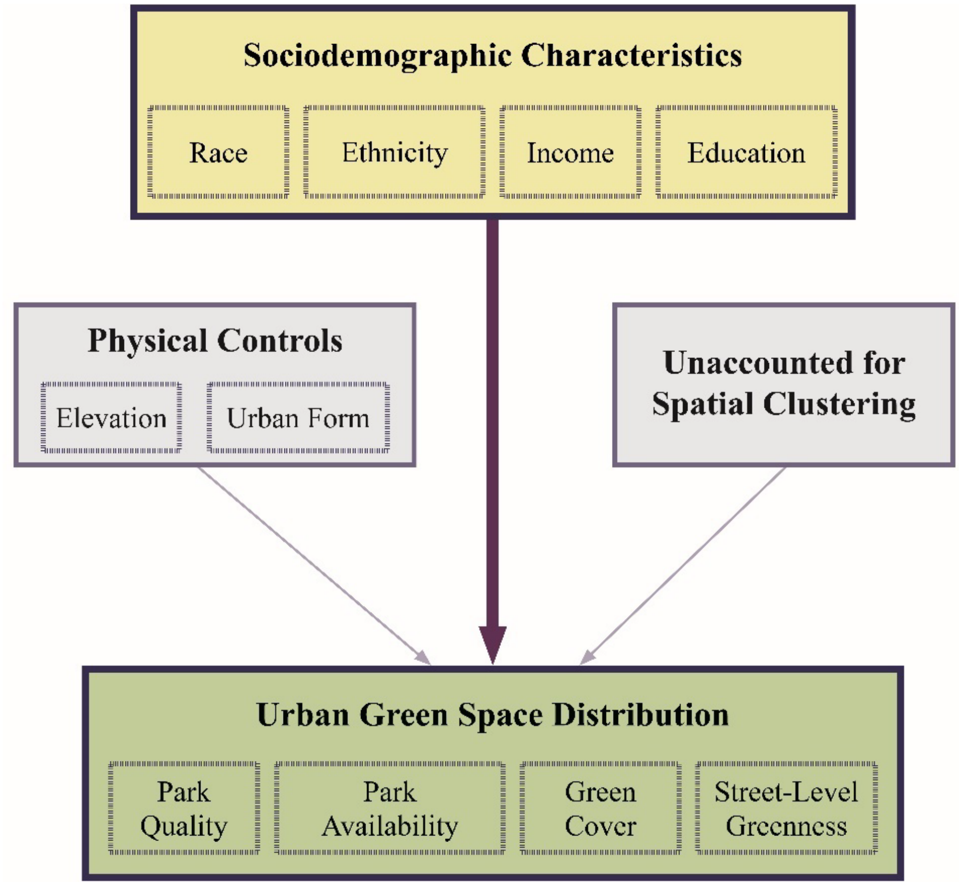

Figure 4.1. Schematic diagram depicting model system, testing for systemic inequities in access to urban green space benefits based on sociodemographic characteristics (i.e., race, ethnicity, income, and education) while controlling for landscape variables and spatial clustering.

2. Methods

2.1 Site Context

This study was conducted in Portland, Oregon, USA (Figure 4.2). In 2021, the City of Portland had a predominantly White population (75.3% identifying as White alone), followed by Hispanic/Latinx (9.8%), Asian (8.7%), Black/African American (5.9%), American Indian and Alaska Native (0.8%), and Native Hawaiian and other Pacific Islander (0.7%) populations (U.S. Census Bureau, 2022d). Portland's tree canopy covered 11,184 hectares in 2020, equivalent to 29.8% citywide tree canopy cover (Portland Parks & Recreation, 2022). Since 2000, tree canopy cover increased by 926 hectares citywide, although tree canopy cover decreased by 333 hectares from 2015 to 2020. Tree canopy cover has not been evenly distributed throughout Portland: while only 28.0% of the city is located west of the Willamette River, this area accounted for 50.7% of the city's total tree canopy cover (Portland Parks & Recreation, 2018b). Portland is home to two of the largest city parks in the United States: Forest Park, in northwest Portland, is the eighth largest municipally owned park in the United States, and Smith and Bybee Wetlands Natural Area in north Portland is the 53rd largest park within a USA city's limits (The Trust for Public Land, 2010).

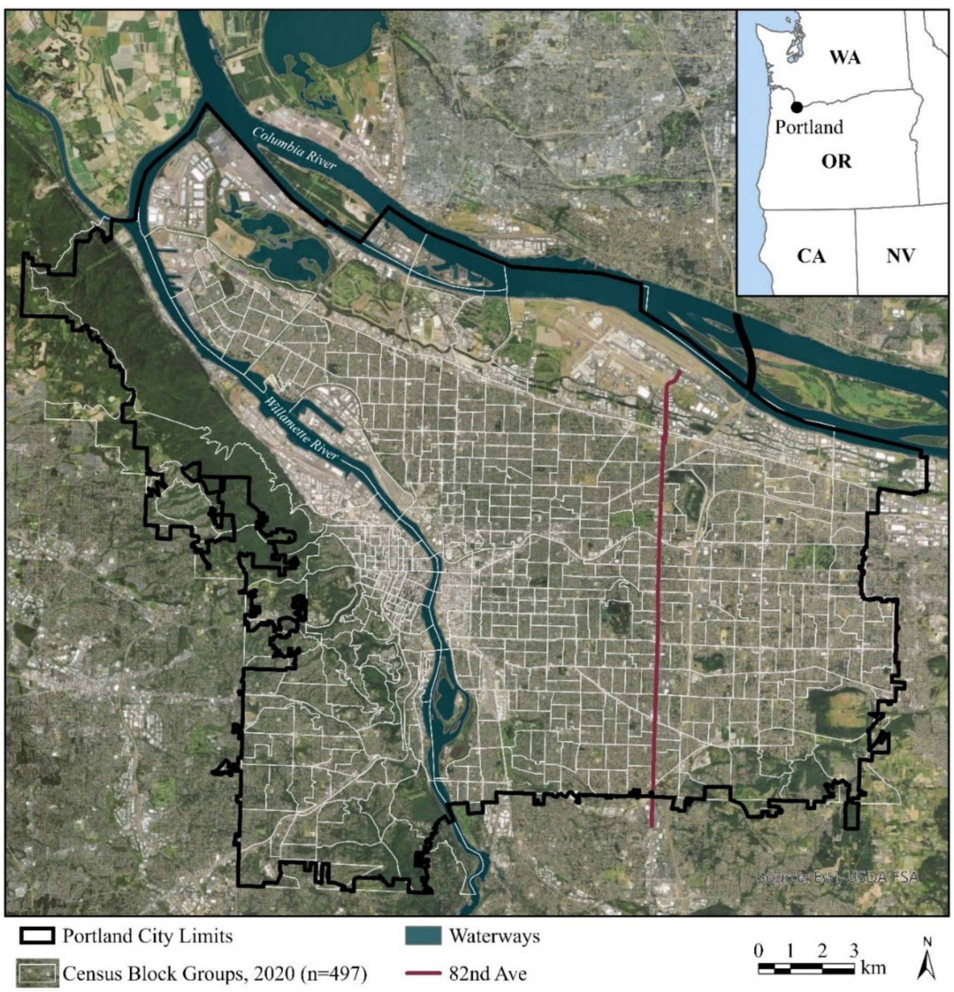

Figure 4.2. Context map of Portland, Oregon, USA depicting city limits and block group boundaries.

2.2 Sociodemographic Data

Sociodemographic data were analyzed at the Census block group scale—the finest spatial resolution for aggregated sociodemographic Census data—using 2020 redistricting geometry (U.S. Census Bureau, 2021). Block groups with their centroids located within the Portland city limits were selected for analysis (n=497; Figure 4.2).

I selected a suite of sociodemographic characteristics similar to those used in previous urban green space distributional justice studies, including variables that account for population-level race, ethnicity, income, and education (e.g., Flocks et al., 2011; Gerrish & Watkins, 2018, 2018; Landry & Chakraborty, 2009; Mennis, 2006; Nesbitt et al., 2019; Rigolon, 2016; Wen et al., 2013). Race data were obtained from 2020 Census redistricting data (U.S. Census Bureau, 2022e), and income, ethnicity, and education data were taken from 2016-2020 American Community Survey 5-year estimates (U.S. Census Bureau, 2022a, 2022b, 2022c). As individual minoritized racial groups each only account for a small proportion of the population (i.e., <10%), race data were used to identify the percent of block group population that did not identify as White only (i.e., Black or African American, American Indian and Alaska Native, Asian, Native Hawaiian and other Pacific Islander, some other race, or multiracial) which will hereafter be referred to as "minoritized racial population". Income was defined as block group median household income, and educational attainment data were used to identify the percent of block group population, ages 25 and older, with no postsecondary education (e.g., Associate's, Bachelor's, Master's, and PhD). Ethnicity was defined as the percent of block group population that identified as Hispanic, Latinx, or Spanish origin.

2.3 Green Space Variables

I collected a broad suite of urban green space metrics to assess park availability, park quality, and green cover. I expanded the scope of green space access/exposure analysis to multiple spatial scales (i.e., within block group and within 400 and 800 m of block group boundaries) to account for the environments surrounding residents living near block group boundaries. As most walking trips fall below one mile with a median walking duration of ten minutes (Yang & Diez-Roux, 2012), I selected 400 and 800 m cutoffs, representing approximately 5- and 10-minute walking times and encompassing a one-mile out-and-back walking distance. For the purposes of this study, the term "park" hereafter refers to free and publicly accessible parks, natural areas, golf courses, cemeteries, and public schoolyards (n=406; see Chapter 3, Section 2.3.2 for details). Park coverage is defined as the percent of each block group area within 400 m or 800 m road distance of a park (Table 4.1; Handy & Niemeier, 1997). All other park availability variables (i.e., number of parks and park area) and park quality variables (i.e., Neighborhood Environment Scoring Tool domain and overall park quality scores) were calculated within each Census block group and within 400 and 800 m road network of each Census block group boundary (Figure C1), while green cover and street-level greenness variables were measured within each Census block group and within 400 and 800 m Euclidean distance of each Census block group boundary (Table 4.1; Figure C2-C4). Green cover variables were categorized by vegetation type (i.e., tree canopy cover and all vegetation cover types) and land use type (i.e., right-of-way, parkland, private land, and all land uses; see Chapter 3, Figure 3.3). I defined private land as all land not located in parks or the right-of-way. Cumulative normalized difference vegetation index (NDVI), calculated based on the ratio of red to near infrared light in high resolution multispectral imagery, has been validated as a measure of neighborhood greenness (Rhew et al., 2011) and was used as a proxy for green cover. In addition to green cover and NDVI variables that provide measures of greenness as seen from above, I sought to represent greenness in a manner comparable to how it might be experienced walking on the street (i.e., street-level greenness). To measure street-level greenness, I used a modified Green View Index (GVI) calculated based on the ratio of green pixels to total pixels from Google Street View images (Li et al., 2015, 2017). I created 360° panoramas by combining three images at each location with 120° horizontal and vertical fields of view. In total, I calculated GVI for 148,086 Google Street View images (Google, 2020), taken during leaf-on period (i.e., May-September) from 2007 to 2020, at 49,362 locations along roadways within Portland city limits. For additional details on all urban green space data collection and processing methods, see Chapter 3, Section 2.3 and Appendix B, Section B2.

Table 4.1. Urban green space metrics, measured for each block group in Portland, Oregon.

Variable	Variable Category	Data Type	Method/Data Source
Number of parks [a]	Park Availability	Count	Oregon Recreation and Conservation Areas (Oregon Metro RLIS, 2020a, 2020b)
Park area (ha) [a]	Park Availability	Continuous	Oregon Recreation and Conservation Areas (Oregon Metro RLIS, 2020a, 2020b)
Park coverage (percent)	Park Availability	Continuous	Oregon Recreation and Conservation Areas (Oregon Metro RLIS, 2020a, 2020b)
Park quality score (Neighborhood Environment Scoring Tool domain and overall scores) [a]	Park Quality	Continuous	Neighborhood Environment Scoring Tool (Gidlow et al., 2018); Oregon Recreation and Conservation Areas (Oregon Metro RLIS, 2020a, 2020b)
Cumulative normalized difference vegetation index (NDVI) [b]	Green Cover	Continuous	National Agriculture Imagery Program (NAIP) 2016 four-band aerial imagery (United States Department of Agriculture, 2022)
Green cover – total, park/open space, private, and right-of way (percent) [b]	Green Cover	Continuous	United States' Environmental Protection Agency EnviroAtlas (US EPA, 2017)
Tree canopy cover – total, park/open space, private, and right-of way (percent) [b]	Green Cover	Continuous	United States' Environmental Protection Agency EnviroAtlas (US EPA, 2017)
Cumulative Green View Index (GVI) [a]	Street-level Greenness	Continuous	Google Street View Static API (Google, 2020)

[a] within block group, and within 400 m and 800 m road network of block group perimeter

[b] within block group, and within 400 m and 800 m Euclidean buffer of block group perimeter

2.4 Confounding Environmental Variables

Because this study is inherently place-based, as opposed to a multi-city evaluation, it is important to consider local biophysical and urban form variables that may impact urban green space characteristics. Elevation has been identified as a potential confounding variable when looking at environmental justice implications of urban green space access/exposure (Berland et al., 2015; Mennis, 2006). I calculated mean elevation by block group from a 10-m resolution digital elevation model (USGS, 2022). Other characteristics of urban form such as residential and commercial density, land use mix, and street characteristics have also been found to have significant relationships with vegetation cover (Mennis, 2006; Pham et al., 2012, 2017). I measured urban form using the neighborhood walkability index described in Chapter 3, Section 2.4, at the block group scale, thus factoring in residential density, street connectivity, land use mix, sidewalk accessibility, and bike infrastructure accessibility.

2.5 Statistical Analysis

Bivariate and multivariate statistical analyses were conducted to identify environmental justice concerns related to urban green space access and exposure in Portland, Oregon. Census block groups that did not contain median household income data (n=25) or lacked complete green cover data coverage (n=1) were removed from the dataset, leaving 471 block groups for analysis. Consistent with methods used by Schwarz et al. (2015), I conducted Spearman's rank correlation to identify nonparametric bivariate relationships between all green space and Census variables. I only considered relationships with Spearman's rank correlation coefficient (r_s) absolute value greater than 0.3, a threshold for medium strength correlation, and variables with Spearman's rank correlation coefficient absolute value greater than 0.5 were considered strong relationships (Cohen, 1977).

Ordinary least squares (OLS) multiple regression was used to evaluate environmental justice concerns for each green space variable (i.e., response variable) in relation to race, ethnicity, income, and educational attainment Census variables (i.e., explanatory variables). Models were generated for each green space response variable with one Census variable and with every combination of two, three, and four Census variables. Mean elevation and urban form variables were included in each model as potential confounding variables. Models were excluded if 1) any Census variable was not significant ($\alpha = 0.05$), 2) the model contained multicollinearity (variance inflation factor ≥ 2), or 3) the sign for any of the Census variable coefficients changed from Spearman's rank correlation. Response variables were transformed if OLS models did not satisfy the residual normality assumption (i.e., Kolmogorov-Smirnov $p < 0.05$; Mishra et al., 2019), and models were removed if residual normality assumption was violated after transformation.

To ensure OLS estimated coefficients were not a product of systematic spatial variation, I measured spatial autocorrelation of model residuals for all models that met OLS modeling criteria, using Moran's *I* for residual spatial autocorrelation (Anselin, 1988; Landry & Chakraborty, 2009; Pham et al., 2012; Schwarz et al., 2015). Spatial autoregressive (SAR) models were generated for all OLS models with significant spatial autocorrelation (i.e., Moran's *I* $p<0.05$) of model residuals. Two SAR models—the spatial error model and spatial lag model—were developed specifically to handle spatial autocorrelation of residuals in OLS models (Anselin, 1988). The spatial error model assumes that error terms are spatially correlated due to omitted factors, while the spatial lag model assumes that the response variable, as well as explanatory variables and error terms are all spatially correlated. To determine whether the spatial error or spatial lag model should be used, Lagrange multiplier and robust Lagrange multiplier spatial dependence test statistics were calculated for OLS models that exhibited spatial autocorrelation of residuals, and choice of model was based on which model type (i.e., spatial error or spatial lag) had more significant test statistics (Anselin, 2005; Landry & Chakraborty, 2009; Pham et al., 2012). I constructed spatial weights for SAR models using queen contiguity-based weights, defining neighbors as those that share common edges and vertices (Anselin, 2005). Spatial autoregressive models were excluded if residuals exhibited spatial autocorrelation (i.e., Global Moran's *I* $p<0.05$) or if neither Census variable was significant. All statistical analyses were conducted in R (R Core Team, 2022), and spatial statistics were generated using "spdep" and "sf" packages (Bivand & Wong, 2018; Pebesma, 2018).

3. Results

3.1 Descriptive Statistics

The 471 Census block groups analyzed for this study had a total population of 621,501, or 96.9% of Portland's estimated 2021 population (U.S. Census Bureau, 2022d). Block group median household income ranged from under $10,000 to $250,000 with a median of $76,006 with clusters of low-income block groups just east of downtown and to the east of 82nd Avenue (Figure 4.3). Block group percent minoritized racial population ranged from 10.9% to 76.3% (median=27.1%) with clusters of high minoritized racial population block groups in the eastern and northern parts of the city (Figure 4.4). Educational attainment had a strong correlation with race (r=0.72) and exhibited very similar spatial clustering (Figure C5). The Hispanic, Latinx, or Spanish origin population varied between 0% and 59.5% at the block group level (median=6.7%; Table 4.2) with small clusters of high Hispanic/Latinx in the northern part of the city and a large cluster to the east (Figure C6).

Green cover varied dramatically across block groups, with total green cover ranging from 2.2% to 94.9% (median=47.4%) and total tree canopy cover ranging from under one percent to over 85% (median=22.1%; Table 4.2). A large cluster of block groups with high tree canopy cover was identified to the west of downtown, while several low canopy cover clusters were located in the downtown area, along the Columbia River, and in Southeast Portland (Figure 4.5). Right-of-way tree canopy cover ranged from 0.3% to 61.9% (median=16.0%) with a cluster of high right-of-way tree canopy cover to the west of downtown and a large cluster of low right-of-way tree canopy cover across the eastern part of the city (Figure 4.6).The median block group had access to four parks within 400 m road distance of the block group boundary, though six block groups no such park access and 32 block groups only had access to one park.

Table 4.2. Sociodemographic and green space characteristics of Census block groups in Portland, Oregon (n=471).

Census Block Group Variable	Median	Range
Median household income [a]	$76,006	$9,606-$250,000
Minoritized racial group [b]	27.1%	10.9-76.3%
Hispanic, Latinx, or Spanish origin [a]	6.7%	0.0-59.5%
No postsecondary education [a]	37.9%	2.0-90.4%
Total green cover [c]	47.4%	2.2-94.9%
Total tree canopy [c]	22.1%	0.5-85.9%
Right-of-way green cover [c]	37.1%	4.8-78.4%
Right-of-way tree canopy [c]	16.0%	0.3-61.9%
Number of parks [d e]	4	0-17
Area of parks [d e]	13.9 ha	0.0-2275.1 ha

Table 4.2 Continued

Neighborhood Environment Scoring Tool (NEST), overall park quality score [d e]	43.6	0.0-84.2

[a] data from 2016-2020 American Community Survey 5-year estimates (U.S. Census Bureau, 2022a, 2022b, 2022c)

[b] data from 2020 Census redistricting data (U.S. Census Bureau, 2022e)

[c] based on “within block group boundary” variable

[d] based on “within 400 m road distance of block group boundary” variable

[e] based on free and publicly accessible parks, natural areas, golf courses, cemeteries, and public schoolyards (n=406)

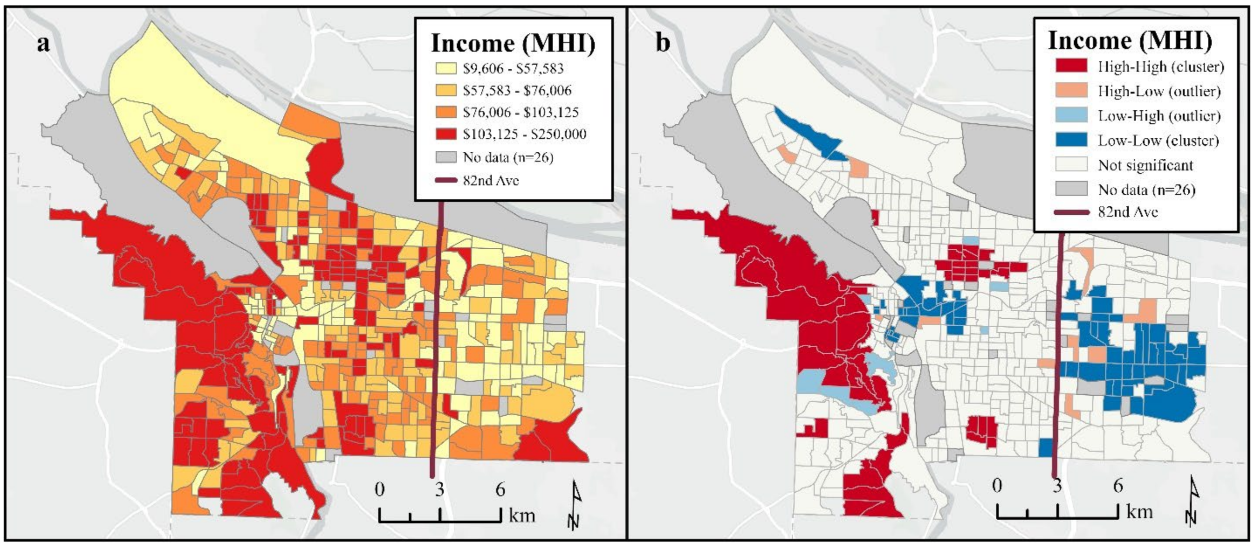

Figure 4.3. a) Block group median household income (MHI) grouped in quartiles (n=471); b) cluster analysis using Local Moran’s I to identify clusters of high- and low-income block groups.

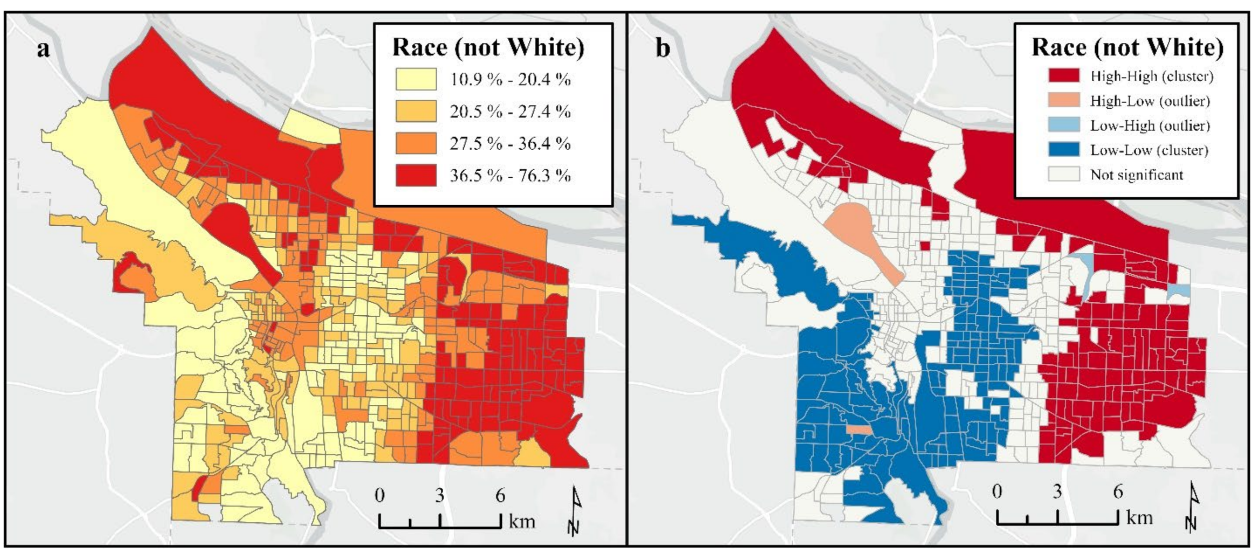

Figure 4.4. a) Block group percent minoritized racial population (i.e., non-White, or multiracial; n=497) in quartiles; b) cluster analysis using Local Moran’s I to identify block groups clusters with high and low minoritized racial population.

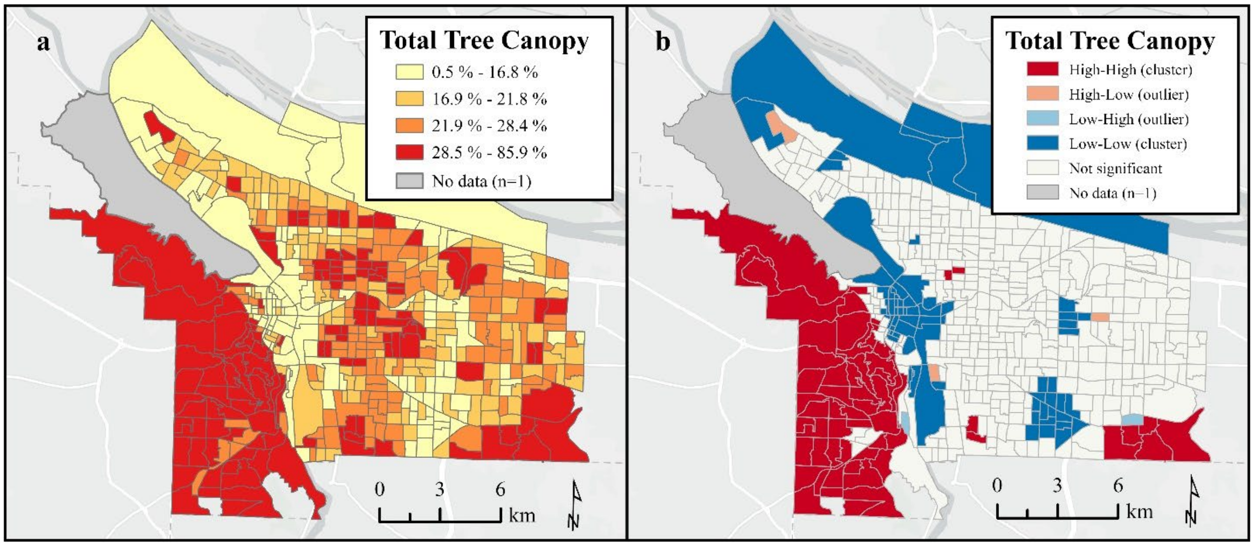

Figure 4.5. a) Block group percent total tree canopy cover grouped in quartiles (n=496); b) cluster analysis using Local Moran's I to identify clusters of high and low total tree canopy cover.

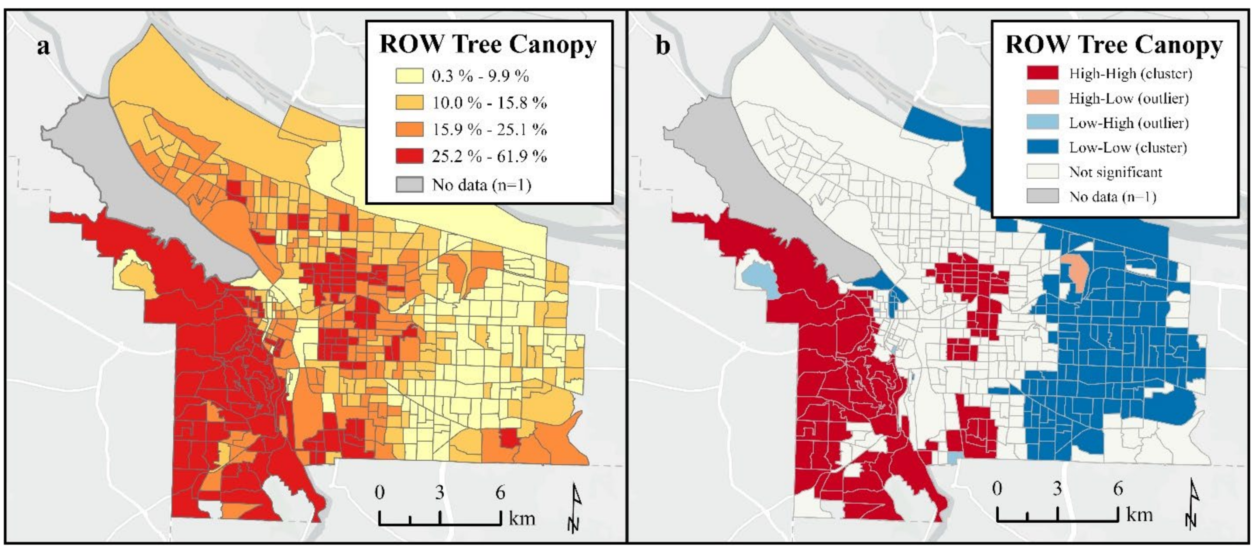

Figure 4.6. a) Block group percent right-of-way (ROW) tree canopy cover grouped in quartiles (n=496); b) cluster analysis using Local Moran's I to identify clusters of high and low right-of-way tree canopy cover.

3.2 Bivariate Spearman's Rank Correlation

Numerous moderate and strong relationships were identified between block group sociodemographic characteristics and green cover variables in bivariate Spearman's rank correlation. The strongest relationships were observed between percent minoritized racial population and percent right-of-way tree canopy cover (r_s=-0.73) and GVI (r_s=-0.71). Race (i.e., percent minoritized racial population) was also associated with decreased right-of-way green cover (r_s=-0.65); cumulative NDVI (r_s=-0.36); and percent tree canopy cover across all land uses (r_s=-0.48), on park land (r_s=-0.39), and on private land (r_s=-0.31; Table 4.3; Table C1). Educational attainment (i.e., percent with no postsecondary education) had strong negative correlations with right-of-way tree canopy cover and GVI (r_s=-0.69 and -0.63, respectively), and moderate negative correlations with tree canopy cover in parks and across all land uses (r_s=-0.33 and -0.32, respectively). Median household income was positively associated with GVI (r_s=-0.50) and cumulative NDVI (r_s=-0.46), as well as tree canopy cover and green cover within the right-of-way (r_s= 0.48 and 0.56, respectively), on private land (r_s=0.40 and 0.36, respectively), and across all land use types (r_s=0.43 for both). Ethnicity (i.e., percent Hispanic/Latinx) had moderate negative associations with right-of-way tree canopy cover (r_s=-0.34), right-of-way green cover (r_s=-0.33), and GVI (r_s=-0.34).

Table 4.3. Summary of environmental justice concerns based on Spearman's rank correlation coefficients (r_s) between green space and Census variables with strong and moderate correlations ($|r_s|$>0.5 and $|r_s|$>0.3, respectively).

Green Space Variable Category *	**Race** *(Percent minoritized racial population)*	**Income** *(Median household income)*	**Education** *(Percent with no postsecondary education)*	**Ethnicity** *(Percent Hispanic/ Latinx)*
Right-of-way (tree canopy)	-0.73 [b]	0.48 [b]	-0.69 [c]	-0.34 [b]
Right-of-way (green cover)	-0.65 [b]	0.56 [b]	-0.49 [b]	-0.33 [a]
Green View Index (GVI)	-0.71 [c]	0.50 [c]	-0.63 [c]	-0.34 [b]
All land uses (tree canopy)	-0.48 [b]	0.43 [a]	-0.32 [b]	-
All land uses (green cover)	-	0.43 [a]	-	-
Cumulative NDVI	-0.36 [b]	0.46 [a]	-	-
Private land (tree canopy)	-0.31 [b]	0.40 [a]	-	-
Private land (green cover)	-	0.36 [a]	-	-
Parks, natural areas, and public schoolyards (tree canopy)	-0.39 [c]	-	-	-
Neighborhood Environment Scoring Tool (NEST), overall	-	-	-0.31 [c]	-
NEST, non-natural aesthetics domain	-	-	-0.34 [c]	-

* r_s reported only for variable with strongest relationship within each green space category

[a] strongest correlation measured for "within block group boundary" variable

[b] strongest correlation measured for "within 400 m of block group boundary" variable

[c] strongest correlation measured for "within 800 m of block group boundary" variable

No park availability variables met the Spearman's rank correlation coefficient threshold for inclusion, and though it didn't meet criteria for inclusion, I identified significant positive correlations between educational attainment and park area within 400 m (r_s=0.11 , p=0.02), as well as ethnicity and park area within 800 m of block group boundaries (r_s=0.12 , p=0.01). Among park quality variables, only Neighborhood Environment Scoring Tool (NEST) overall score and NEST non-natural aesthetics domain score (i.e., decorative water fountain, public art, and historic/attractive buildings or structures) had moderate negative associations with educational attainment (r_s=-0.31 and -0.34, respectively; Table 4.3).

3.3 Multivariate Modeling

3.3.1 Models with One Census Variable

There were 103 models that satisfied OLS modeling criteria with one Census variable. All models had significant spatial autocorrelation of residuals in OLS regression (Moran's I p<1.0E-24), and only the 28 models that did not exhibit significant spatial autocorrelation of residuals (Moran's I p>0.05) in SAR modeling were considered here. Race, educational attainment, income, and ethnicity were all significantly associated with multiple right-of-way green cover variables (p<0.001) in SAR models (Table C4-C7). All four sociodemographic variables were associated with right-of-way tree canopy cover, while race, ethnicity, and income were associated with right-of-way green cover. In addition, income, ethnicity, and education were associated with GVI (i.e., street-level greenness). Standardized regression coefficients, or beta coefficients (β), for sociodemographic variables were greater in magnitude than beta coefficients for mean elevation and urban form in all right-of-way/street-level greenness OLS models (Table C3), and elevation was not significant in any right-of-way/street-level greenness SAR models (Table C4-C7). Significant correlations were identified between Census variables and numerous other green cover variables, including tree canopy cover on private land (race, ethnicity, and income), on parkland (race, ethnicity, income, and educational attainment), and across all land uses (race, income, and educational attainment), as well as total green cover (ethnicity), and NDVI (race and income). However, all non-right-of-way green cover variables had stronger associations (i.e., Spearman's rank correlation and OLS beta coefficient magnitude) with mean elevation than any sociodemographic variables (Table C2-C3).

Only four park quality models met SAR modeling criteria. Educational attainment was significantly correlated with NEST natural aesthetics and usability domain scores, and neither mean elevation nor urban form were significant in SAR models (Table C7). In addition, race and income were significantly associated with NEST amenities domain scores, although these OLS and SAR models had lower goodness-of-fit (adjusted-$R^2 \leq 0.06$ and Nagelkerke pseudo-$R^2 \leq 0.29$) than all other models (Table C3-C5).

3.3.2 Models with Two Census Variables

A total of 43 models with two Census variables satisfied OLS model criteria, and the 19 distinct response variables were all related to green cover or street-level greenness (i.e., tree canopy, green cover, GVI, or NDVI). All 43 OLS model residuals had significant spatial autocorrelation (Moran's I p<1.0E-25), and twenty-five of the 43 SAR models contained spatial autocorrelation of model residuals, leaving 18 models that satisfied SAR model criteria. Median household income and race were significantly associated (p<0.01) with right-of-way tree canopy, right-of-way green cover, GVI, total tree canopy, and private land tree canopy in best-fit models (i.e., highest Nagelkerke pseudo-R^2 among models with the same response variable; Table 4.4). Median household income was the only significant Census variable in the NDVI model, while ethnicity was the only significant Census variable associated with either parkland tree canopy or total green cover (Table 4.4).

Table 4.4. Summary of estimated coefficients for best-fit spatial autoregressive (SAR) model models with two sociodemographic predictors and no spatial autocorrelation of model residuals.

	ROW Tree Canopy [ab]	ROW Green Cover [b]	GVI [ab]	Total Tree Canopy [ab]	Total Green Cover [b]	NDVI [b]	Private Land Tree Canopy [b]	Parkland Tree Canopy [c]
Intercept	1.35***	16.09***	1.51***	4.06***	21.17***	0.03*	17.84***	3.77*
Median household income ($10k)	0.05***	0.75***	0.02***	0.04***	-	3.6e-03***	0.31**	0.16
Race (percent minoritized racial population)	-0.02***	-0.19***	-7.2e-03***	-0.02**	-	-2.80E-04	-0.17***	-
Ethnicity (percent Hispanic/Latinx)	-	-	-	-	-0.13**	-	-	-0.13*
Education (percent no postsecondary)	-	-	-	-	-0.04	-	-	-
Elevation (mean)	1.30E-04	-0.01	1.60E-05	0.01***	0.05***	3.4e-04***	0.15***	0.03*
Urban form	-0.01	-0.66***	-0.02**	-0.09***	-1.54***	-5.7e-03***	-1.26***	-0.24
Pseudo-R^2	0.66	0.62	0.63	0.67	0.7	0.73	0.77	0.66
SAR Type (SEM or SLAG)	SLAG	SLAG	SLAG	SEM	SLAG	SLAG	SEM	SLAG

* $p<0.05$; ** $p<0.01$; *** $p<0.001$

ROW – right-of-way; GVI – green view index; NDVI – normalized difference vegetation index

SEM – Spatial error model; SLAG – spatial lag model

[a] response variable transformed (square-root transformation)

[b] measured within block group boundaries

[c] measured within 800 m of block group boundaries

Neither elevation nor urban form were significant predictors of right-of-way tree canopy cover, and while urban form was significantly associated with both GVI and right-of-way green cover, combined OLS beta coefficients for race and income were more than 2.5 times larger than elevation and urban form beta coefficients in all three models (Table 4.4; Table C8). Best-fit total tree canopy, total green cover, NDVI, and private land tree canopy models had the highest Nagelkerke pseudo-R^2 among all SAR models, although elevation and urban form were highly significant ($p<0.001$). Elevation had stronger associations (i.e., Spearman's rank correlation and OLS beta coefficient) with total tree canopy, total green cover, NDVI, and private land tree canopy than any significant Census variable, and the combined beta coefficients of elevation and urban form were between 1.8 and 6.2 times greater than the combined race and income beta coefficients (Table C1-C2; Table C10).Although SAR model coefficients for transformed variables (i.e., right-of-way tree canopy and total tree canopy cover) and indices (i.e., GVI and NDVI) are difficult to interpret, the best-fit right-of-way green cover and private tree canopy models suggests a 1.9% decrease in right-of-way green cover and 1.7% decrease in private tree canopy cover for every 10% increase in minoritized racial population (B=-0.19 and -0.17, respectively; Table 4.4). In the same models, a 0.75% increase in right-of-way green cover and 0.31% increase in private tree canopy cover are expected for every $10,000 increase in median household income (B=0.75 and 0.31, respectively). Additionally, total green cover and parkland tree canopy cover models revealed expected 1.3% decreases in their respective coverage for every 10% increase in Hispanic/Latinx population (B =-0.13).

4. Discussion

This study proposed a methodology for evaluating distributional justice concerns related to urban green space access/exposure and applied it in Portland, Oregon. Urban green space distributional justice was assessed based on three categories of access/exposure: park availability (i.e., number of parks and park area), park quality (i.e., NEST overall park quality scores as well as access, amenities, recreational facilities, natural and non-natural aesthetics, incivilities, and usability domains), and green cover (i.e., tree canopy and green cover on right-of-way, private land, parkland, and across all land uses). This case study identified distributional justice concerns at the block group scale in Portland, Oregon based on urban green space access/exposure and characterized relationships between environmental and social characteristics of the urban environment to inform urban green space planning, policy, and decision-making.

4.1 Urban Green Space Distributional Justice Concerns for Portland, Oregon

4.1.1 Park Equity Assessment

Reducing disparities in access to parks, natural areas, and services is one of the six objectives listed in Portland's Parks and Recreation Five-Year Racial Equity Plan (Portland Parks & Recreation, 2017). My analysis found no race-, ethnicity-, income-, or education-based inequities in park availability and even identified weak but positive associations between accessible park area, block group percent Hispanic/Latinx, and block group percent with no postsecondary education. This analysis also uncovered six block groups without access to a park, natural area, or public schoolyard within 400 m of block group boundaries, two of which were in the lower quartile for median household income and the upper quartile for percent population with no postsecondary education, percent population from minoritized racial groups, and percent Hispanic/Latinx. In line with the Portland Parks & Recreation objective to prioritize property acquisition for the establishment of parks that serve communities of color and low-income neighborhoods (Portland Parks & Recreation, 2017), these block groups would be ideal locations for future park development initiatives.

Equitable access to parks does not ensure that all parks support park user needs, and my quantitative assessment of park quality uncovered multiple inequities. Spatial autoregressive models found that block groups with higher proportions of Hispanic/Latinx residents had significantly less tree canopy cover on parkland within 800 m of block group boundaries (Table 4.4; Table C7). In separate SAR models, park amenities (i.e., seating, trash can, toilets, shelters, picnic tables, and drinking fountains) were inequitably distributed based on block group median household income and percent minoritized racial population (Table C4-C5). Additionally, block groups with higher proportions of residents with no post-secondary education had lower natural aesthetics (i.e., the combination of water features, views, tree cover, and maintained vegetation areas) and usability (i.e., the diversity of active and passive recreational opportunities) scores based on parks accessible within 400 and 800 m of block group boundaries, respectively (Table C6).

4.1.2 Green Cover Equity Assessment

Findings from tree canopy and green cover models revealed significant disparities in tree and green cover access for marginalized communities in Portland, Oregon. Consistent with the results from many other equity assessments of urban green cover, I found race- and income-based disparities in total block group tree canopy cover (Table 4.4; Gerrish & Watkins, 2018; Pham et al., 2012; Watkins & Gerrish, 2018). It is unsurprising that inequities identified in total tree canopy models were consistent with those observed for total green cover, NDVI, and private tree canopy cover as these green cover variables are all highly correlated ($r_s > 0.85$). These findings support the use of NDVI as a proxy for total green cover and tree canopy cover, particularly in areas where green cover data may not be available. In addition to sociodemographic factors, block group elevation and urban form were highly significant predictors of total tree canopy cover, total green cover, NDVI, and private tree canopy cover (Table 4.4), further reinforcing findings that have linked urban green cover distribution with terrain, development patterns, and community sociodemographic character (Berland et al., 2015; Mennis, 2006; Pham et al., 2012, 2013). In Portland, much of the highest elevation areas are west of the Willamette River where tree canopy cover exceeds 54%, while areas east of the Willamette River have an estimate 20.5% tree canopy cover (Portland Parks & Recreation, 2018b).

Distributional inequities were most pronounced for right-of-way greenness (i.e., tree canopy cover, green cover, and street-level greenness). In bivariate analyses, the strongest race-, ethnicity-, and education-based disparities were detected for right-of-way tree canopy cover, while the strongest income-based disparity was observed for right-of-way green cover (Table 4.3). Multivariate SAR models confirmed the significance of these relationships (Table 4.4; Table C4-C7), and unlike the findings for all other green cover variables, changes in right-of-way tree canopy and green cover characteristics were more closely associated with block group sociodemographic characteristics than either elevation or urban form (Table C1-C3; Table C8-C10). These findings mirror outcomes from a study in Montreal, Canada where street trees and vegetation had significant and negative associations with block-level percent minoritized racial population and percent low-income population in SAR models, though their model suggested a slightly more modest relationship between street vegetation and block-level minoritized racial population (Pham et al., 2012). Landry and Chakraborty (2009) also identified inequitable distribution of right-of-way tree canopy adjacent to residential land uses based on race, ethnicity (i.e., percent Hispanic/Latinx), and median household income in Tampa, Florida, USA. Portland's Parks and Recreation racial equity plan highlights the need to update the City's Urban Forest Management Plan and Citywide Tree Planting Strategy with particular attention to tree planting in low-income neighborhoods with low tree canopy cover (Portland Parks & Recreation, 2017). My results suggest that while tree planting in parks and on private land would meaningfully contribute to reducing tree canopy disparities, the inequities observed between race, income, and right-of-way tree canopy cover are the most significant and pressing distributional injustices related to urban green space in Portland.

Though I did not set out to establish causation for the disparities in urban green space access/exposure, reflecting on historical urban planning context may be instructive for contextualizing current urban green space distribution inequities. In the 1930s, following the Great Depression, the United States government established the Home Owner's Loan Corporation (HOLC) which developed mortgage security maps for urban areas across the United States, ranking areas based on investment risk. The highest risk areas, which encompassed predominantly Black/African American communities, were deemed "hazardous" investments, making it difficult for existing property owners to finance home improvement projects and barred potential home buyers from obtaining mortgages. This practice of discriminatory lending and systematic disinvestment, known as redlining, has been associated with loss of generational wealth in the Black/African American community (Rothstein, 2017), as well as geographic racial segregation and racial disparities in health outcomes (Nardone et al., 2020). In a recent study of 37 cities in the United States, Locke et al. (2021) found that neighborhoods receiving "hazardous" grades had consistently lower tree canopy cover than all other areas delineated in the HOLC maps. Another recent study identified links between street tree diversity and tree size have been linked to institutionalized racially discriminatory housing policies (i.e., redlining) in Baltimore, Maryland, USA (Burghardt et al., 2022). This pattern of systematic community disinvestment, as well as racially exclusionary neighborhood housing covenants and the use of eminent domain under the guise of urban renewal, have impacted the spatial distribution of Portland's minoritized racial groups, particularly the Black/African American community (Barber et al., 2018; Gibson, 2007).

The legacy of these policies and actions may partially explain the inequitable distribution of tree canopy and green cover found in this study. I used openly available HOLC data (Nelson et al., n.d.) to compare HOLC mortgage security grades with block group-level green cover in Portland. In qualitative visual analysis of the areas where the datasets overlap, the areas designated "best" and "desirable" (A and B grades, respectively) appear to overlap block groups with greater right-of-way tree canopy cover than areas defined as "declining" and "hazardous" (C and D grades, respectively; Figure 4.7). This visual pattern was confirmed quantitatively using unpaired two-sample Student's t-tests to measure differences in mean tree canopy and total green cover based on HOLC grades. Comparing block groups with their centroids in A and B grade areas to block groups in C and D grade areas, I found significant differences between tree and green cover on right-of-way, on private land, and across all land uses. I identified a 12.6% percent difference in means for right-of-way tree canopy cover (t-statistic=8.1, p=4.7E-13) and a 9.3% difference (t-statistic=7.9, p=1.2E-12) in tree canopy cover across all land uses (Table C13). These data suggest a potential throughline between patterns of disinvestment related to past racist urban planning policies and current inequities in access to urban environmental amenities.

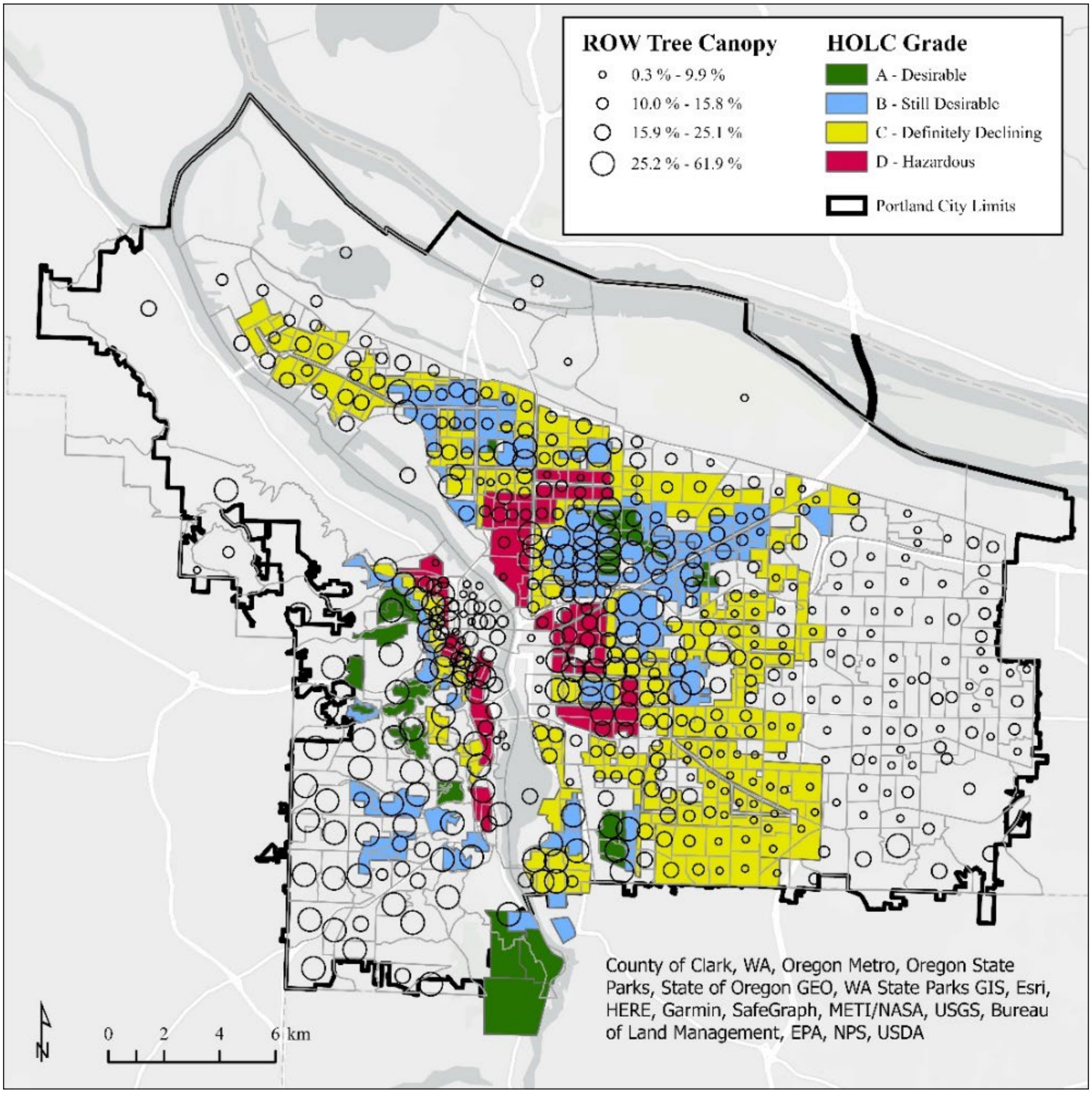

Figure 4.7. Mapped comparison of right-of-way (ROW) tree canopy cover (percent of right-of-way with block group) with Home Owner's Loan Corporation (HOLC) mortgage security risk grades.

4.2 Urban Green Space Planning for Distributional Justice

Where urban green space disparities persist, targeting equal access and exposure requires equitable allocation of resources such that funds are directed predominantly to communities with the least access/exposure. While there may be many methods for identifying areas most in need of urban green space investment, I have provided an example methodology for identifying priority locations for community engagement related to green space development and enhancement. I identified priority block groups as those in the lower quartile for the green space characteristic in question and in the upper quartile (race, ethnicity, and educational attainment) or lower quartile (median household income) for all significant sociodemographic variables present in the best-fit SAR model. I further stratified block groups into four priority tiers, using the 10th, 15th, 20th, and 25th percentiles as cutoffs for priority block groups based on median household income and urban green space variables and 90th, 85th, 80th, and 75th percentiles for race, ethnicity, and education variables. For example, to create the prioritization map for total tree canopy cover, block groups in the upper quartile for percent minoritized racial population and the lower quartile for total tree canopy cover and median household income were considered priorities, while any block groups above the 90th percentile for percent minoritized racial population and below the 10th percentile for total tree canopy cover and median household income were identified as the highest priority.

For park-based equity considerations, I generated maps locating priority block groups for improvements based on park tree canopy cover and NEST natural aesthetics, usability, and amenities domains (Figure 4.8-4.9). I also created tables of park names that met the prioritization criteria for each park quality in question (e.g., for NEST amenities, the list includes parks within 400 m of block groups in the lower quartile for NEST amenities and the upper quartile for Hispanic/Latinx population; Table C14-C17). In total, I identified 117 parks, 48 schoolyards, and 7 cemeteries that should be considered for park quality improvements. While this analysis provides a basis for assessing park equity and an example for how to identify priority areas for park development and improvement, future in-depth analysis of the distribution of specific park programs and facilities, as well as consideration of potential barriers, such as street connectivity, traffic speed, sidewalk availability, and perceptions of safety, may provide further insight into relationships between park access, park quality, neighborhood environment, and park use (A. Kaczynski et al., 2012; Lapham et al., 2016). In addition, park improvement planning should meaningfully involve and empower marginalized community members throughout decision-making processes and respond to their social, cultural, and recreational needs (Fors et al., 2021; Jennings et al., 2019).

In the green cover priorities assessment, I identified 47 priority block groups for potential tree canopy expansion (i.e., across all land uses, on private land, and on right-of-way), 45 of which were located east of the Willamette River, mostly concentrated east of 82nd Avenue (Figure 4.10-4.11). These findings were consistent with resident perceptions of tree canopy cover: a survey of approximately 3,000 Portland residents found that residents living east of 82nd Avenue were less likely to believe their neighborhood had enough trees (Portland Parks & Recreation, 2018a). While Portland Parks & Recreation set a 35% target for right-of-way tree canopy citywide (Portland Parks & Recreation, 2004), the 38 block groups identified for right-of-way tree canopy expansion range between two and ten percent, indicating a significant need for right-of-way tree canopy expansion. In terms of tree planting potential, Portland Parks & Recreation estimated that over 80% of the 8,452 hectares of potential tree planting space in the city was located east of the Willamette River, representing enough area to plant over one million trees (Portland Parks & Recreation, 2018b). Combining Portland Parks & Recreation's existing potential tree planting data with priority block groups for tree canopy expansion would provide specific locations for tree planting to promote equity in urban tree canopy cover. Although this approach targets only a small percentage of block groups for urban forest expansion, priority areas could be expanded by including all block groups above the median for percent minoritized racial population and below the median for green cover and median household income.

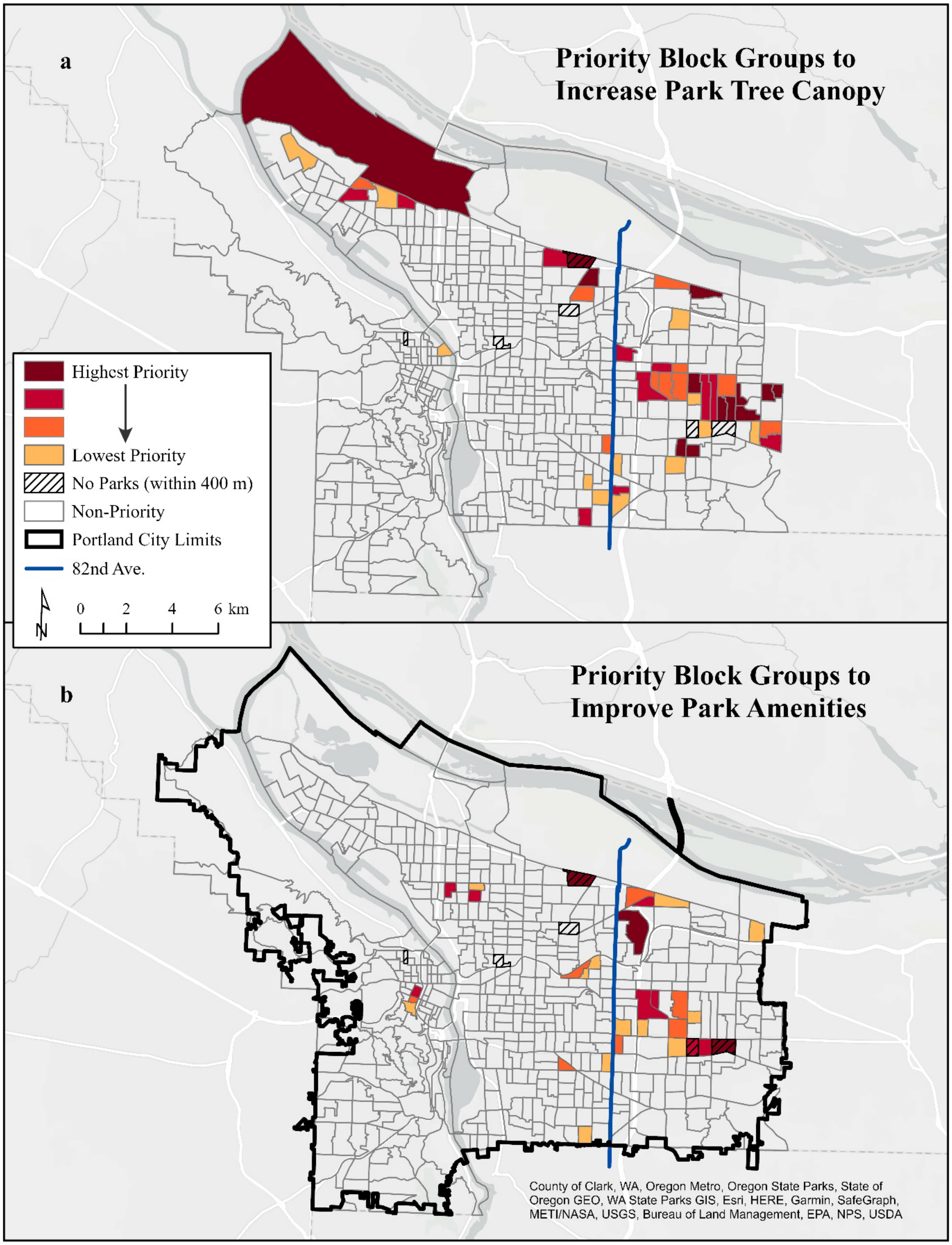

Figure 4.8. Priority block groups for a) parkland tree canopy expansion based on block group parkland tree canopy cover and percent Hispanic/Latinx, and b) park amenities enhancements based on block group Neighborhood Environment Scoring Tool (NEST) amenities domain scores, median household income, and percent minoritized racial population.

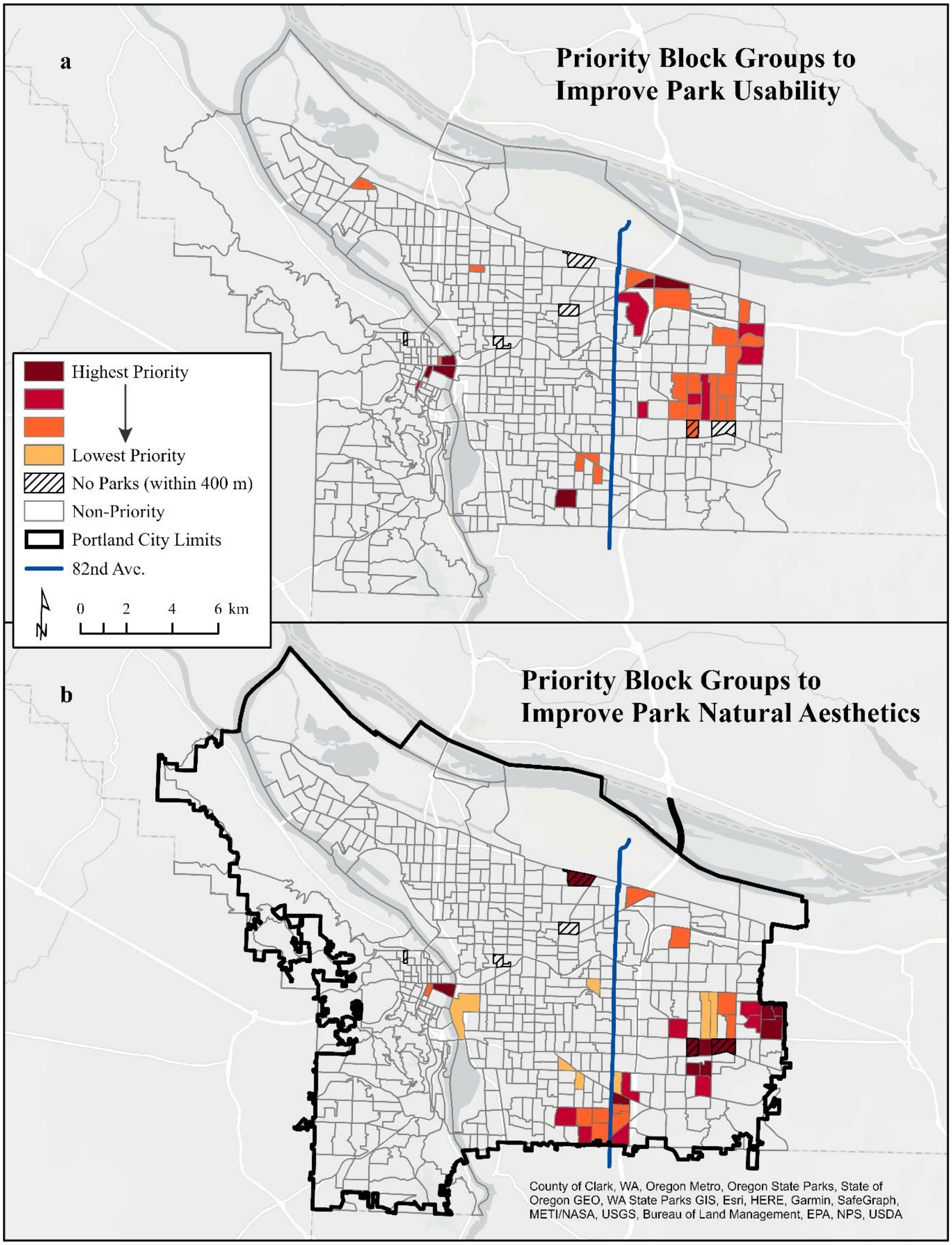

Figure 4.9. Priority block groups to improve a) park usability and b) natural aesthetics; block group selection based on Neighborhood Environmental Scoring Tool (NEST) usability and natural aesthetics domain scores (a and b, respectively), as well as percent of block group population with no postsecondary education.

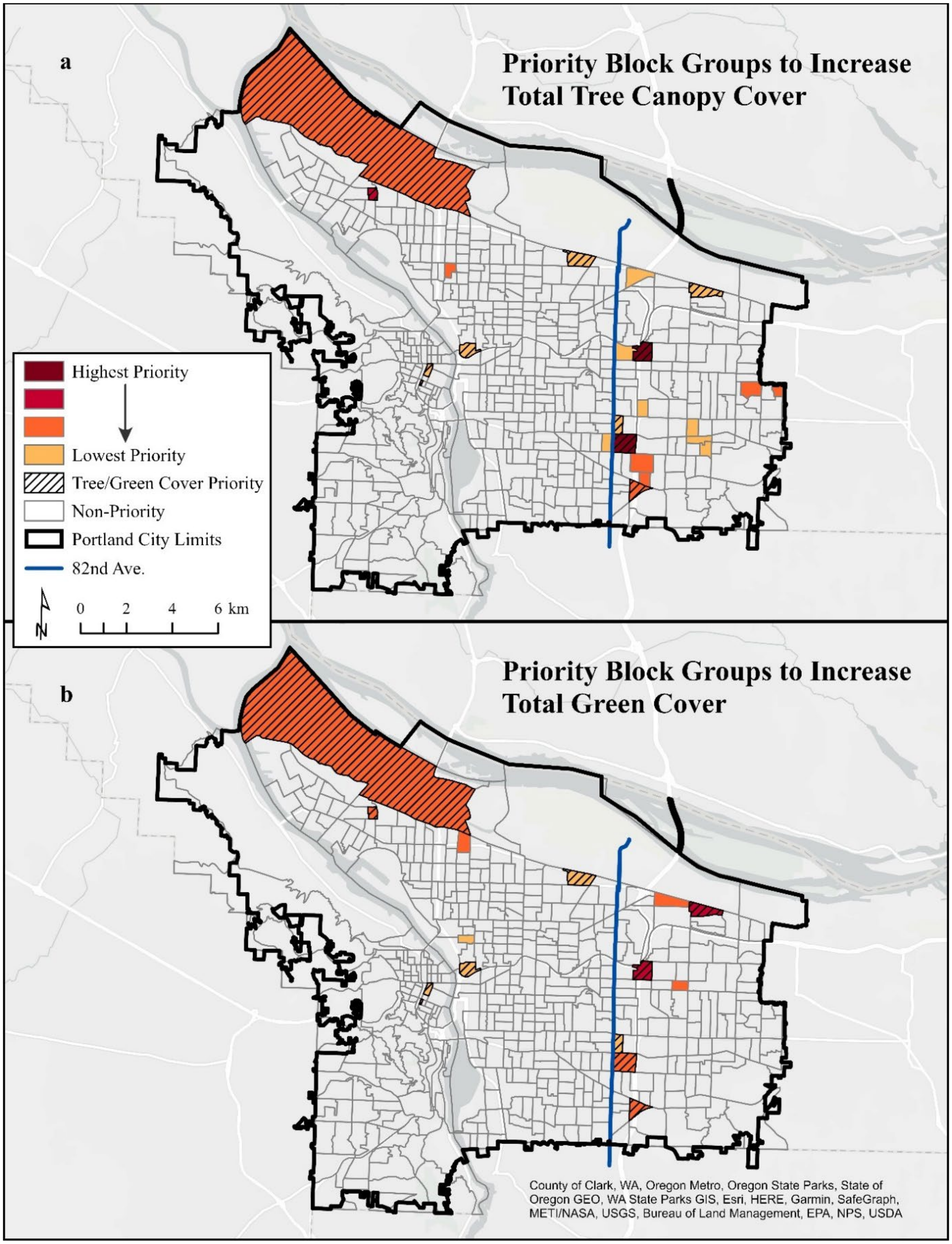

Figure 4.10. Priority block groups for increased a) total tree canopy cover, based on percent total tree canopy cover, median household income, and percent minoritized racial population, and b) total green cover, based on percent total green cover and percent Hispanic/Latinx.

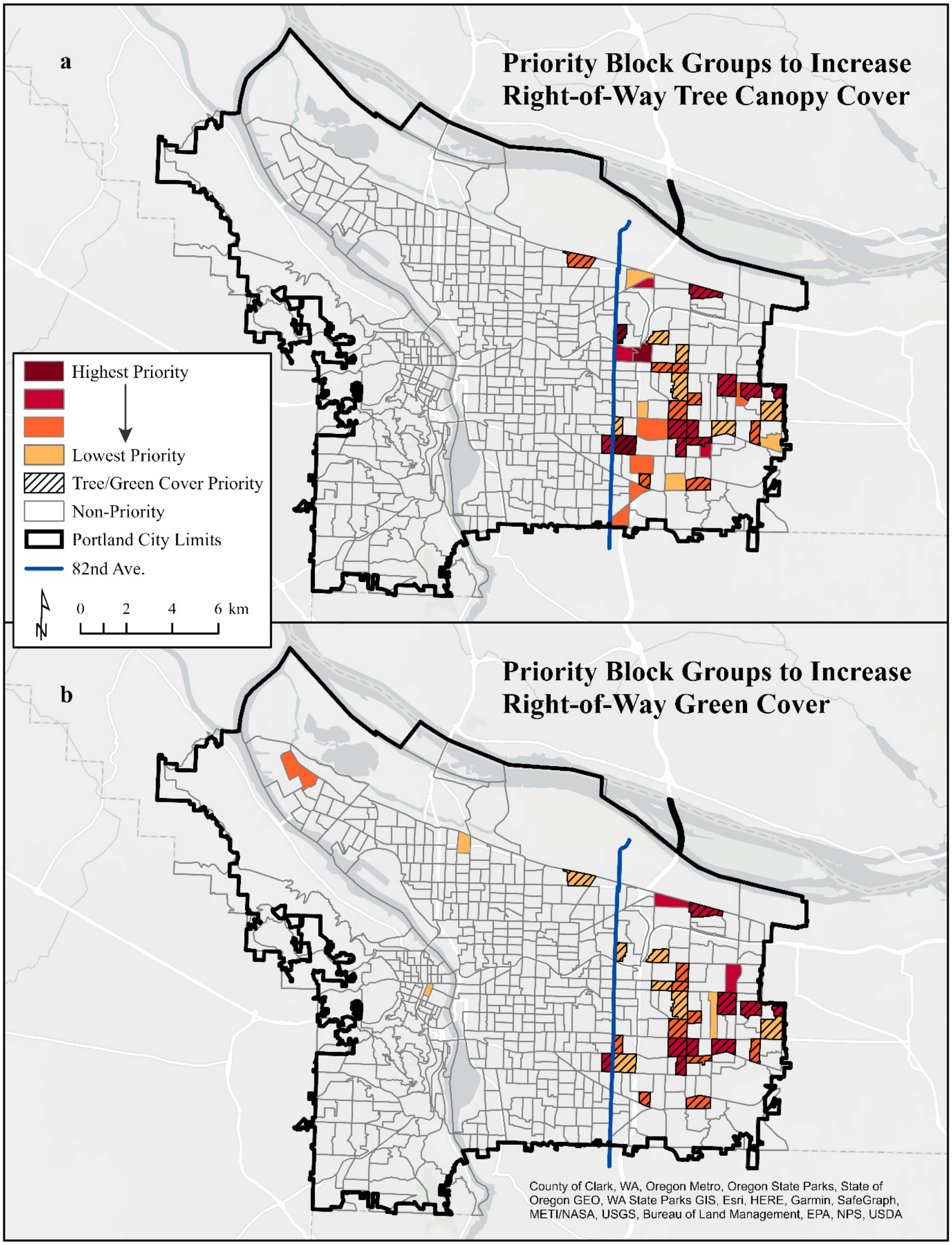

Figure 4.11. Priority block groups for increased a) right-of-way tree canopy cover based on percent right-of-way tree canopy cover, median household income, and percent minoritized racial population, and b) right-of-way green cover based on percent right-of-way green cover, median household income, and percent minoritized racial population.

4.3 Challenges to Addressing Urban Green Space Inequity

The findings and recommendations presented here are only a starting place for addressing disparities in urban green space exposure and access. I identified citywide distributional injustices related to urban green space access, as well as locations for potential urban green space investments to mitigate existing disparities. Careful consideration of policy, planning and procedural justice is necessary to identify and avoid potential unintended consequences of green space enhancement and expansion.

Increasing green space, whether parks or trees, in low-income and minoritized racial communities may initiate gentrification. The addition of parks and/or street trees can catalyze the restructuring of neighborhoods by increasing home values and rent costs, which may shift demographics, and force the displacement of particularly vulnerable residents (Checker, 2011; Cole et al., 2017; Donovan et al., 2021; Gould & Lewis, 2012; Wolch et al., 2014). Urban green space development may increase benefits for marginalized communities in the short-term, but in the long-term, these communities may face increased hardship associated with displacement, relocation, or alienation. Gould and Lewis (2012) documented how the process of ecological restoration and redesign of Prospect Park in Brooklyn, New York, USA led to new housing construction, an influx of White residents, and a dramatic decrease in Black population in the predominantly non-White surrounding neighborhoods which were accompanied by increased rent prices, relative to price increases across Brooklyn. Additionally, a recent study in Portland, Oregon found that both street tree planting and increases in tree canopy cover were associated with increased median single-family house sale price (Donovan et al., 2021). Tree planting was associated with median sale price increases of $131 and $265 per tree, six and twelve years after planting, respectively, and a one-percent increase in Census tract tree canopy cover corresponded with a median sale price increase of $882. As stated by Gould and Lewis, "without clearly focused public policy intervention, in situ environmental improvements will tend to increase racial and class inequality, and decrease environmental justice" (2012, p. 114). These findings suggest the need to consider how marginalized populations are impacted by urban greening, both in the short- and long-term, and how housing policy might be used to protect against green gentrification.

Even urban greening initiatives intended to provide compensatory equity (i.e., supporting communities who are less able to afford private tree planting and maintenance with greater public tree assets or subsidies specifically for tree planting and maintenance on private land) have resulted in less equitable outcomes. A study in Milwaukee, Wisconsin, USA found that homeowners accounted for 89% of the applicant pool for a tree giveaway program, and the strong positive correlation between median household income and homeownership suggests that this program may have increased inequitable tree canopy cover outcomes (Perkins et al., 2004). In a similar study, Locke et al. (2016) revealed that high income communities with already high tree canopy cover were most likely to participate in tree planting programs that provided free or low-cost trees for planting on private property in Baltimore, Maryland, USA and Washington, D.C., USA. As cities such as Portland consider implementing tree subsidy and giveaway programs to decrease tree canopy cover inequity (Portland Parks & Recreation, 2018a), these policies need to include specific need-based criteria to preclude high-income residents and those living in high tree canopy neighborhoods from participating.

Finally, an urban green space planning process oriented towards environmentally just outcomes should be led by the marginalized communities who experience disparities in access to environmental benefits. Cities frequently express the importance of stakeholder participation in planning processes (e.g., City of Los Angeles Department of Recreation and Parks, 2009; City of New York Parks & Recreation, 2014; Portland Parks & Recreation, 2017, 2018a), and it is critical that stakeholder engagement processes are inclusive of and responsive to perspectives from marginalized communities. Portland Parks & Recreation has made clear efforts to engage marginalized communities in the urban forest planning process through culturally specific focus groups and public surveys (Portland Parks & Recreation, 2018a). The results from outreach efforts revealed barriers to tree planting in marginalized communities which included a lack of accessible educational information, concerns over damages caused by trees, costs associated with tree planting and maintenance, and distrust of government agencies. Participants highlighted the importance of culturally and linguistically specific outreach, using established and trusted community leaders or organizations, as well as financial assistance with costs of buying, planting, and maintaining trees. The assessment provided in the present study, in conjunction with the outreach conducted by Portland Parks & Recreation, provides an opportunity for targeted urban green space improvements that address community concerns and promote urban environmental health equity.

5. Conclusion

This study established a process for assessing urban green space distributional justice concerns based on race, ethnicity, income, and educational attainment to characterize inequities in park access, park quality, and green cover exposure in Portland, Oregon and provided recommendations for priority locations for intervention. Combining evaluations of park access, park quality, and green cover into a single analytical approach allowed for a more complete understanding of urban green space inequities than if urban green space characteristics were considered independently. Additionally, generating separate green cover measures based on land use type allowed for increasingly specific assessments of urban green space disparities. While my analyses did not reveal systematic park access inequities, and only minor park quality concerns, I found clear and compelling evidence of distributional injustices in Portland, Oregon related to tree canopy and green cover across various land uses based on race, ethnicity, income, and educational attainment. The strongest and most consistent urban green space disparities were associated with right-of-way tree canopy cover, even after accounting for elevation, urban form, and spatial clustering. These findings provide a foundation for equitable urban green space planning in Portland, Oregon, as well as an avenue for cities to identify and address distributional inequities.

References Cited

Alcock, I., White, M. P., Wheeler, B. W., Fleming, L. E., & Depledge, M. H. (2014). Longitudinal Effects on Mental Health of Moving to Greener and Less Green Urban Areas. *Environmental Science & Technology*, *48*(2), 1247–1255. https://doi.org/10.1021/es403688w

Anguelovski, I. (2016). From Toxic Sites to Parks as (Green) LULUs? New Challenges of Inequity, Privilege, Gentrification, and Exclusion for Urban Environmental Justice. *Journal of Planning Literature*, *31*(1), 23–36. https://doi.org/10.1177/0885412215610491

Anselin, L. (1988). *Spatial econometrics: Methods and models*. Kluwer Academic Publishers.

Anselin, L. (2005). *Exploring Spatial Data with GeoDa: A Workbook*. https://www.geos.ed.ac.uk/~gisteac/fspat/geodaworkbook.pdf

Astell-Burt, T., Feng, X., Mavoa, S., Badland, H. M., & Giles-Corti, B. (2014). Do low-income neighbourhoods have the least green space? A cross-sectional study of Australia's most populous cities. *BMC Public Health*, *14*(1). https://doi.org/10.1186/1471-2458-14-292

Bai, T., Mayer, A. L., Shuster, W. D., & Tian, G. (2018). The Hydrologic Role of Urban Green Space in Mitigating Flooding (Luohe, China). *Sustainability*, *10*(10), Article 10. https://doi.org/10.3390/su10103584

Bailey, A. W., Allen, G., Herndon, J., & Demastus, C. (2018). Cognitive benefits of walking in natural versus built environments. *World Leisure Journal*, *60*(4), 293–305. https://doi.org/10.1080/16078055.2018.1445025

Barber, K., Hart, L., Jewell, C., Miller, M., & Smith, G. (2018). *Invisible Walls: Mapping Residential Segregation In Portland*. Oregon Historical Society. https://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1042&context=hist_fac

Barr, D. A. (2014). Health disparities in the United States: Social class, race, ethnicity, and health (Second edition.). Johns Hopkins University Press.

Berland, A., Schwarz, K., Herrmann, D., & Hopton, M. (2015). How Environmental Justice Patterns are Shaped by Place: Terrain and Tree Canopy in Cincinnati, Ohio, USA. *Cities and the Environment (CATE)*, *8*(1). https://digitalcommons.lmu.edu/cate/vol8/iss1/1

Beyer, K., Kaltenbach, A., Szabo, A., Bogar, S., Nieto, F., & Malecki, K. (2014). Exposure to Neighborhood Green Space and Mental Health: Evidence from the Survey of the Health of Wisconsin. *International Journal of Environmental Research and Public Health*, *11*(3), 3453–3472. https://doi.org/10.3390/ijerph110303453

Bivand, R. S., & Wong, D. W. S. (2018). Comparing implementations of global and local indicators of spatial association. *TEST*, *27*(3), 716–748. https://doi.org/10.1007/s11749-018-0599-x

Burghardt, K. T., Avolio, M. L., Locke, D. H., Grove, J. M., Sonti, N. F., & Swan, C. M. (2022). Current street tree communities reflect race-based housing policy and modern attempts to remedy environmental injustice. *Ecology*. https://doi.org/10.1002/ecy.3881

Checker, M. (2011). Wiped Out by the "Greenwave": Environmental Gentrification and the Paradoxical Politics of Urban Sustainability. *City & Society*, *23*(2), 210–229. https://doi.org/10.1111/j.1548-744X.2011.01063.x

City of Los Angeles Department of Recreation and Parks. (2009). *2009 Citywide Community Needs Assessment*. https://www.laparks.org/sites/default/files/projects/2009%20Community%20Needs%20Assessment%20-%20Final.pdf

City of New York Parks & Recreation. (2014). *NYC Parks: Framework for an Equitable Future*.

Cohen, J. (1977). Statistical Power Analysis for the Behavioral Sciences (Revised Edition). Academic Press.

Cole, H. V. S., Garcia Lamarca, M., Connolly, J. J. T., & Anguelovski, I. (2017). Are green cities healthy and equitable? Unpacking the relationship between health, green space and gentrification. *Journal of Epidemiology and Community Health*, *71*(11), 1118.

de Vries, S., Verheij, R. A., Groenewegen, P. P., & Spreeuwenberg, P. (2003). Natural Environments—Healthy Environments? An Exploratory Analysis of the Relationship between Greenspace and Health. *Environment and Planning A: Economy and Space*, *35*(10), 1717–1731. https://doi.org/10.1068/a35111

Donovan, G. H., Prestemon, J. P., Butry, D. T., Kaminski, A. R., & Monleon, V. J. (2021). The politics of urban trees: Tree planting is associated with gentrification in Portland, Oregon. *Forest Policy and Economics. 124: 102387.*, *124*, 102387. https://doi.org/10.1016/j.forpol.2020.102387

Engelberg, J. K., Conway, T. L., Geremia, C., Cain, K. L., Saelens, B. E., Glanz, K., Frank, L. D., & Sallis, J. F. (2016). Socioeconomic and race/ethnic disparities in observed park quality. *BMC Public Health*, *16*(1). https://doi.org/10.1186/s12889-016-3055-4

Flocks, J., Escobedo, F., Wade, J., Varela, S., & Wald, C. (2011). Environmental Justice Implications of Urban Tree Cover in Miami-Dade County, Florida. *Environmental Justice*, *4*(2), 125–134. https://doi.org/10.1089/env.2010.0018

Fors, H., Hagemann, F. A., Sang, Å. O., & Randrup, T. B. (2021). Striving for Inclusion—A Systematic Review of Long-Term Participation in Strategic Management of Urban Green Spaces. *Frontiers in Sustainable Cities*, *3*. https://www.frontiersin.org/articles/10.3389/frsc.2021.572423

Frank, L. D., Schmid, T. L., Sallis, J. F., Chapman, J., & Saelens, B. E. (2005). Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ. *American Journal of Preventive Medicine*, *28*(2, Supplement 2), 117–125. https://doi.org/10.1016/j.amepre.2004.11.001

Gerrish, E., & Watkins, S. L. (2018). The relationship between urban forests and income: A meta-analysis. *Landscape and Urban Planning*, *170*, 293–308. https://doi.org/10.1016/j.landurbplan.2017.09.005

Gibson, K. (2007). Bleeding Albina: A History of Community Disinvestment, 1940-2000. *Transforming Anthropology*, *15*(1), 3–25. https://doi.org/10.1525/tran.2007.15.1.03

Gidlow, C., van Kempen, E., Smith, G., Triguero-Mas, M., Kruize, H., Gražulevičienė, R., Ellis, N., Hurst, G., Masterson, D., Cirach, M., van den Berg, M., Smart, W., Dėdelė, A., Maas, J., & Nieuwenhuijsen, M. J. (2018). Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening*, *29*, 322–333. https://doi.org/10.1016/j.ufug.2017.12.007

Google. (2020). *Street View Static API overview*. Google Developers. https://developers.google.com/maps/documentation/streetview/overview

Gould, K. A., & Lewis, T. L. (2012). The environmental injustice of green gentrification: The case of Brooklyn's Prospect Park. In J. N. DeSena & T. Shortell (Eds.), *The world in Brooklyn: Gentrification, immigration, and ethnic politics in a global city* (pp. 113–146). Lexington Books.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science*, *319*(5864), 756–760. https://doi.org/10.1126/science.1150195

Handy, S. L., & Niemeier, D. A. (1997). Measuring Accessibility: An Exploration of Issues and Alternatives. *Environment and Planning A*, *29*(7), 1175–1194. https://doi.org/10.1068/a291175

Heckler, M. M. (1985). *Report of the Secretary's Task Force on Black and Minority Health*. U.S. Department of Health and Human Services. https://minorityhealth.hhs.gov/assets/pdf/checked/1/ANDERSON.pdf

Hockey, M., Rocks, T., Ruusunen, A., Jacka, F. N., Huang, W., Liao, B., Aune, D., Wang, Y., Nie, J., & O'Neil, A. (2022). Psychological distress as a risk factor for all-cause, chronic disease- and suicide-specific mortality: A prospective analysis using data from the National Health Interview Survey. *Social Psychiatry and Psychiatric Epidemiology*, *57*(3), 541–552. https://doi.org/10.1007/s00127-021-02116-7

Hoffimann, E., Barros, H., & Ribeiro, A. (2017). Socioeconomic Inequalities in Green Space Quality and Accessibility—Evidence from a Southern European City. *International Journal of Environmental Research and Public Health*, *14*(8), 916. https://doi.org/10.3390/ijerph14080916

Huang, S., Qi, J., Li, W., Dong, J., & van den Bosch, C. K. (2021). The Contribution to Stress Recovery and Attention Restoration Potential of Exposure to Urban Green Spaces in Low-Density Residential Areas. *International Journal of Environmental Research and Public Health*, *18*(16), 8713. https://doi.org/10.3390/ijerph18168713

Hunter, R. F., Christian, H., Veitch, J., Astell-Burt, T., Hipp, J. A., & Schipperijn, J. (2015). The impact of interventions to promote physical activity in urban green space: A systematic review and recommendations for future research. *Social Science & Medicine*, *124*, 246–256. https://doi.org/10.1016/j.socscimed.2014.11.051

Jennings, V., Browning, M. H. E. M., & Rigolon, A. (2019). Urban Green Space at the Nexus of Environmental Justice and Health Equity. In V. Jennings, M. H. E. M. Browning, & A. Rigolon, *Urban Green Spaces* (pp. 47–69). Springer International Publishing. https://doi.org/10.1007/978-3-030-10469-6_4

Jennings, V., & Gaither, C. (2015). Approaching Environmental Health Disparities and Green Spaces: An Ecosystem Services Perspective. *International Journal of Environmental Research and Public Health*, *12*(2), 1952–1968. https://doi.org/10.3390/ijerph120201952

Jennings, V., Johnson Gaither, C., & Gragg, R. S. (2012). Promoting Environmental Justice Through Urban Green Space Access: A Synopsis. *Environmental Justice*, *5*(1), 1–7. https://doi.org/10.1089/env.2011.0007

Kaczynski, A., Koohsari, M., Stanis, S. W., Bergstrom, R., & Sugiyama, T. (2012). Association of street connectivity and traffic speed with park usage and park-based physical activity. *Journal of Science and Medicine in Sport*, *15*, S31–S31. https://doi.org/10.1016/j.jsams.2012.11.075

Kaczynski, A. T., Besenyi, G. M., Stanis, S. A. W., Koohsari, M. J., Oestman, K. B., Bergstrom, R., Potwarka, L. R., & Reis, R. S. (2014). Are park proximity and park features related to park use and park-based physical activity among adults? Variations by multiple socio-demographic characteristics. *The International Journal of Behavioral Nutrition and Physical Activity*, *11*(1), 146. https://doi.org/10.1186/s12966-014-0146-4

Kaczynski, A. T., & Henderson, K. A. (2007). Environmental Correlates of Physical Activity: A Review of Evidence about Parks and Recreation. *Leisure Sciences*, *29*(4), 315–354. https://doi.org/10.1080/01490400701394865

Kaczynski, A. T., Potwarka, L. R., & Saelens, B. E. (2008). Association of Park Size, Distance, and Features With Physical Activity in Neighborhood Parks. *American Journal of Public Health*, *98*(8), 1451–1456. https://doi.org/10.2105/AJPH.2007.129064

Kadaverugu, A., Nageshwar Rao, C., & Viswanadh, G. K. (2021). Quantification of flood mitigation services by urban green spaces using InVEST model: A case study of Hyderabad city, India. *Modeling Earth Systems and Environment*, *7*(1), 589–602. https://doi.org/10.1007/s40808-020-00937-0

Khomenko, S., Cirach, M., Pereira-Barboza, E., Mueller, N., Barrera-Gómez, J., Rojas-Rueda, D., Hoogh, K. de, Hoek, G., & Nieuwenhuijsen, M. (2021). Premature mortality due to air pollution in European cities: A health impact assessment. *The Lancet Planetary Health*, *5*(3), e121–e134. https://doi.org/10.1016/S2542-5196(20)30272-2

Landry, S. M., & Chakraborty, J. (2009). Street Trees and Equity: Evaluating the Spatial Distribution of an Urban Amenity. *Environment and Planning A: Economy and Space*, *41*(11), 2651–2670. https://doi.org/10.1068/a41236

Lapham, S. C., Cohen, D. A., Han, B., Williamson, S., Evenson, K. R., McKenzie, T. L., Hillier, A., & Ward, P. (2016). How important is perception of safety to park use? A four-city survey. *Urban Studies*, *53*(12), 2624–2636. https://doi.org/10.1177/0042098015592822

Li, X., Ratti, C., & Seiferling, I. (2017). Mapping Urban Landscapes Along Streets Using Google Street View. In M. P. Peterson (Ed.), *Advances in Cartography and GIScience* (pp. 341–356). Springer International Publishing. https://doi.org/10.1007/978-3-319-57336-6_24

Li, X., Zhang, C., Li, W., Ricard, R., Meng, Q., & Zhang, W. (2015). Assessing street-level urban greenery using Google Street View and a modified green view index. *Urban Forestry & Urban Greening*, *14*(3), 675–685. https://doi.org/10.1016/j.ufug.2015.06.006

Liang, L., & Gong, P. (2020). Urban and air pollution: A multi-city study of long-term effects of urban landscape patterns on air quality trends. *Scientific Reports*, *10*(1), Article 1. https://doi.org/10.1038/s41598-020-74524-9

Locke, D. H., & Grove, J. M. (2016). Doing the hard work where it's easiest? Examining the relationships between urban greening programs and social and ecological characteristics. *Applied Spatial Analysis and Policy.*, *9*, 77–96. https://doi.org/10.1007/s12061-014-9131-1

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. *Npj Urban Sustainability*, *1*(1), Article 1. https://doi.org/10.1038/s42949-021-00022-0

Maas, J. (2006). Green space, urbanity, and health: How strong is the relation? *Journal of Epidemiology & Community Health*, *60*(7), 587–592. https://doi.org/10.1136/jech.2005.043125

Marando, F., Salvatori, E., Sebastiani, A., Fusaro, L., & Manes, F. (2019). Regulating Ecosystem Services and Green Infrastructure: Assessment of Urban Heat Island effect mitigation in the municipality of Rome, Italy. *Ecological Modelling*, *392*, 92–102. https://doi.org/10.1016/j.ecolmodel.2018.11.011

Mennis, J. (2006). Socioeconomic-Vegetation Relationships in Urban, Residential Land. *Photogrammetric Engineering & Remote Sensing*, *72*(8), 911–921. https://doi.org/10.14358/PERS.72.8.911

Mills, J. R., Cunningham, P., & Donovan, G. H. (2016). Urban forests and social inequality in the Pacific Northwest. *Urban Forestry & Urban Greening*, *16*, 188–196. https://doi.org/10.1016/j.ufug.2016.02.011

Mishra, P., Pandey, C. M., Singh, U., Gupta, A., Sahu, C., & Keshri, A. (2019). Descriptive Statistics and Normality Tests for Statistical Data. *Annals of Cardiac Anaesthesia*, *22*(1), 67–72. https://doi.org/10.4103/aca.ACA_157_18

Mohajerani, A., Bakaric, J., & Jeffrey-Bailey, T. (2017). The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. *Journal of Environmental Management*, *197*, 522–538. https://doi.org/10.1016/j.jenvman.2017.03.095

Murage, P., Kovats, S., Sarran, C., Taylor, J., McInnes, R., & Hajat, S. (2020). What individual and neighbourhood-level factors increase the risk of heat-related mortality? A case-crossover study of over 185,000 deaths in London using high-resolution climate datasets. *Environment International*, *134*, 105292. https://doi.org/10.1016/j.envint.2019.105292

Nardone, A., Chiang, J., & Corburn, J. (2020). Historic Redlining and Urban Health Today in U.S. Cities. *Environmental Justice*, *13*(4), 109–119. https://doi.org/10.1089/env.2020.0011

National Center for Health Statistics. (2012). *Health, United States, 2011: With Special Feature on Socioeconomic Status and Health*. https://www.ncbi.nlm.nih.gov/books/NBK98752/

Nelson, R. K., Winling, L., Marciano, R., Connolly, N., & et al. (n.d.). *Mapping Inequality*. American Panorama. Retrieved January 12, 2023, from https://dsl.richmond.edu/panorama/redlining/#loc=12/45.523/-122.715&city=portland-or&text=downloads

Nesbitt, L., Meitner, M. J., Girling, C., Sheppard, S. R. J., & Lu, Y. (2019). Who has access to urban vegetation? A spatial analysis of distributional green equity in 10 US cities. *Landscape and Urban Planning*, *181*, 51–79. https://doi.org/10.1016/j.landurbplan.2018.08.007

Nowak, D. J., & Dwyer, J. F. (2007). Understanding the Benefits and Costs of Urban Forest Ecosystems. In *Urban and Community Forestry in the Northeast* (pp. 25–46).

Nowak, D. J., Hirabayashi, S., Bodine, A., & Greenfield, E. (2014). Tree and forest effects on air quality and human health in the United States. *Environmental Pollution*, *193*, 119–129. https://doi.org/10.1016/j.envpol.2014.05.028

Oregon Metro RLIS. (2020a). *ORCA Sites* [Map]. https://rlisdiscovery.oregonmetro.gov/

Oregon Metro RLIS. (2020b). *Schools* [Map]. https://rlisdiscovery.oregonmetro.gov/

Pebesma, E. (2018). Simple Features for R: Standardized Support for Spatial Vector Data. *The R Journal*, *10*(1), 439. https://doi.org/10.32614/RJ-2018-009

Perkins, H. A., Heynen, N., & Wilson, J. (2004). Inequitable access to urban reforestation: The impact of urban political economy on housing tenure and urban forests. *Cities*, *21*(4), 291–299. https://doi.org/10.1016/j.cities.2004.04.002

Pham, T.-T.-H., Apparicio, P., Landry, S., & Lewnard, J. (2017). Disentangling the effects of urban form and socio-demographic context on street tree cover: A multi-level analysis from Montréal. *Landscape and Urban Planning*, *157*, 422–433. https://doi.org/10.1016/j.landurbplan.2016.09.001

Pham, T.-T.-H., Apparicio, P., Landry, S., Séguin, A.-M., & Gagnon, M. (2013). Predictors of the distribution of street and backyard vegetation in Montreal, Canada. *Urban Forestry & Urban Greening*, *12*(1), 18–27. https://doi.org/10.1016/j.ufug.2012.09.002

Pham, T.-T.-H., Apparicio, P., Séguin, A.-M., Landry, S., & Gagnon, M. (2012). Spatial distribution of vegetation in Montreal: An uneven distribution or environmental inequity? *Landscape and Urban Planning*, *107*(3), 214–224. https://doi.org/10.1016/j.landurbplan.2012.06.002

Portland Parks & Recreation. (2004). Portland Urban Forestry Management Plan.

Portland Parks & Recreation. (2017). *Five-Year Racial Equity Plan*.

Portland Parks & Recreation. (2018a). *Growing a more equitable urban forest: Portland's citywide tree planting strategy*. https://www.portland.gov/parks/documents/tree-planting-strategy/download

Portland Parks & Recreation. (2018b). *Tree Canopy and Potential in Portland, Oregon*. https://www.portland.gov/sites/default/files/2020-08/tree-canopy-and-potential-2018.pdf

Portland Parks & Recreation. (2022). *Tree Canopy Monitoring: Protocol and Monitoring from 2000-2020*. https://www.portland.gov/trees/documents/tree-canopy-monitoring-2000-2020/download

R Core Team. (2022). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Rhew, I. C., Vander Stoep, A., Kearney, A., Smith, N. L., & Dunbar, M. D. (2011). Validation of the normalized difference vegetation index as a measure of neighborhood greenness. *Annals of Epidemiology*, *21*(12), 946–952. https://doi.org/10.1016/j.annepidem.2011.09.001

Rigolon, A. (2016). A complex landscape of inequity in access to urban parks: A literature review. *Landscape and Urban Planning*, *153*, 160–169. https://doi.org/10.1016/j.landurbplan.2016.05.017

Rigolon, A., Browning, M. H. E. M., McAnirlin, O., & Yoon, H. (Violet). (2021). Green Space and Health Equity: A Systematic Review on the Potential of Green Space to Reduce Health Disparities. *International Journal of Environmental Research and Public Health*, *18*(5), 2563. https://doi.org/10.3390/ijerph18052563

Rothstein, R. (2017). *The color of law: A forgotten history of how our government segregated America* (First edition.). Liveright Publishing Corporation, a division of W.W. Norton & Company.

Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., Salvo, D., Schipperijn, J., Smith, G., Cain, K. L., Davey, R., Kerr, J., Lai, P.-C., Mitáš, J., Reis, R., Sarmiento, O. L., Schofield, G., Troelsen, J., Van Dyck, D., … Owen, N. (2016). Physical activity in relation to urban environments in 14 cities worldwide: A cross-sectional study. *Lancet (London, England)*, *387*(10034), 2207–2217. https://doi.org/10.1016/S0140-6736(15)01284-2

Schwarz, K., Fragkias, M., Boone, C. G., Zhou, W., McHale, M., Grove, J. M., O'Neil-Dunne, J., McFadden, J. P., Buckley, G. L., Childers, D., Ogden, L., Pincetl, S., Pataki, D., Whitmer, A., & Cadenasso, M. L. (2015). Trees Grow on Money: Urban Tree Canopy Cover and Environmental Justice. *PLoS ONE*, *10*(4), e0122051. https://doi.org/10.1371/journal.pone.0122051

Shindell, D., Zhang, Y., Scott, M., Ru, M., Stark, K., & Ebi, K. L. (2020). The Effects of Heat Exposure on Human Mortality Throughout the United States. *GeoHealth*, *4*(4), e2019GH000234. https://doi.org/10.1029/2019GH000234

The Trust for Public Land. (2010). *The 150 Largest City Parks*. http://cloud.tpl.org/pubs/ccpe-largest-oldest-most-visited-parks-4-2011-update.pdf

Uejio, C. K., Wilhelmi, O. V., Golden, J. S., Mills, D. M., Gulino, S. P., & Samenow, J. P. (2011). Intra-urban societal vulnerability to extreme heat: The role of heat exposure and the built environment, socioeconomics, and neighborhood stability. *Health & Place*, *17*(2), 498–507. https://doi.org/10.1016/j.healthplace.2010.12.005

United Nations. (2019). *World Urbanization Prospects 2018 Highlights*. https://population.un.org/wup/Publications/Files/WUP2018-Highlights.pdf

United States Department of Agriculture. (2022). *NAIP GeoHub*. https://naip-usdaonline.hub.arcgis.com/

U.S. Census Bureau. (2021). *TIGER/Line: Shapefiles* [Map]. https://www.census.gov/geographies/mapping-files/2020/geo/tiger-line-file.html

U.S. Census Bureau. (2022a). Educational Attainment for the Population 25 Years and Over, 2016-2020 American Community Survey 5-Year Estimates. https://data.census.gov/table?g=0500000US41051$1500000&tid=ACSDT5Y2020.B15003

U.S. Census Bureau. (2022b). *Hispanic or Latino Origin by Race, 2016-2020 American Community Survey 5-Year Estimates*. https://data.census.gov/table?g=0500000US41051$1500000&tid=ACSDT5Y2020.B03002

U.S. Census Bureau. (2022c). Median Household Income in the Past 12 Months (in 2020 Inflation-Adjusted Dollars), 2016-2020 American Community Survey 5-Year Estimates. https://data.census.gov/table?g=0500000US41051$1500000&tid=ACSDT5Y2020.B19013

U.S. Census Bureau. (2022d). *QuickFacts: Portland city, Oregon*. https://www.census.gov/quickfacts/portlandcityoregon

U.S. Census Bureau. (2022e). *Race, 2020 Census Redistricting Data*. https://data.census.gov/table?g=0500000US41051$1500000&tid=DECENNIALPL2020.P1

US EPA. (2017). *EnviroAtlas Data Download: Step 2* [Data and Tools]. https://www.epa.gov/enviroatlas/data-download-step-2

USGS. (2022). 1/3rd arc-second Digital Elevation Models (DEMs)—USGS National Map 3DEP Downloadable Data Collection. https://data.usgs.gov/datacatalog/data/USGS:3a81321b-c153-416f-98b7-cc8e5f0e17c3

Voelkel, J., & Shandas, V. (2017). Towards Systematic Prediction of Urban Heat Islands: Grounding Measurements, Assessing Modeling Techniques. *Climate*, *5*(2), 41. https://doi.org/10.3390/cli5020041

Walker, J. T., Mowen, A. J., Hendricks, W. W., Kruger, J., Morrow, J. R., & Bricker, K. (2009). Physical activity in the park setting (PA-PS) questionnaire: Reliability in a California statewide sample. *Journal of Physical Activity & Health*, *6 Suppl 1*, S97-104. https://doi.org/10.1123/jpah.6.s1.s97

Watkins, S. L., & Gerrish, E. (2018). The relationship between urban forests and race: A meta-analysis. *Journal of Environmental Management*, *209*, 152–168. https://doi.org/10.1016/j.jenvman.2017.12.021

Wen, M., Zhang, X., Harris, C. D., Holt, J. B., & Croft, J. B. (2013). Spatial Disparities in the Distribution of Parks and Green Spaces in the USA. *Annals of Behavioral Medicine*, *45*(suppl_1), S18–S27. https://doi.org/10.1007/s12160-012-9426-x

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough.' *Landscape and Urban Planning*, *125*, 234–244. https://doi.org/10.1016/j.landurbplan.2014.01.017

Wolf, K. L., Lam, S. T., McKeen, J. K., Richardson, G. R. A., van den Bosch, M., & Bardekjian, A. C. (2020). Urban Trees and Human Health: A Scoping Review. *International Journal of Environmental Research and Public Health*, *17*(12), 4371. https://doi.org/10.3390/ijerph17124371

World Health Organization. (2006). *Constitution of the World Health Organization*. https://www.who.int/governance/eb/who_constitution_en.pdf

World Health Organization. (2009). *Global health risks: Mortality and burden of disease attributable to selected major risks*. https://www.who.int/publications/i/item/9789241563871

Yang, Y., & Diez-Roux, A. V. (2012). Walking Distance by Trip Purpose and Population Subgroups. *American Journal of Preventive Medicine*, *43*(1), 11–19. https://doi.org/10.1016/j.amepre.2012.03.015

CHAPTER V

CONCLUSION: PROMOTING HEALTH EQUITY AND ENVIRONMENTAL JUSTICE THROUGH URBAN GREEN SPACE RESEARCH

Research at the Intersection of Urban Green Space, Health, and Environmental Justice

With this dissertation, I sought to investigate relationships between health, environmental justice, and urban landscapes—particularly related to urban green space—to inform urban green space design and planning. The goals of this research were to 1) search for evidence of health being used as motivation for historic urban green space planning, 2) examine the consequences of urban planning decisions on community health, 3) investigate associations between urban landscapes, physical activity, and mental well-being, and 4) construct and test a methodology to identify disparities in urban green space access and exposure based on race, ethnicity, and income.

In Chapter 2, I explored how public health catalyzed landscape architecture and urban planning in the United States and traced the meandering connections between health and urban landscape design and planning to the current discourse in both research and practice, centered on how urban green space impacts well-being, health equity, and environmental justice. This chapter revealed that public health was critical to the establishment of large urban parks and park systems in cities; exposed the socially unjust urban planning decisions that led to segregation, community disinvestment, urban decay, urban renewal, and displacement; illustrated how the environmentalism and environmental justice movements have informed current urban green space planning research and practice; and called for multidisciplinary action to promote health equity through environmentally just urban green space planning.

In Chapter 3, I evaluated associations between mental well-being, physical activity, and urban green space access/exposure based on a survey of residents in Portland, Oregon. This study improved on previous approaches by including a wide range individual and community-level health-related factors into modeling. Findings revealed that having at least one park within 400 m walking distance of home significantly increased the likelihood of park use. While no direct associations were observed between urban green space and neighborhood-based physical activity, residents who reported using a neighborhood park on a weekly basis were more than twice as likely to achieve moderate levels of neighborhood-based physical activity, indicating an indirect connection between park access and physical activity outcomes. Residents were also more likely to meet a moderate threshold for neighborhood-based physical activity if they lived in areas where characteristics of the built environment (i.e., intersection density, residential density, land use mix, bicycle infrastructure, and sidewalk coverage) were considered more walkable. Additionally, the quantity of vegetation cover and the number of parks in the 800 m surrounding survey respondents' homes had significant associations with mental well-being that were comparable in magnitude to the associations between mental well-being and total physical activity or the presence of a mental illness. Although this study was cross-sectional, and therefore cannot be used to make causal inferences, the findings support the theory that characteristics of urban neighborhoods impact physical activity outcomes and that various components of urban green space provide mental health benefits, even in models that include a suite of other potential causal factors. This study demonstrates that cities should consider the distribution of publicly managed environmental assets such as parks and street trees as critical resources for promoting health equity.

In Chapter 4, I presented and tested a methodology for identifying environmental justice concerns based on a broad array of urban green space characteristics (i.e., park quality, park availability, and green cover), and prioritizing specific areas for urban green space resource allocation. Models based on Census and urban green space data for Portland, Oregon revealed various distributional inequities, including significant disparities in total tree canopy cover (i.e., trees across all land uses), right-of-way tree canopy cover (i.e., street trees), and tree canopy cover on private land based on race and income. I then created maps that identified areas throughout the city that should be prioritized for targeted investments based on specific urban green space characteristics. This study expanded upon previous urban green space equity research by 1) including park access, park quality, and green cover characteristics into a single, comprehensive assessment, 2) subdividing green cover into distinct land uses, and 3) providing an example approach for identifying priority areas for urban green space investment.

Promoting Health Equity with Urban Green Space: Challenges & Future Opportunities

As outlined above, this dissertation 1) contextualized urban green space health equity research through a historical analysis of relationships between urban landscapes and health in the United States and 2) contributed to the body of knowledge at the intersection of urban green space, health, and distributional justice through original investigations that attempted to embrace the complexity of urban socio-ecological systems. Chapters 2, 3, and 4 illustrate that urban green space access and exposure are environmental justice and health equity concerns necessitating a collective effort from academics, landscape architects, urban planners, public health professionals, housing policy experts, social justice advocates, and community members to address current urban green space disparities and protect against potential displacement resulting from urban green space enhancement.

While Chapters 3 and 4 establish urban green space access/exposure as a potential health equity issue and identify existing distributional injustices based on urban green space access, this work is only the beginning of a place-based urban green space planning process within a larger environmental justice and health equity agenda. There is a preponderance of evidence to suggest that environmental conditions are associated with health outcomes (Bratman et al., 2019; Kondo et al., 2018; Velarde et al., 2007; World Health Organization, 2010b, 2010a), and the findings from Chapter 3 support theories that connect vegetation exposure to mental well-being through either stress reduction or attention restoration (Bratman et al., 2012). Most studies investigating relationships between health and urban green space control for sociodemographic factors such as race, ethnicity, and income; however, no studies, to my knowledge, have studied associations between urban green space and health in marginalized communities explicitly. I encourage future studies to consider sampling strategies and analytical approaches that allow researchers to identify relationships between urban green space and health in specific marginalized communities.

Evidence of urban green space inequities from one city do not necessarily translate to another. Nationwide policies (e.g., Home Owner's Loan Corporation Act and Housing Act of 1954) and planning agendas (e.g., City Beautiful Movement) that entrenched racial and economic segregation and urban renewal may explain the consistent race-, income-, and ethnicity-based disparities observed in urban green space equity studies (Gerrish & Watkins, 2018; Rigolon, 2016; Watkins & Gerrish, 2018). Yet, no two cities have identical sociodemographic make-up, green space distribution, land use patterns, or local policies, all of which may impact urban green space access/exposure. The methodology proposed in Chapter 4 establishes a process by which urban green space planners can inventory a suite of vegetation and park-based characteristics, identify existing disparities in urban green space access/exposure, and locate priority areas for targeted investment. This work also provides a path towards distributional justice in Portland, Oregon.

The potential that urban green space developments initiate processes of gentrification and displacement in the communities the projects were intended to serve necessitates further research, specifically surrounding policy and implementation. Numerous studies have documented patterns where tree plantings and park improvements have been linked to real estate price increases and demographic shifts (Checker, 2011; Donovan et al., 2021; Gould & Lewis, 2012). Rather than boosting access and exposure to environmental amenities, urban green space improvements may be more harmful to marginalized communities than healthful (Anguelovski, 2016). This reality has led communities and activists to fight against urban greening for fear that the associated economic development will lead to displacement of those that cannot afford to live in the newly revitalized neighborhood. Does even well-intentioned urban green space improvement fall into the same trappings of traditional urban planning strategies that have recurrently promoted economic development and urban revitalization? What strategies are currently being considered, or employed, to combat the process of green gentrification at the policy or activist level? Are there examples of activists and policymakers working together to protect marginalized communities from green gentrification while working to provide urban environmental health equity? While urban green space distributional equity should continue to be a target, the consequences of urban green space enhancement and expansion, as well as the policy and public involvement that could protect against green gentrification and displacement, need to be further explored and understood.

Another important consideration in the design and planning of environmentally just urban landscapes centers around how procedural and interactional justice are built into decision-making processes. Providing equitable access to urban green space does not ensure that marginalized communities feel a sense of ownership or belonging, and cities such as Portland are working to create more inclusive processes that respond to communities' cultural values (Portland Parks & Recreation, 2017). There is an opportunity for researchers to study how cities are attempting to create inclusive, equitable planning processes; if marginalized community members feel heard, respected, and meaningfully included throughout the decision-making process; and whether the outcomes reflect marginalized community members' needs and preferences.

The equitable distribution of urban green space is not necessarily the panacea for health inequity. The socio-ecological model of health considers individual, community, environmental, and societal factors to all impact health outcomes (U.S. Department of Health and Human Services, 2022). Economic stability, education, social support, community context, and access to health care have been identified as critical to health (U.S. Department of Health and Human Services, 2022), in addition to various environmental conditions from housing, sanitation, and transportation to food and urban green space access (Frumkin, 2005). Achieving health equity necessitates a collaborative approach that includes academics, policymakers, and professional practitioners, community members, and activists where the multiple factors that impact health outcomes are considered and addressed as a connected system.

References Cited

Anguelovski, I. (2016). From Toxic Sites to Parks as (Green) LULUs? New Challenges of Inequity, Privilege, Gentrification, and Exclusion for Urban Environmental Justice. *Journal of Planning Literature*, *31*(1), 23–36. https://doi.org/10.1177/0885412215610491

Bratman, G. N., Anderson, C. B., Berman, M. G., Cochran, B., de Vries, S., Flanders, J., Folke, C., Frumkin, H., Gross, J. J., Hartig, T., Kahn, P. H., Kuo, M., Lawler, J. J., Levin, P. S., Lindahl, T., Meyer-Lindenberg, A., Mitchell, R., Ouyang, Z., Roe, J., … Daily, G. C. (2019). Nature and mental health: An ecosystem service perspective. *Science Advances*, *5*(7), eaax0903. https://doi.org/10.1126/sciadv.aax0903

Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health: Nature experience, cognitive function, and mental health. *Annals of the New York Academy of Sciences*, *1249*(1), 118–136. https://doi.org/10.1111/j.1749-6632.2011.06400.x

Checker, M. (2011). Wiped Out by the "Greenwave": Environmental Gentrification and the Paradoxical Politics of Urban Sustainability. *City & Society*, *23*(2), 210–229. https://doi.org/10.1111/j.1548-744X.2011.01063.x

Donovan, G. H., Prestemon, J. P., Butry, D. T., Kaminski, A. R., & Monleon, V. J. (2021). The politics of urban trees: Tree planting is associated with gentrification in Portland, Oregon. *Forest Policy and Economics. 124: 102387.*, *124*, 102387. https://doi.org/10.1016/j.forpol.2020.102387

Frumkin, H. (2005). Guest Editorial: Health, Equity, and the Built Environment. *Environmental Health Perspectives*, *113*(5), A290–A291. https://doi.org/10.1289/ehp.113-a290

Gerrish, E., & Watkins, S. L. (2018). The relationship between urban forests and income: A meta-analysis. *Landscape and Urban Planning*, *170*, 293–308. https://doi.org/10.1016/j.landurbplan.2017.09.005

Gould, K. A., & Lewis, T. L. (2012). The environmental injustice of green gentrification: The case of Brooklyn's Prospect Park. In J. N. DeSena & T. Shortell (Eds.), *The world in Brooklyn: Gentrification, immigration, and ethnic politics in a global city* (pp. 113–146). Lexington Books.

Kondo, M. C., Fluehr, J. M., McKeon, T., & Branas, C. C. (2018). Urban Green Space and Its Impact on Human Health. *International Journal of Environmental Research and Public Health*, *15*(3), 445. https://doi.org/10.3390/ijerph15030445

Portland Parks & Recreation. (2017). *Five-Year Racial Equity Plan*.

Rigolon, A. (2016). A complex landscape of inequity in access to urban parks: A literature review. *Landscape and Urban Planning*, *153*, 160–169. https://doi.org/10.1016/j.landurbplan.2016.05.017

U.S. Department of Health and Human Services. (n.d.). *Healthy People 2030*. Retrieved February 4, 2023, from https://health.gov/healthypeople

U.S. Department of Health and Human Services. (2022). *Health Equity and Health Disparities Environmental Scan*. U.S. Department of Health and Human Services, Office of the Assistant Secretary for Health, Office of Disease Prevention and Health Promotion. https://health.gov/sites/default/files/2022-04/HP2030-HealthEquityEnvironmentalScan.pdf

Velarde, M. D., Fry, G., & Tveit, M. (2007). Health effects of viewing landscapes – Landscape types in environmental psychology. *Urban Forestry & Urban Greening*, *6*(4), 199–212. https://doi.org/10.1016/j.ufug.2007.07.001

Watkins, S. L., & Gerrish, E. (2018). The relationship between urban forests and race: A meta-analysis. *Journal of Environmental Management*, *209*, 152–168. https://doi.org/10.1016/j.jenvman.2017.12.021

World Health Organization. (2010a). *Hidden cities: Unmasking and overcoming health inequities in urban settings.* http://apps.who.int/iris/bitstream/handle/10665/44439/9789241548038_eng.pdf?sequence=1

World Health Organization. (2010b). *Urbanization and health*. World Health Organization. https://doi.org/10/en/index.html

APPENDIX A

SURVEY QUESTIONS

<u>Mental Well-being Questions:</u>

*******The four questions below come directly from the Office of National Statistics Integrated Household Survey to assess evaluative, eudemonic, and experiential subjective well-being* (Office of National Statistics, 2018).

On each of the following four questions, please rank your responses on a scale from 0, meaning "not satisfied at al", to 10, meaning "completely satisfied".

1. Overall, how satisfied are you with your life nowadays?

Not satisfied at all										***Completely Satisfied***
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

2. Overall, to what extent do you feel that the things you do in your life are worthwhile?

Not satisfied at all										***Completely Satisfied***
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

3. Overall, how happy did you feel yesterday?

Not satisfied at all										***Completely Satisfied***
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

4. Overall, how anxious did you feel yesterday?

Not satisfied at all										***Completely Satisfied***
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

**The five Likert-scale questions below are from the WHO-5 Well-being Index* (World Health Organization, 1998).

Please indicate for each of the five statements which is closest to how you have been feeling over the last two weeks. Notice that higher numbers mean better well-being.						
Over the last two weeks…	5 All of the time	4 Most of the time	3 More than half of the time	2 Less than half of the time	1 Some of the time	0 At no time
I have felt cheerful and in good spirits						
I have felt calm and relaxed						
I have felt active and vigorous						
I woke up feeling fresh and rested						
My daily life has been filled with things that interest me						

<u>Neighborhood-based Physical Activity Questions:</u>

*** These questions have been adapted from the Neighborhood Physical Activity Questionnaire* (Giles-Corti et al., 2006).

In the next section, we ask you about your typical weekly physical activity in and around your neighborhood or local area (this includes everywhere within a 10–15-minute walk, or about a half-mile, of your home).

1. In a usual week, do you do any vigorous intensity physical activities (like jogging, aerobics, or competitive tennis) in your neighborhood or local area? Vigorous intensity physical activities make you breathe harder or puff and pant.
   - ☐ Yes
   - ☐ No
2. In a usual week, how many times do you do vigorous intensity physical activities which makes you breathe harder or puff and pant in your neighborhood or local area?
3. Please estimate the total time you spend doing vigorous intensity physical activities in your neighborhood or local area in a usual week (example: 3 times by 20 minutes = 0 hours and 60 minutes OR 1 hour and 0 minutes).
4. In a usual week, do you walk either to get to or from somewhere (such as walking to a store or to public transport) or for recreation, health, or fitness (including walking your dog) in your neighborhood or local area?
   - ☐ Yes
   - ☐ No

5. In a usual week, how many times do you walk in your neighborhood or local area?

6. Please estimate the total time you spend walking in your neighborhood or local area in a usual week (example: 5 times by 20 minutes = 100 minutes or 1 hour and 40 minutes).

7. In a usual week, do you do any other moderate intensity physical activities like gentle swimming, social tennis, golf or heavy gardening in your neighborhood or local area? Moderate intensity physical activities do not make you breathe harder or puff and pant. Please do not include walking in this category.

    - ☐ Yes
    - ☐ No

8. In a usual week, how many times do you do moderate intensity physical activities which do not make you breathe harder or puff and pant in your neighborhood or local area? Please do not include walking in this category.?

9. Please estimate the total time you spend doing moderate intensity physical activity in a usual week in your neighborhood or local area (example: 3 times by 20 minutes = 0 hours and 60 minutes OR 1 hour and 0 minutes). Please do not include time spent walking in this category.

<u>Park Use Questions:</u>

1. In the past month, how many times visited a park, open space, or outdoor recreation area?

    - ☐ 0 times
    - ☐ 1 time
    - ☐ 2 times
    - ☐ 3 times
    - ☐ About once per week
    - ☐ Multiple times per week
    - ☐ About once per day
    - ☐ Multiple times per day

2. In the past month, how many times visited a park, open space, or outdoor recreation area in your neighborhood (10-15 minutes walk, or about a half-mile, from your home)?

    - ☐ 0 times
    - ☐ 1 time
    - ☐ 2 times
    - ☐ 3 times
    - ☐ About once per week
    - ☐ Multiple times per week
    - ☐ About once per day
    - ☐ Multiple times per day

Physical Activity Questions:

*** These questions come directly from the International Physical Activity Questionnaire – short form* (2002).

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the last 7 days. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise, or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

1. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling?

    _____ days per week

    ☐ No vigorous physical activity → Skip to question 3

2. How much time did you usually spend doing vigorous physical activities on one of those days?

    ____ hours per day

    ____ minutes per day

    ☐ Don't know/Not Sure

Think about all the **moderate** activities that you did in the **last 7 days**. Moderate activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

    _____ days per week

    ☐ No moderate physical activity → Skip to question 5

4. How much time did you usually spend doing moderate physical activities on one of those days?

    ____ hours per day

    ____ minutes per day

    ☐ Don't know/Not Sure

Think about the time you spent **walking** in **the last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the last 7 days, on how many days did you walk for at least 10 minutes at a time?

    _____ days per week

    ☐ No walking → Skip to question 7

6. How much time did you usually spend on one of those days walking as part of your work?

    ____ hours per day

    ____ minutes per day

    ☐ Don't know/Not Sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

    ____ hours per day

    ____ minutes per day

    ☐ Don't know/Not Sure

General Health:

*** The first question in directly from the SF-36 health survey questionnaire* (RAND Corporation, 1992).

1. In general, would you say your health is:

    ☐ Excellent
    ☐ Very good
    ☐ Good
    ☐ Fair
    ☐ Poor

2. What is your weight? _____pounds (lbs)

3. What is your height? ___ft ___in

4. Do you currently have any mental health conditions diagnosed by a health professional?

    ☐ Yes
    ☐ No
    ☐ Unsure/Don't know

5. How much sleep do you usually get at night on weekdays or workdays?

    ☐ Less than 5 hours
    ☐ 5-6 hours
    ☐ 7-8 hours
    ☐ More than 8 hours

6. Does your health or medical condition(s) limit or prevent you from engaging in physical activity?

	Not at all (1)	Somewhat (2)	Significantly (3)
Light physical activities (example: walking)			
Moderate physical activities (example: gentle swimming or cycling)			
Vigorous physical activity (example: jogging/running or competitive sports)			

<u>Resident Self-Selection:</u>

From the following list, select any factors that were important considerations when you were deciding to move to your current housing *(select all that apply)*:

- ☐ Safety of neighborhood
- ☐ Cost of housing
- ☐ Type of housing (example: house, duplex, or apartment)
- ☐ Visual appeal of neighborhood
- ☐ Quality of schools
- ☐ Distance to family/friends
- ☐ Distance to schools
- ☐ Time of commute
- ☐ Distance to grocery store
- ☐ Distance to restaurants
- ☐ Distance to downtown
- ☐ Distance to major roads or highways
- ☐ Distance to public transit (bus or light rail)
- ☐ Ease of parking
- ☐ Ease of driving
- ☐ Ease of walking
- ☐ Ease of biking

Perceived Neighborhood Environment Walkability:

** *The following questions come the* Neighborhood Environment Walkability Scale (Cerin et al., 2006).

We would like to find out more information about the way that you perceive or think about your neighborhood. In the following questions, both "neighborhood" and "walking distance" mean anywhere within a 10–15-minute walk (about a half-mile) from your home.

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
A1. Stores are within easy walking distance.				
A2. There are many places to go within walking distance at my home.				
A3. It is easy to walk to a transit stop (bus, train) from my home.				
B1. There are sidewalks on most of the streets in my neighborhood.				
B2. Sidewalks are separated from the road/traffic in my neighborhood by parked cars.				
B3. There is a grass/dirt strip that separates the streets from the sidewalks in my neighborhood.				
B4. My neighborhood is well lit at night.				
B5. Walkers and bikers on the streets in my neighborhood can be easily seen by people in their homes.				
B6. There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighborhood.				
C1. There are trees along the streets in my neighborhood.				
C2. There are many interesting things to look at while walking in my neighborhood.				
C3. There are many attractive natural sights in my neighborhood.				
C4. There are attractive buildings/homes in my neighborhood.				
D1. There is so much traffic along nearby streets that it makes it difficult or unpleasant to walk in my neighborhood.				
D2. The speed of traffic on most nearby streets is usually slow.				
D3. Most drivers exceed the posted limits while driving in my neighborhood.				
E1. There is a high crime rate in my neighborhood.				
E2. The crime rate in my neighborhood makes it unsafe to go on walks during the day.				
E3. The crime rate in my neighborhood makes it unsafe to go on walks at night.				
F1. Parking is difficult in local shopping areas.				
G1. There are major barriers to walking in my neighborhood that make it hard to get from place to place (for example, freeways, railway lines, rivers, canyons, hillsides).				

Subscale A: land-use mix/access; Subscale B: infrastructure and safety for walking; Subscale C: aesthetics; Subscale D: traffic hazards; Subscale E: crime; Subscale F: lack of parking; Subscale G: physical barriers

Perceived Neighborhood Social Cohesion:

*** The following questions come the Perceived Neighborhood Social Cohesion – Brief Form* (Dupuis et al., 2016; Kim & Kawachi, 2017)

Indicate the degree to which you agree with the following statements about your neighborhood.

	Strongly Agree	Agree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Disagree	Disagree	Strongly Disagree
I really feel part of this area.							
If you were in trouble, there are lots of people in this area who would help you.							
Most people in this area can be trusted.							
Most people in this area are friendly.							

<u>Sociodemographic and Lifestyle Preference Questions:</u>

1. What is your age?
   - ☐ Under 18
   - ☐ 18-29 years old
   - ☐ 30-39 years old
   - ☐ 40-49 years old
   - ☐ 50-59 years old
   - ☐ 60-69 years old
   - ☐ 70+ years old
2. With which gender do you identify? (Select all that apply)
   - ☐ Male
   - ☐ Female
   - ☐ Transgender
   - ☐ Non-binary/non-conforming
   - ☐ Prefer not to respond
   - ☐ Other ____________________
3. Are you Hispanic, Latino, Latina, Latinx, or Spanish origin?
   - ☐ Yes, I am Hispanic, Latino, Latina, Latinx, or Spanish origin
   - ☐ No, I am not Hispanic, Latino, Latina, Latinx, or Spanish origin
4. What is your race? (Select all that apply)
   - ☐ American Indian or Alaska Native
   - ☐ Asian
   - ☐ Black or African American
   - ☐ Native Hawaiian or Pacific Islander
   - ☐ White

- ☐ Other

5. What is your yearly household income (the total combined income that is made yearly by all working members of your household)?
    - ☐ Less than $10,000
    - ☐ $10,000 to $19,999
    - ☐ $20,000 to $29,999
    - ☐ $30,000 to $39,999
    - ☐ $40,000 to $49,999
    - ☐ $50,000 to $59,999
    - ☐ $60,000 to $69,999
    - ☐ $70,000 to $79,999
    - ☐ $80,000 to $89,999
    - ☐ $90,000 to $99, 999
    - ☐ $100,000 or more

6. What is your employment status?
    - ☐ Employed full-time
    - ☐ Employed part-time
    - ☐ Currently unemployed but looking for a job
    - ☐ Not employed (stay-at-home parent, retired, on disability, etc.)

7. What is the highest level of education that you have completed?
    - ☐ Elementary school
    - ☐ middle school/junior high
    - ☐ High school or GED
    - ☐ Trade/technical school or 2-year college
    - ☐ 4-year college/university
    - ☐ Professional/graduate school

8. Do you have access to a working car?
    - ☐ Yes
    - ☐ No

9. Do you own your own home?
    - ☐ Yes
    - ☐ No

10. Do you have a dog?
    - ☐ Yes
    - ☐ No

11. Are you a smoker?
    - ☐ Yes
    - ☐ No

References Cited:

Cerin, E., Saelens, B. E., Sallis, J. F., & Frank, L. D. (2006). Neighborhood Environment Walkability Scale: Validity and development of a short form. Medicine and Science in Sports and Exercise, 38(9), 1682–1691. https://doi.org/10.1249/01.mss.0000227639.83607.4d

Dupuis, M., Studer, J., Henchoz, Y., Deline, S., Baggio, S., N'Goran, A., Mohler-Kuo, M., & Gmel, G. (2016). Validation of French and German versions of a Perceived Neighborhood Social Cohesion Questionnaire among young Swiss males, and its relationship with substance use. Journal of Health Psychology, 21(2), 171–182. https://doi.org/10.1177/1359105314524010

Giles-Corti, B., Timperio, A., Cutt, H., Pikora, T. J., Bull, F. C. L., Knuiman, M., Bulsara, M., Van Niel, K., & Shilton, T. (2006). Development of a reliable measure of walking within and outside the local neighborhood: RESIDE's Neighborhood Physical Activity Questionnaire. Preventive Medicine, 42(6), 455–459. https://doi.org/10.1016/j.ypmed.2006.01.019

International Physical Activity Questionnaire. (2002). https://sites.google.com/site/theipaq/questionnaire_links

Kim, E. S., & Kawachi, I. (2017). Perceived Neighborhood Social Cohesion and Preventive Healthcare Use. American Journal of Preventive Medicine, 53(2), e35–e40. https://doi.org/10.1016/j.amepre.2017.01.007

Office of National Statistics. (2018). Personal well-being user guidance. https://www.ons.gov.uk/peoplepopulationandcommunity/wellbeing/methodologies/personalwellbeingsurveyuserguide

RAND Corporation. (1992). 36-Item Short Form Survey Instrument (SF-36). https://www.rand.org/health-care/surveys_tools/mos/36-item-short-form/survey-instrument.html

World Health Organization. (1998). WHO-5 Well-Being Index. Psychiatric Research Unit.

APPENDIX B

SUPPLEMENTAL INFORMATION FOR CHAPTER 3

B1. Survey Variable Descriptions

Table B1. Description of control variables present in park use, neighborhood-based physical activity, and mental well-being models.

Variable Name	**Variable Category**	**Variable Description**	**Models**
Gender	Sociodemographic	Respondents who identify male only= 1; female, transgender, non-binary/non-conforming=0	All
Race	Sociodemographic	Respondents who identify as American Indian or Alaska Native, Asian, Black or African American, Native Hawaiian or Pacific Islander, other race, or multiple races = 1; white only=0	All
Ethnicity	Sociodemographic	Respondents who identify as Hispanic, Latino, Latina, Latinx, or Spanish origin = 1; non-Hispanic=0	All
Household income	Sociodemographic	Reported household income (coded 0-10) in $10,000 increments; less than $10,000=0; greater than $100,000=10	All
Employment	Sociodemographic	Currently unemployed and looking for work=1; full/part time employed or not employed (e.g., stay-at-home parent, retired, on disability, etc.) =0	All
Education	Sociodemographic	Highest level of education completed; four-year college/university or professional/graduate degree = 1; elementary, middle, high school, and trade/technical/two-year college=0	All
Age	Sociodemographic	Ordinal variable based on age where age 18-29=1; age 30-39=2; age 40-49=3; age 50-59=4; age 60-69=5; age 70+=6	All
Homeownership	Sociodemographic	Homeowner=1; not homeowner=0	All
Car access	Sociodemographic/ Lifestyle Preference	Access to a working car=1; no access to a working car=0	All
Dog ownership	Lifestyle Preference	Dog owner=1; not dog owner=0	All
Smoker	General Health	Smoker=1; non-smoke=0	All
General health	General Health	Self-reported general health from SF-36 health questionnaire; poor=0; fair=1; good=2; very good=3, excellent=4	All
Mental health condition	General Health	Mental health condition diagnosed by a health professional=1; no mental health conditions diagnosed by health professional or unsure/don't know=0	All
Body mass index (BMI)	General Health	Metric BMI derived from reported weight and heigh; BMI=weight (kg)/[height (m)]^2	All

Sleep	General Health	Average sleep quantity on a weeknight/worknight; 7 or more hours=1; less than 7 hours=0)	All
Physical activity limitations	General Health	Health or medical condition that significantly prevents respondent from participating in vigorous physical activity=1; no significant limitations to vigorous physical activity=0	Physical activity and park use models
Resident self-selection (park access)	Resident self-selection	Park access was an important consideration when respondent was deciding to move to your current housing; true=1; false=0	All
Resident self-selection (street trees)	Resident self-selection	Street trees were an important consideration when respondent was deciding to move to your current housing; true=1; false=0	All
Resident self-selection (easy walking)	Resident self-selection	Ease of walking was an important consideration when respondent was deciding to move to your current housing; true=1; false=0	All
Resident self-selection (easy biking)	Resident self-selection	Ease of biking was an important consideration when respondent was deciding to move to your current housing; true=1; false=0	All
Resident self-selection (yard access)	Resident self-selection	Yard access was an important consideration when respondent was deciding to move to your current housing; true=1; false=0	All
Neighborhood walkability index	Neighborhood Walkability	Sum of z-scores for residential density, street connectivity, land use mix, sidewalk-to-road-length ratio, and bike-infrastructure-to-road-length ratio within a one-kilometer road-network from each survey participant's place of residence (see Chapter 3, Table 3.2)	Physical activity and park use models
Subjective neighborhood walkability index	Neighborhood Walkability	Sum of z-scores from seven abbreviated Neighborhood Environment Walkability Scale (NEWS-A) subscales (land-use-mix, parking, walking/biking infrastructure, crime, traffic hazards, aesthetics/surroundings, and hilliness)	All
Park use (neighborhood park)	Park Use	About one visit per week or greater=1; between 0-3 visits in the past month=0	Physical activity model
Park use (any park)	Park Use	About one visit per week or greater=1; between 0-3 visits in the past month=0	Mental well-being models
Total physical activity	Physical Activity	All weekly physical activity (i.e., walking and moderate and vigorous physical activity) as recorded from International Physical Activity Questionnaire (IPAQ); measured in thousands of metabolic equivalent minutes per week (kMET-minutes/week)	Mental well-being models
Social Cohesion	Social Cohesion	Average of four items from the Perceived Neighborhood Social Cohesion questionnaire, scored on a 7-point Likert scale that measure each individual's sense of belonging as well as their perceptions of neighbor friendliness, trustworthiness, and helpfulness	Mental well-being models

B2. Methods

B2.1 Park Access and Availability

Figure B1. Park access was defined as the distance, in meters, from each survey respondent's place of residence to the nearest park.

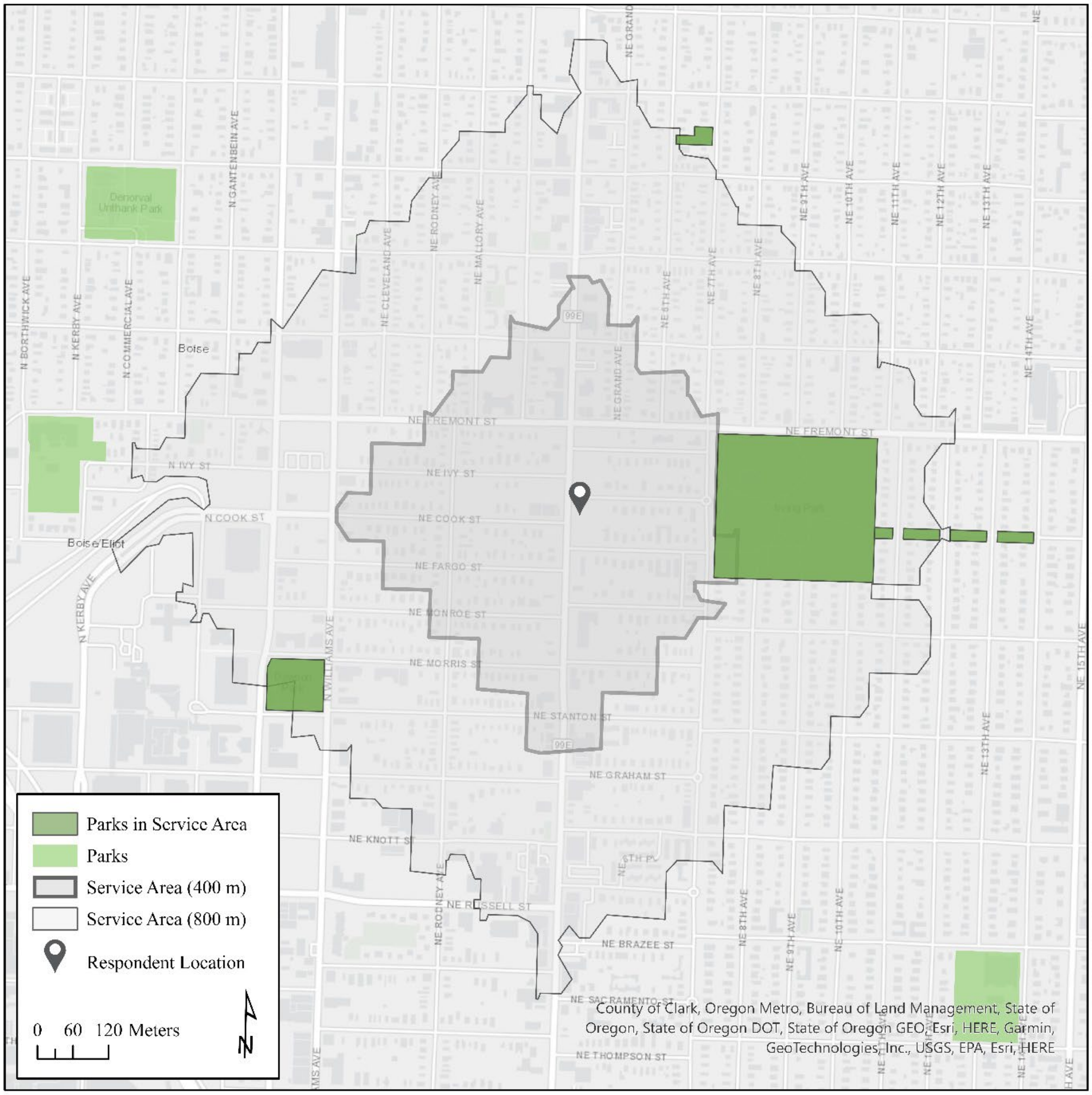

Figure B2. Park availability was defined as the number of parks and the area of parks, in hectares, accessible within 400 and 800 m walking distance, based on road network, from each survey respondent's place of residence.

B2.2 Park Audits

A variety of park audit tools have been created to assess qualities of urban green space, most of which include evaluations of recreation facilities, amenities, natural qualities, maintenance, accessibility, and safety (e.g., Broomhall et al., 2004; Engelberg et al., 2016; Gidlow et al., 2012, 2018; Kaczynski et al., 2012). Every audit tool is slightly different; however, Gidlow et al. (2012) developed the

Neighborhood Green Space Tool by conducting a thorough investigation of existing green space audit tools and an extensive stakeholder participation process. The Neighborhood Green Space Tool was further refined, with input from experts and extensive field testing, to create the Natural Environment Scoring Tool (NEST) which contains 47 items and a reported mean completion time of 16 minutes (Gidlow et al., 2018). Each park receives a score, out of 100, for each of the eight domains (i.e., the sum of the item scores within the domain divided by the total possible score for the domain multiplied by 100), as well as an overall score (i.e., a weighted sum of the domain scores, excluding the useability domain, dependent on the park type), providing numerous metrics by which to compare park quality (Gidlow et al., 2018). Specific methods for calculating weights for each domain in the overall score are outlined in Gidlow et al. (2018). The complete NEST survey can be found in Gidlow et al. (2018) supplemental information.

While the NEST is an ideal audit tool for rating and comparing parks, the Community Park Audit Tool (CPAT) provides a more complete account of park activity areas (Kaczynski et al., 2012). Using the partial CPAT, I identified the presence or absence of each activity area (playgrounds, soccer/football fields, baseball fields, swimming pools, splash pads, basketball courts, tennis courts, volleyball courts, trails, fitness equipment, skateparks, dog parks, open/green spaces, and lakes) and obtained a count of the total number of different activity areas within each park, natural area, or public schoolyard.

To obtain the list of potential sites for auditing, I used the Oregon Metro RLIS Outdoor Recreation and Conservation Areas ("ORCA Sites") data and selected all sites within city limits, excluding those that were categorized as community gardens, stand-alone community centers (i.e., not adjacent to or within a park), or homeowners associations (Oregon Metro RLIS, 2020a). This list included all schools (public and private), parks and natural areas, golf courses, cemeteries, and sites listed as "Other". Public schools were identified using the Oregon Metro RLIS "Schools" dataset, and all private school sites were removed from the dataset (Oregon Metro RLIS, 2020b). There was a total of 634 parks, natural areas, cemeteries, golf courses, and public schoolyards that were identified within the city limits of Portland. Each site was visited, and they were audited if they were free to enter (i.e., no payment necessary) and accessible (i.e., not locked, fenced off completely, or only accessible from a boat). Sites were also not audited if they were identified as vacant lots, small grass patches with no other amenities, or natural areas with no paths or access points. Several types of facilities (i.e., baseball stadiums, tennis courts, pools, and buildings) that were listed separately in the "ORCA Sites" dataset but were located within another park were combined into the audit of the park in which the facility was located. In several locations, audits of parks and adjacent schoolyards were combined if they were not able to be distinguished from one another on the ground.

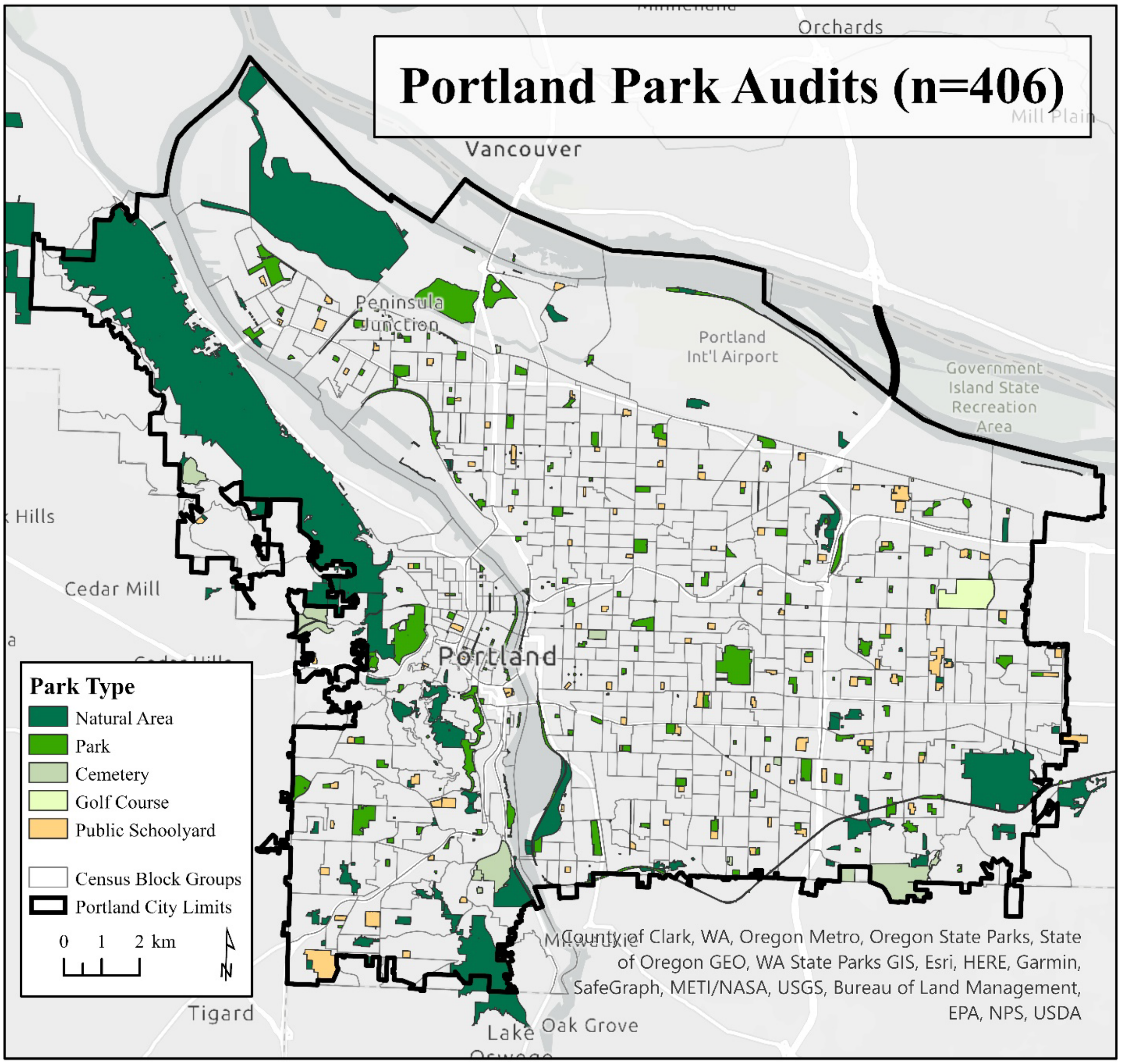

Figure B3. All audited parks (n=406), symbolized by park type.

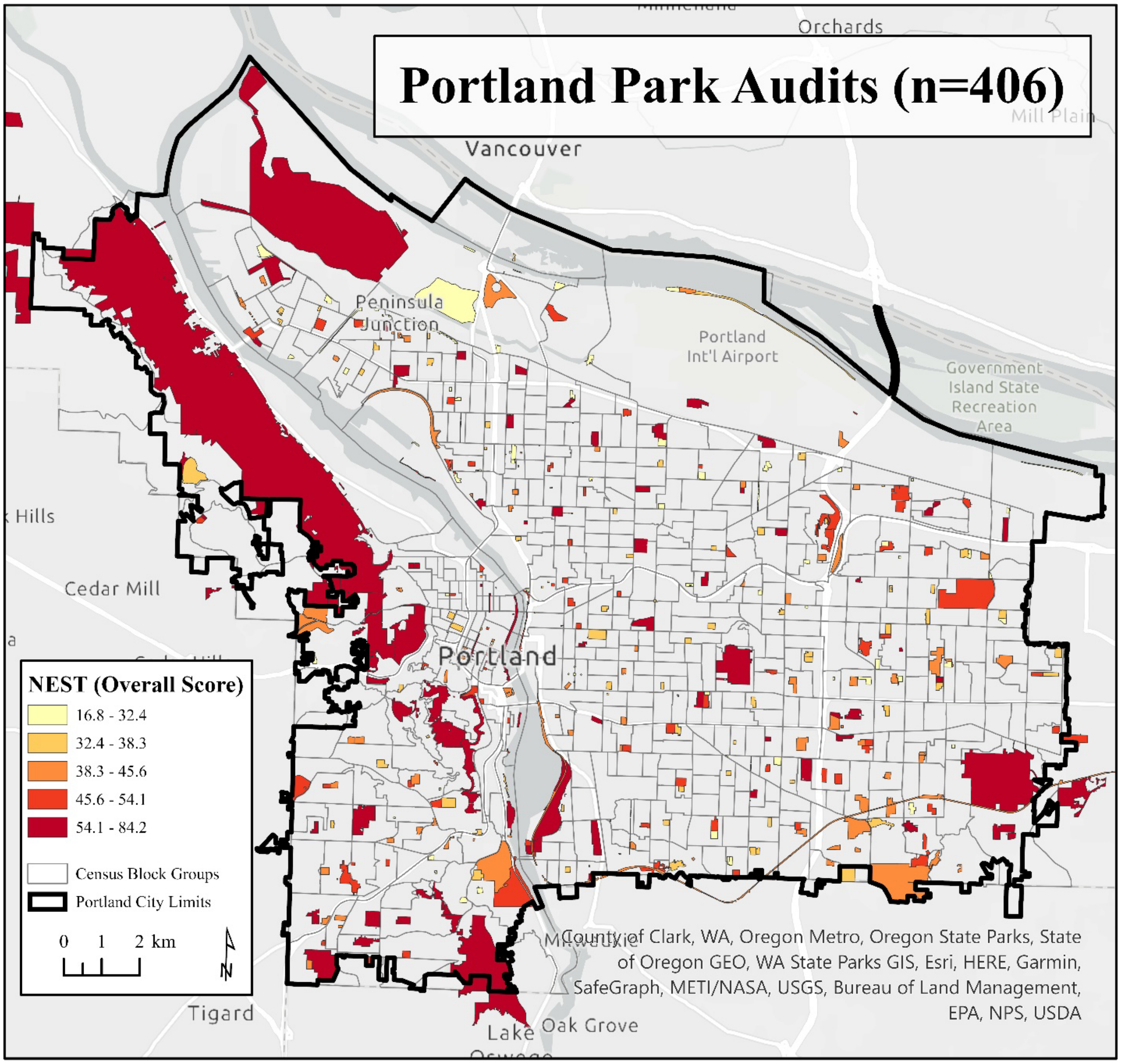

Figure B4. All audited parks (n=406), symbolized by Neighborhood Environment Scoring Tool (NEST) overall score.

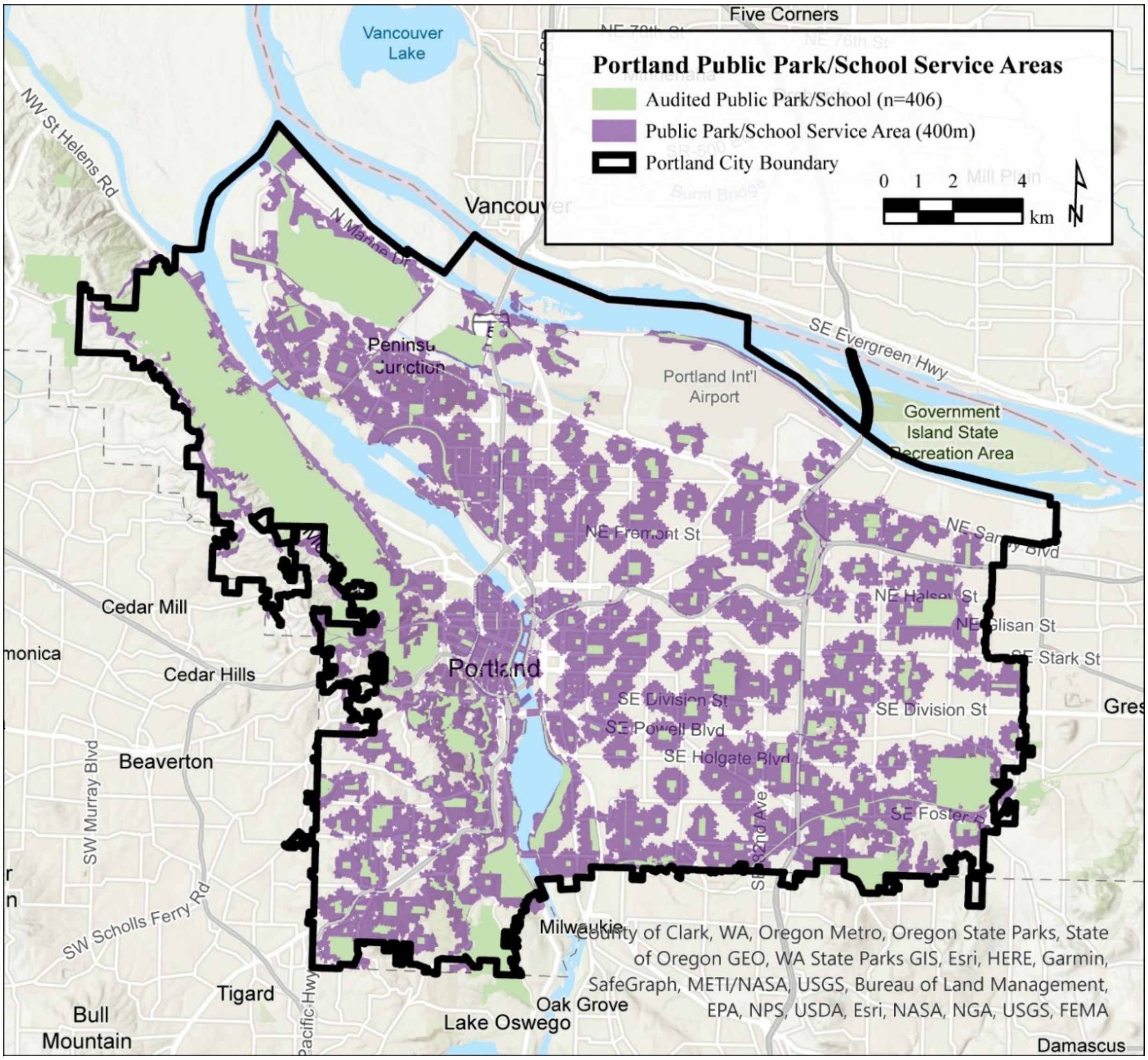

Figure B5. Map depicting all public parks, natural areas, and schoolyards and the 400 m service area surrounding each. In total, 51.8% of the City of Portland has access to at least one park, natural area, or schoolyard within 400 m.

B2.3 Land Cover

I used one-meter resolution urban land cover data for Portland from the United States' Environmental Protection Agency EnviroAtlas (US EPA, 2017) to calculate total vegetation cover and tree canopy cover. Tree canopy cover was defined as pixels identified by the EPA as tree cover, and total vegetation was identified as tree, herbaceous, woody wetlands, and emergent wetlands.

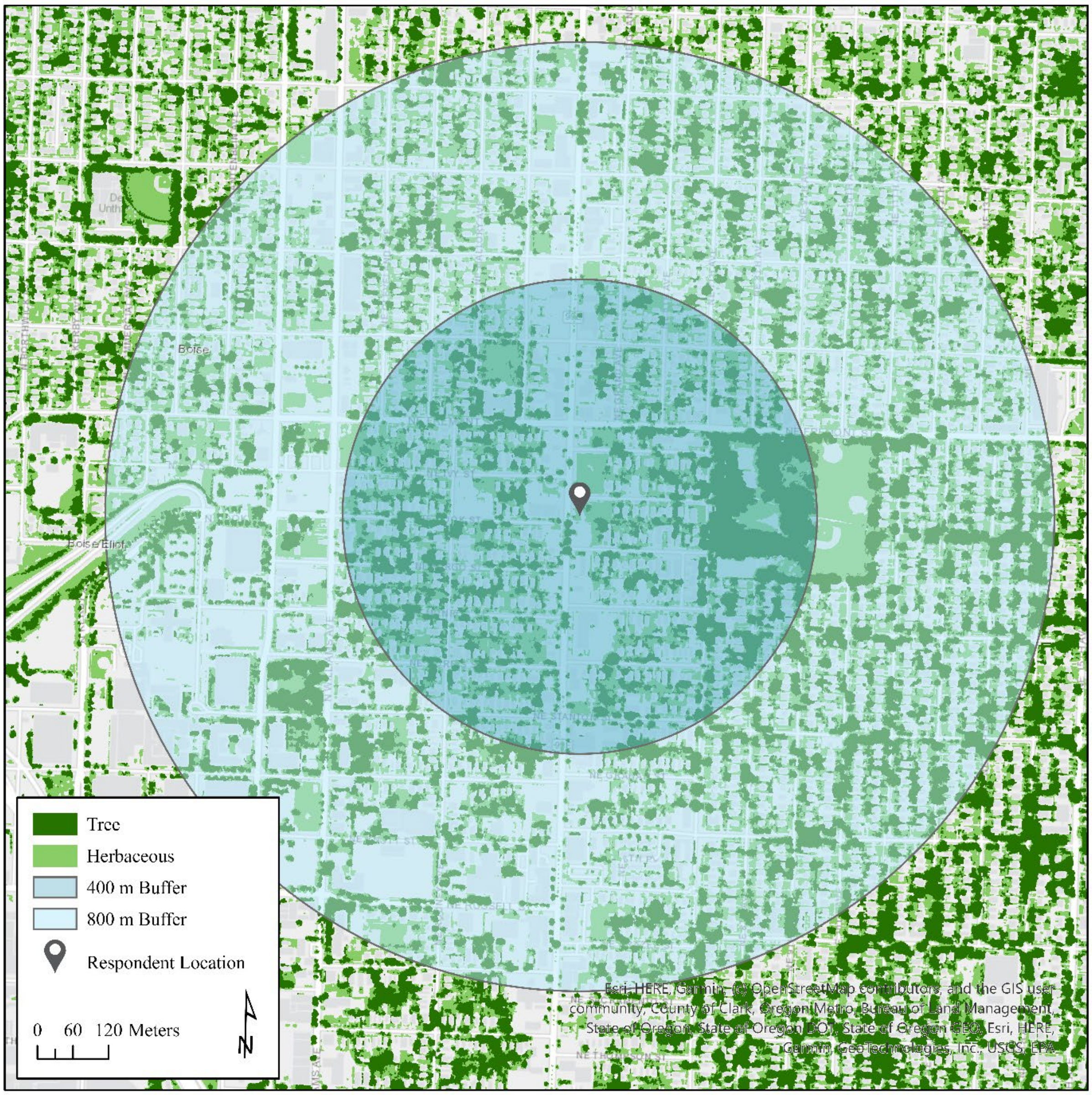

Figure B6. Green cover variables were defined as percent tree canopy cover and percent total vegetation (i.e., tree and herbaceous) within 400 and 800 m Euclidean buffers.

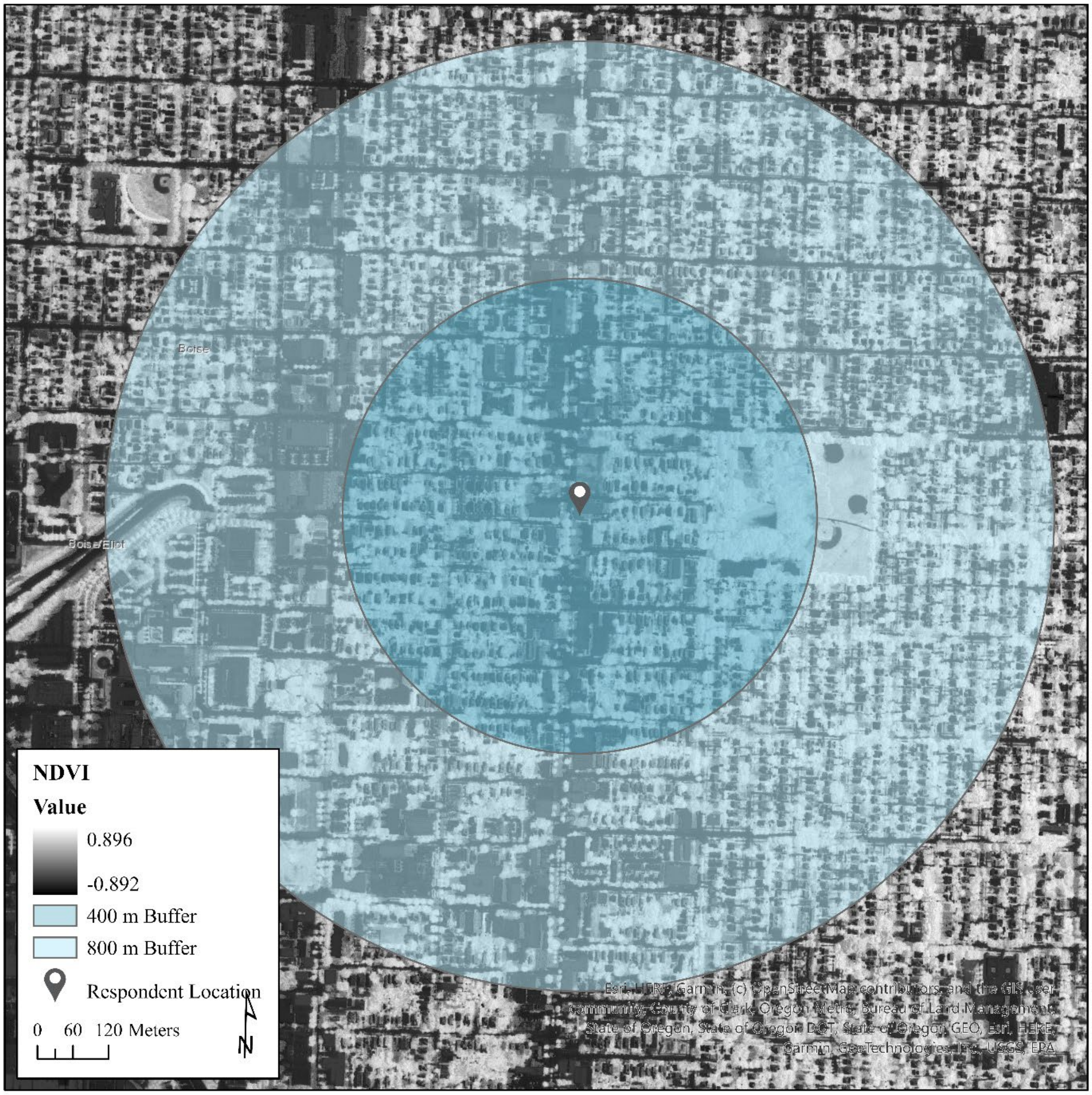

Figure B7. Cumulative normalized difference vegetation index (NDVI) was defined as the mean NDVI within 400 and 800 m Euclidean buffers.

B2.4 Street-level Greenness

While aerial imagery provides data that can be used to measure greenness as seen from above, this is not generally how humans experience greenness. I measured street-level greenness (i.e., greenness from ground level on street landscapes) following the approach proposed by Li et al. (2015) where Green View Index (i.e., percent of image pixels identified as green) was calculated using Google Street View panoramas. I generated a shapefile of points, spaced 50 m apart, along all roadways (excluding freeways, private roads, and unimproved roads) within the city limits of Portland, OR, USA. As the 50 m spacing was assessed along the road network, I removed points that were less than 35 m apart in Euclidean distance to minimize location redundancy around intersections. Using image metadata, three Google Street View images (120° in horizontal and vertical directions) were requested from the Google Street View Static API (Google, 2020) for each point to create 360° panoramas (Figure B2). To ensure images were consistent, images were removed for locations where images were taken during months when most deciduous trees do not have leaves (October-April). These images were replaced with older images for the same location, taken during leaf-on period (i.e., May-September) where possible. I used modified open-source code from Li et al. (2018/2020) to generate a Green View Index for each image, leveraging "NumPy" and "PyMeanShift" Python packages to classify green pixels and calculate the percent of green pixels (Figure B3; Harris et al., 2020; Jean, 2012). Mean Green View Index was then calculated for each location. In total, 148,086 images were analyzed across 49,362 locations.

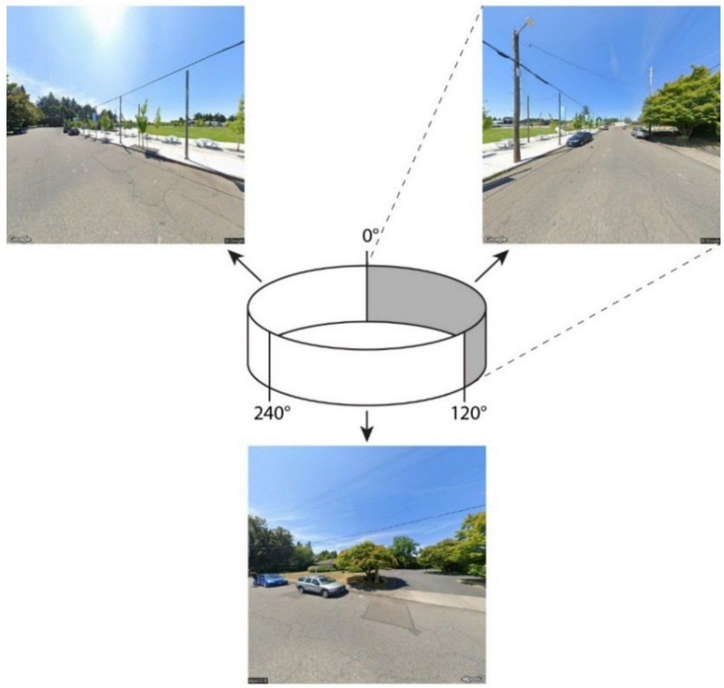

Figure B8. Three Google Street View images (120° horizontal and vertical field for each image) create a 360° panorama.

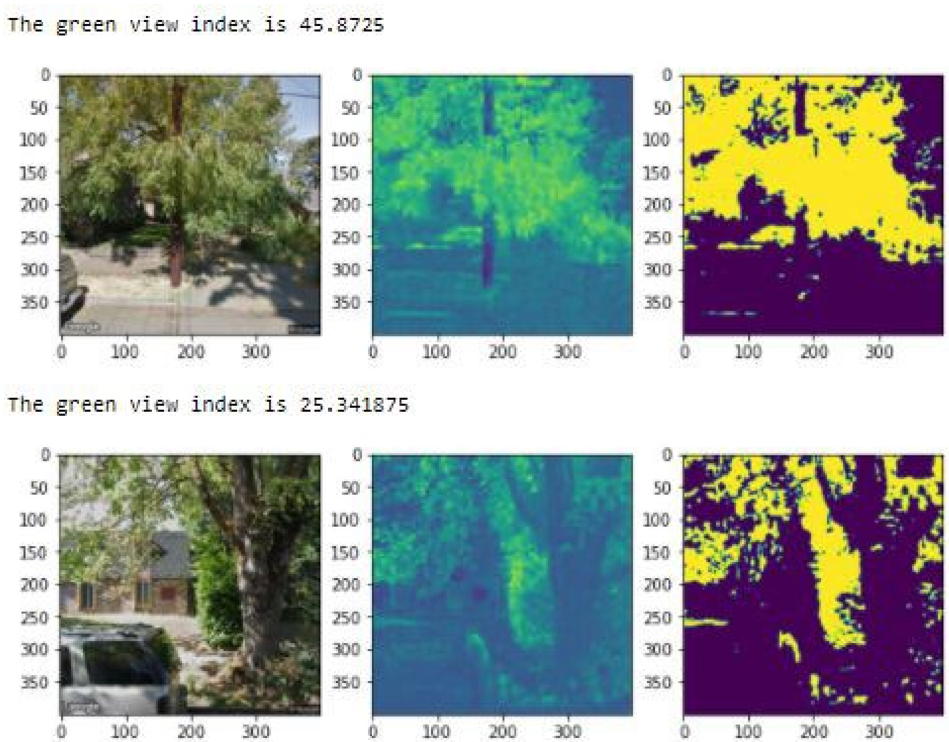

Figure B9. Example of Green View Index calculated using Google Street View images, "NumPy" and "PyMeanShift" Python packages (Harris et al., 2020; Jean, 2012), and modified open-source code (Li et al., 2018/2020).

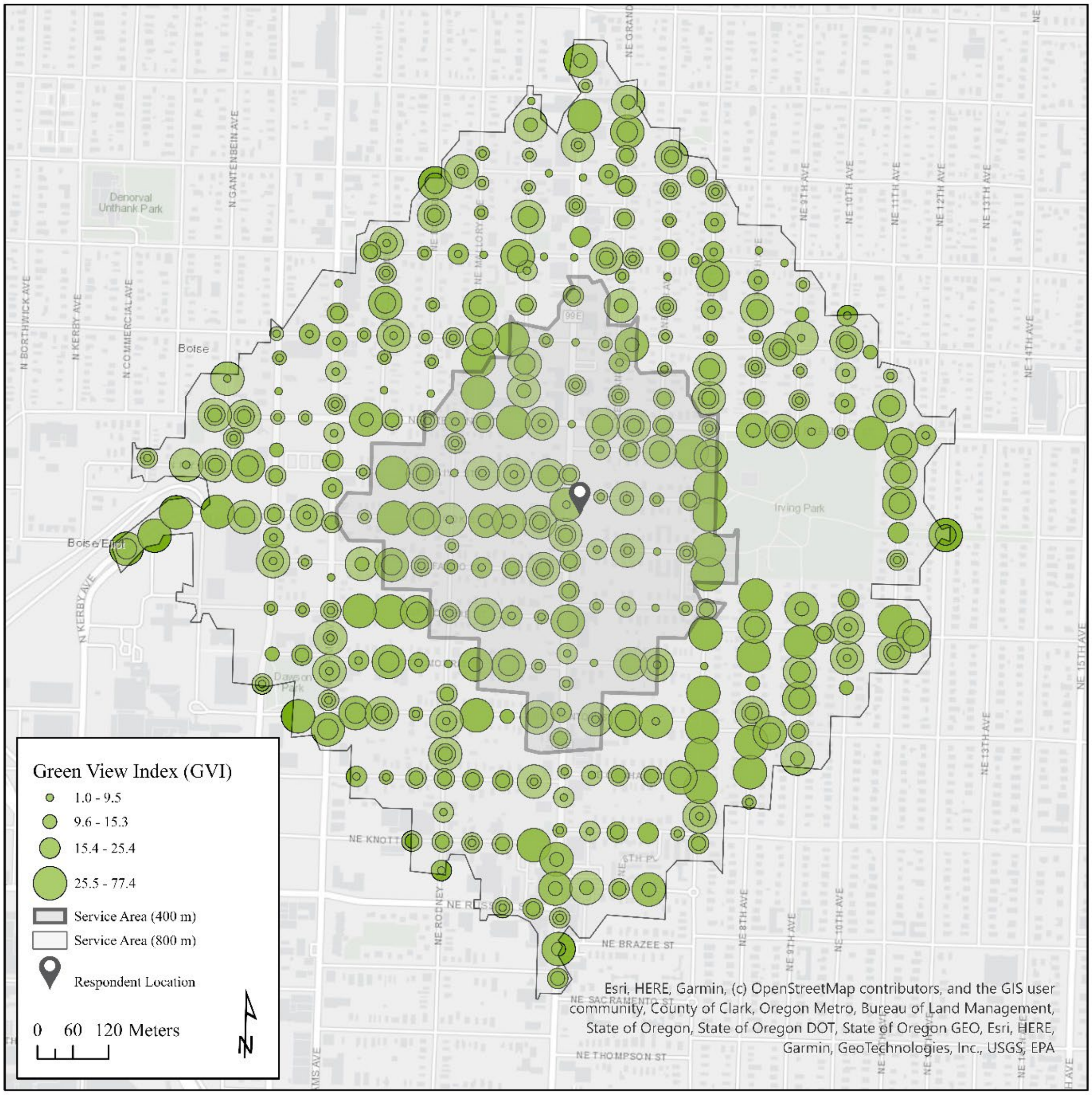

Figure B10. Green view index (GVI) was defined as the mean GVI for all points within 400 and 800 m walking distance based on road network.

B2.5 Survey

During data collection with Qualtrics Panels, the following criteria were used to remove low quality samples (a total of 281 samples were removed during data collection, leaving 547 quality responses):

1. The sum of daily moderate and vigorous physical activity and sitting time was greater than 24 hours.
2. The sum of daily walking and sitting time was greater than 24 hours.
3. Response time was less than half of median response rate from the entire sample.
4. Responses identified as straight-lining (i.e., same response for all questions) for the four Office of National Statistics mental well-being questions.
5. Geolocated point from map question and street/cross-street information were not within Portland city limits.

After survey data collection was complete, the following criteria were used to further remove low quality samples (a total of 125 samples were removed after data collection, leaving 422 quality samples for data analysis):

1. Survey respondent answered “No” to the question, “were you able to move the marker on the map to the block where you live?” and streets/cross streets do not exist, were not entered, or do not cross
2. Total reported physical activity was less than total reported neighborhood-based physical activity.
3. Road network service area (800 m) or Euclidean buffer (800 m) surrounding respondent’s place of residence extended beyond the Portland city limits (green space variables were collected only within Portland city limits).
4. Body mass index (BMI) less than 12 or greater than 70 were considered implausible (Cheng et al., 2016).

B3. Results:

Table B2. Logistic regression model for neighborhood park use (weekly) with control variables only (n=422; AIC=508.5).

Predictor Variable	Odds Ratio	Confidence Interval (95%)	z-score
(Intercept)	0.09	0.02 - 0.38	-3.25*
Smoker (yes=1)	3.22	1.83 - 5.73	4.02***
Resident self-selection, park access (yes=1)	2.97	1.73 - 5.14	3.92***
Neighborhood walkability index, subjective	1.10	1.02 - 1.18	2.43*
Resident self-selection, walkability (yes=1)	1.77	1.05 - 2.97	2.16*
Age [b]	0.82	0.68 - 0.98	-2.13*
Car access (yes=1)	1.96	1.05 - 3.73	2.09*
Neighborhood walkability index, objective	1.06	0.99 - 1.14	1.57
Dog ownership (yes=1)	1.49	0.9 - 2.46	1.56
Employment status (unemployed=1)	0.63	0.32 - 1.23	-1.33
Resident self-selection, bikeability (yes=1)	1.58	0.8 - 3.12	1.32
Mental illness, diagnosed (yes=1)	0.72	0.44 - 1.17	-1.31
Resident self-selection, street trees (yes=1)	1.47	0.82 - 2.66	1.29
General health [b]	1.20	0.91 - 1.58	1.27
Resident self-selection, private yard (yes=1)	0.72	0.39 - 1.29	-1.09
Body Mass Index (BMI)	1.02	0.99 - 1.05	1.05
Home ownership (yes=1)	1.35	0.74 - 2.49	0.98
Vigorous physical activity limitation (yes=1)	0.78	0.44 - 1.36	-0.87
Education (postsecondary degree=1)	0.87	0.5 - 1.5	-0.50
Sleep (less than 7 hours=1)	1.11	0.69 - 1.77	0.43
Ethnicity (Hispanic/Latinx=1)	0.85	0.39 - 1.85	-0.40
Race (not White alone=1)	1.09	0.64 - 1.84	0.31
Gender (male=1)	0.95	0.57 - 1.59	-0.19
Household income [b]	1.00	0.91 - 1.09	-0.10

* $p<0.05$; ** $p<0.01$; *** $p<0.001$

Table B3. Summary of logistic regression models for neighborhood park use (weekly) with all control variables, one significant green space predictor ($p < 0.05$), and a lower Akaike information criterion (AIC) than the baseline model (controls only).

Green Space Variable	Odds Ratio	AIC	Green Space Category
PrkCntBinary_400	3.91***	484.73	Park Availability
PlyGrd_400 [a]	2.96***	490.05	Park Quality
Trl1_400 [a]	2.99***	491.95	Park Quality
OpnGrn_400 [a]	2.82***	493.27	Park Quality
PrkNear_km [a]	0.17***	495.93	Park Access
Trl1_800 [a]	6.74**	497.07	Park Quality
PrkCnt_400 [a]	1.48***	497.9	Park Availability
PrkVeg_400	1.01**	500.74	Green Cover
Bsktbl_400 [a]	2.15**	500.85	Park Quality
DogPark_400 [a]	2.66**	503.16	Park Quality
Sport_400 [a]	2.03**	503.46	Park Quality
NEST_800	1.03*	503.79	Park Quality
Sport_800	1.9*	503.96	Park Quality
Access_800	1.01*	504.03	Park Quality
PlyGrd_800	2.52*	505.03	Park Quality
OpnGrn_800 [a]	3.13*	505.32	Park Quality
PrkTree_400	1.01*	506.37	Green Cover
Trl3_800	1.66*	506.43	Park Quality

* $p<0.05$; ** $p<0.01$; *** $p<0.001$

PrkCntBinary – one or more parks = 1, no parks = 0; PrkCnt – park count (i.e., number of parks); PrkNear_km – distance to nearest park (in kilometers); NEST – Neighborhood Environment Scoring Tool overall score; Inciv – Neighborhood Environment Scoring Tool incivilities domain; Access – Neighborhood Environment Scoring Tool access domain; Trl1 – number of parks with at least one trail; Trl3 – number of parks with at least three trails; OpnGrn – number of parks with open lawn or grass area; DogPark – number of parks with a dog park; Sport – number of parks one or more atheletic fields (e.g., soccer/football field); Bsktbl – number of parks with basketball courts; PlyGrd – number of parks with playgrounds; Splash – number of parks with splash pads; PrkTree – parkland tree canopy cover; PrkVeg – parkland vegetation cover; x_400 – within 400 m of place of residence; x_800 – within 800 m of place of residence

[a] Variables with strong correlation (tetrachoric correlation > 0.6 for binary variables and point-biserial correlation >|0.6| for all else) with PrkCntBinary_400.

Table B4. Summary of binomial logistic regression models for neighborhood-based physical activity (moderate to high) with all controls and one significant green space predictor ($p < 0.05$). All park quality variables have negative relationships with neighborhood-based physical activity, indicating that higher park quality domain (recreation and incivility) and overall scores, as well as access to basketball courts, playgrounds, trails, and splash pads reduce the likelihood that residents meet the threshold for moderate to high neighborhood-based physical activity.

Green Space Variable	**Odds Ratio**	**AIC**	**Green Space Category**
PrkCnt_400	0.733706**	542.7632	Park Availability
Inciv_800	0.985403*	543.8869	Park Quality
PlyGrd_400	0.566281*	544.8488	Park Quality
Bsktbl_800	0.534967*	545.0318	Park Quality
Rec_800	0.982407*	545.6351	Park Quality
NEST_800	0.981217*	546.2999	Park Quality
Bsktbl_400	0.618044*	546.6563	Park Quality
PrkNear_km	2.316309*	546.8083	Park Access
Splash_400	0.472347*	546.8431	Park Quality

* p<0.05; ** p<0.01; *** p<0.001

PrkCnt – park count (i.e., number of parks); NEST – Neighborhood Environment Scoring Tool (NEST) overall score; Inciv – Neighborhood Environment Scoring Tool (NEST) incivilities domain; Rec – Neighborhood Environment Scoring Tool (NEST) recreational facilities domain; Bsktbl –number of parks with basketball courts; PlyGrd –number of parks with playgrounds; Splash –number of parks with splash pads; x_400 – within 400 m of place of residence; x_800 – within 800 m of place of residence

Table B5. Baseline (controls only) ordinary least squares (OLS) regression model for mental well-being (n=422; Adj R^2=0.38).

Predictor Variable	**Estimated Coefficient**	**Standardized Coefficient (β)**	**Standard Error**
(Intercept)	22.57***	NA	6.09
General health [a]	7.52***	0.34	1.05
Sleep (less than 7 hours=1)	-7.36***	-0.17	1.76
Mental illness, diagnosed (yes=1)	-7.11***	-0.16	1.84
Physical activity, total (kMET-m/wk)	0.70**	0.13	0.24
Neighborhood social cohesion	1.58*	0.10	0.78
Age [a]	1.37*	0.09	0.66
Education (postsecondary degree=1)	3.87	0.09	2.07
Neighborhood walkability index, subjective	0.50	0.08	0.30
Dog ownership (yes=1)	-3.51	-0.08	1.92
Gender (male=1)	3.47	0.08	1.94
Employment status (unemployed=1)	-4.70	-0.08	2.51
Smoker (yes=1)	-3.51	-0.07	2.17
Resident self-selection, bikeability (yes=1)	3.79	0.06	2.66
Car access (yes=1)	-2.93	-0.06	2.33
Park use, weekly (yes=1)	-2.31	-0.05	1.92
Resident self-selection, street trees (yes=1)	2.73	0.05	2.29
Neighborhood walkability index, objective	-0.31	-0.05	0.27
Home ownership (yes=1)	2.22	0.05	2.32
Household income [a]	-0.25	-0.04	0.35
Ethnicity (Hispanic/Latinx=1)	-2.55	-0.03	2.99
Body Mass Index (BMI)	0.09	0.03	0.11
Race (not White alone=1)	1.21	0.02	2.01
Resident self-selection, walkability (yes=1)	-0.90	-0.02	2.00
Resident self-selection, park access (yes=1)	-0.38	-0.01	2.17
Resident self-selection, private yard (yes=1)	0.23	0.00	2.19

* $p<0.05$; ** $p<0.01$; *** $p<0.001$

[a] ordinal variable (see Table B1 for recoding details)

Table B6. Summary of ordinary least squares (OLS) linear regression models for mental well-being with all control variables, one significant green space predictor ($p < 0.05$), and an adjusted-R^2 greater than the baseline model (controls only).

Green Space Variable	Estimated Coefficient	Adj. R^2	Green Space Category
Prk_Veg_400	0.07**	0.39	Green Cover
NDVI_800	30.27**	0.39	Green Cover
NDVI_400	29.03**	0.38	Green Cover
PrkHa_400	0.11*	0.38	Park Availability
Prk_Tree_400	0.08*	0.38	Green Cover
Tot_Veg_800	0.16*	0.38	Green Cover
Row_Veg_400	0.21*	0.38	Green Cover
Tot_Veg_400	0.14*	0.38	Green Cover
Tot_Tree_400	0.21*	0.38	Green Cover
Tot_Tree_800	0.21*	0.38	Green Cover
PrkCntBinary_400	4.25*	0.38	Park Availability
Row_Veg_800	0.23*	0.38	Green Cover
Pri_Tree_800	0.18*	0.38	Green Cover
PrkCnt_800	0.81*	0.38	Park Availability
NEST_800	0.14*	0.38	Park Quality (NEST)
Pri_Tree_400	0.17*	0.38	Green Cover
Inciv_800	0.09*	0.38	Park Quality (NEST)
Pri_Veg_800	0.11*	0.38	Green Cover

* p<0.05; ** p<0.01; *** p<0.001

PrkCnt – park count (i.e., number of parks); PrkCntBinary – one or more parks = 1, no parks = 0; PrkHa – park area (hectares); NEST – Neighborhood Environment Scoring Tool (NEST) overall score; Inciv – Neighborhood Environment Scoring Tool (NEST) incivilities domain; NDVI – normalized difference vegetation index; ROW – right-of-way; Tot – total across all land uses; Pri – private land; Prk – parkland; x_Tree – tree canopy cover; x_Veg – vegetation cover; x_400 – within 400 m of place of residence; x_800 – within 800 m of place of residence

Table B7. Summary of ordinary least squares (OLS) linear regression models for mental well-being with all control variables, two significant green space predictors ($p < 0.05$), and an adjusted-R^2 greater than the best fit model with all control variables and one green space predictor.

Green Space Variable 1 (GSV1)	Green Space Variable 2 (GSV2)	Estimated Coefficient (GSV1)	Estimated Coefficient (GSV2)	Adj. R^2	RMSE [a]
NDVI_800	PrkCnt_800	40.58***	1.22**	0.40	16.52
NDVI_400	PrkCnt_800	40.01***	1.24**	0.40	16.52
Tot_Veg_800	PrkCnt_800	0.22**	1.22**	0.40	16.54
Tot_Veg_400	PrkCnt_800	0.21**	1.27**	0.40	16.55
NDVI_800	Prk_Veg_400	27.08*	0.06**	0.39	16.56
NDVI_800	PrkCntBinary_400	33.01**	4.77**	0.39	16.57
Pri_Veg_800	PrkCnt_800	0.18**	1.29**	0.39	16.58

Table B7 continued

Green Space Variable 1 (GSV1)	Green Space Variable 2 (GSV2)	Estimated Coefficient (GSV1)	Estimated Coefficient (GSV2)	Adj. R^2	RMSE [a]
Pri_Tree_400	PrkCnt_800	0.27**	1.27**	0.39	16.58
Tot_Veg_800	Prk_Veg_400	0.13*	0.06**	0.39	16.58
NDVI_400	Prk_Veg_400	23.63*	0.06*	0.39	16.59
Tot_Tree_400	PrkCnt_800	0.27**	1.09**	0.39	16.59
Row_Veg_800	Prk_Veg_400	0.21*	0.07**	0.39	16.59
Pri_Veg_400	PrkCnt_800	0.17**	1.34**	0.39	16.59
Pri_Tree_800	PrkCnt_800	0.26**	1.15**	0.39	16.60
NDVI_400	PrkCntBinary_400	29.90**	4.41*	0.39	16.60
NDVI_800	PrkNear_km	37.16**	-6.95*	0.39	16.60
Tot_Veg_800	PrkCntBinary_400	0.17**	4.64*	0.39	16.60
Row_Veg_800	PrkCnt_800	0.29**	1.05**	0.39	16.61
NDVI_800	Prk_Tree_400	27.35*	0.07*	0.39	16.61
Tot_Tree_800	PrkCnt_800	0.26**	1.02**	0.39	16.61
Row_Veg_400	PrkCnt_800	0.24**	0.99*	0.39	16.61
NDVI_800	Amen_800	33.37**	0.11*	0.39	16.62
Tot_Veg_800	Prk_Tree_400	0.14*	0.07*	0.39	16.62
NDVI_800	NEST_800	29.71**	0.13*	0.39	16.63
Row_Veg_800	PrkCntBinary_400	0.25*	4.49*	0.39	16.63
NDVI_400	Prk_Tree_400	24.83*	0.07*	0.39	16.63
Pri_Tree_800	PrkCntBinary_400	0.20*	4.71*	0.39	16.63
Tot_Veg_400	PrkCntBinary_400	0.15*	4.31*	0.39	16.63
NDVI_400	PrkNear_km	33.67**	-6.15*	0.39	16.63
Tot_Veg_800	PrkNear_km	0.19**	-6.73*	0.39	16.64
Pri_Veg_800	PrkCntBinary_400	0.13*	4.85**	0.39	16.64
Row_Veg_800	PrkHa_400	0.21*	0.10*	0.39	16.64
Row_Veg_400	PrkHa_400	0.18*	0.09*	0.39	16.64
Tot_Veg_400	Prk_Tree_400	0.13*	0.07*	0.39	16.64
Pri_Veg_800	Prk_Tree_400	0.11*	0.08*	0.39	16.64
Tot_Veg_800	Amen_800	0.18**	0.11*	0.39	16.64
Tot_Veg_800	NEST_800	0.15*	0.14*	0.39	16.65

* $p<0.05$; ** $p<0.01$; *** $p<0.001$

NDVI – normalized difference vegetation index; Tot – total across all land uses; ROW – right-of-way; Pri – private land; Prk – parkland; x_Tree – tree canopy cover; x_Veg – vegetation cover; PrkCnt – park count (i.e., number of parks); PrkCntBinary – one or more parks = 1, no parks = 0; PrkHa – park area (hectares); PrkNear_km – distance to nearest park (in kilometers); NEST – Neighborhood Environment Scoring Tool (NEST) overall score; Amen – Neighborhood Environment Scoring Tool (NEST) amenities domain; x_400 – within 400 m of place of residence; x_800 – within 800 m of place of residence

[a] root-mean-square error

Table B8. Summary of binomial logistic regression models for ONS Anxiety (6 and up) with all controls and one significant green space predictor ($p < 0.05$).

Green Space Variable	Odds Ratio	AIC	Green Space Category
NDVI_800	2.8E-03***	522.19	Green Cover
Tot_Veg_800	0.97***	523.63	Green Cover
Pri_Veg_800	0.97***	524.67	Green Cover
Pri_Tree_800	0.96**	525.64	Green Cover
Tot_Tree_800	0.96**	525.69	Green Cover
Prk_Veg_800	0.98**	528.29	Green Cover
Pri_Veg_400	0.98**	529.35	Green Cover
NDVI_400	0.02**	529.51	Green Cover
Tot_Veg_400	0.98*	530.57	Green Cover
Pri_Tree_400	0.97*	530.98	Green Cover
PrkHa_800	0.99*	532.1	Park Availability
Row_Veg_800	0.97*	532.5	Green Cover
Prk_Tree_800	0.99*	532.83	Green Cover

* p<0.05; ** p<0.01; *** p<0.001

NDVI – normalized difference vegetation index; ROW – right-of-way; Tot – total across all land uses; Pri – private land; Prk – parkland; x_Tree – tree canopy cover; x_Veg – vegetation cover; PrkCnt – park count (i.e., number of parks); PrkHa – park area (i.e., number of hectares); x_400 – within 400 m of place of residence; x_800 – within 800 m of place of residence

References Cited:

Broomhall, M. H., Giles-Corti, B., & Lange, B. (2004). *Quality of Public Open Space Tool (POST); The University of Western Australia: Perth, Australia, 2004.* The University of Western Australia.

Cheng, F. W., Gao, X., Mitchell, D. C., Wood, C., Still, C. D., Rolston, D., & Jensen, G. L. (2016). Body mass index and all-cause mortality among older adults. *Obesity*, *24*(10), 2232–2239. https://doi.org/10.1002/oby.21612

Engelberg, J. K., Conway, T. L., Geremia, C., Cain, K. L., Saelens, B. E., Glanz, K., Frank, L. D., & Sallis, J. F. (2016). Socioeconomic and race/ethnic disparities in observed park quality. *BMC Public Health*, *16*(1). https://doi.org/10.1186/s12889-016-3055-4

Gidlow, C., Ellis, N. J., & Bostock, S. (2012). Development of the Neighbourhood Green Space Tool (NGST). *Landscape and Urban Planning*, *106*(4), 347–358. https://doi.org/10.1016/j.landurbplan.2012.04.007

Gidlow, C., van Kempen, E., Smith, G., Triguero-Mas, M., Kruize, H., Gražulevičienė, R., Ellis, N., Hurst, G., Masterson, D., Cirach, M., van den Berg, M., Smart, W., Dėdelė, A., Maas, J., &

Nieuwenhuijsen, M. J. (2018). Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening*, *29*, 322–333. https://doi.org/10.1016/j.ufug.2017.12.007

Google. (2020). *Street View Static API overview*. Google Developers. https://developers.google.com/maps/documentation/streetview/overview

Harris, C. R., Millman, K. J., van der Walt, S. J., Gommers, R., Virtanen, P., Cournapeau, D., Wieser, E., Taylor, J., Berg, S., Smith, N. J., Kern, R., Picus, M., Hoyer, S., van Kerkwijk, M. H., Brett, M., Haldane, A., Fernández del Río, J., Wiebe, M., Peterson, P., … Oliphant, T. E. (2020). Array programming with NumPy. *Nature*, *585*, 357–362. https://doi.org/10.1038/s41586-020-2649-2

Jean, F. (2012). *PyMeanShift*. https://github.com/clememic/pymeanshift/blob/master/pymeanshift.py

Kaczynski, A. T., Wilhelm Stanis, S. A., & Besenyi, G. M. (2012). Development and Testing of a Community Stakeholder Park Audit Tool. *American Journal of Preventive Medicine*, *42*(3), 242–249. https://doi.org/10.1016/j.amepre.2011.10.018

Li, X., Seiferling, I., Cai, B., Abdulhai, M., & So, W. (2020). *Mittrees/Treepedia_Public* [Python]. https://github.com/mittrees/Treepedia_Public (Original work published 2018)

Li, X., Zhang, C., Li, W., Ricard, R., Meng, Q., & Zhang, W. (2015). Assessing street-level urban greenery using Google Street View and a modified green view index. *Urban Forestry & Urban Greening*, *14*(3), 675–685. https://doi.org/10.1016/j.ufug.2015.06.006

Oregon Metro RLIS. (2020a). *ORCA Sites* [Map]. https://rlisdiscovery.oregonmetro.gov/

Oregon Metro RLIS. (2020b). *Schools* [Map]. https://rlisdiscovery.oregonmetro.gov/

US EPA. (2017). *EnviroAtlas Data Download: Step 2* [Data and Tools]. https://www.epa.gov/enviroatlas/data-download-step-2

APPENDIX C

SUPPLEMENTAL INFORMATION FOR CHAPTER 4

C1. Urban Green Space Variables: Example Maps

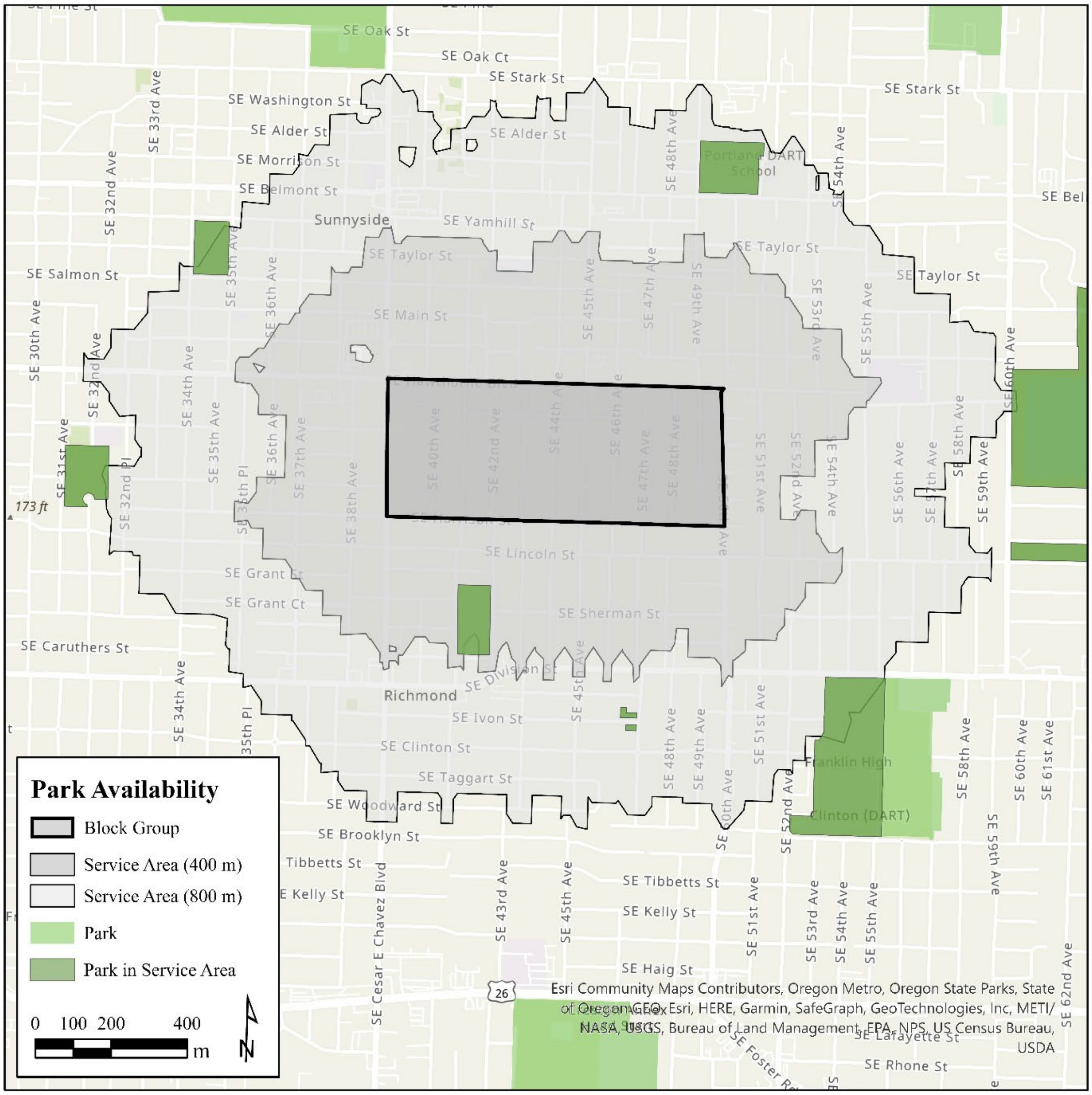

Figure C1. Park availability was defined as the number of parks and the area of parks, in hectares, accessible within the block group boundary and within 400 and 800 m walking distance from the block group boundary based on road network.

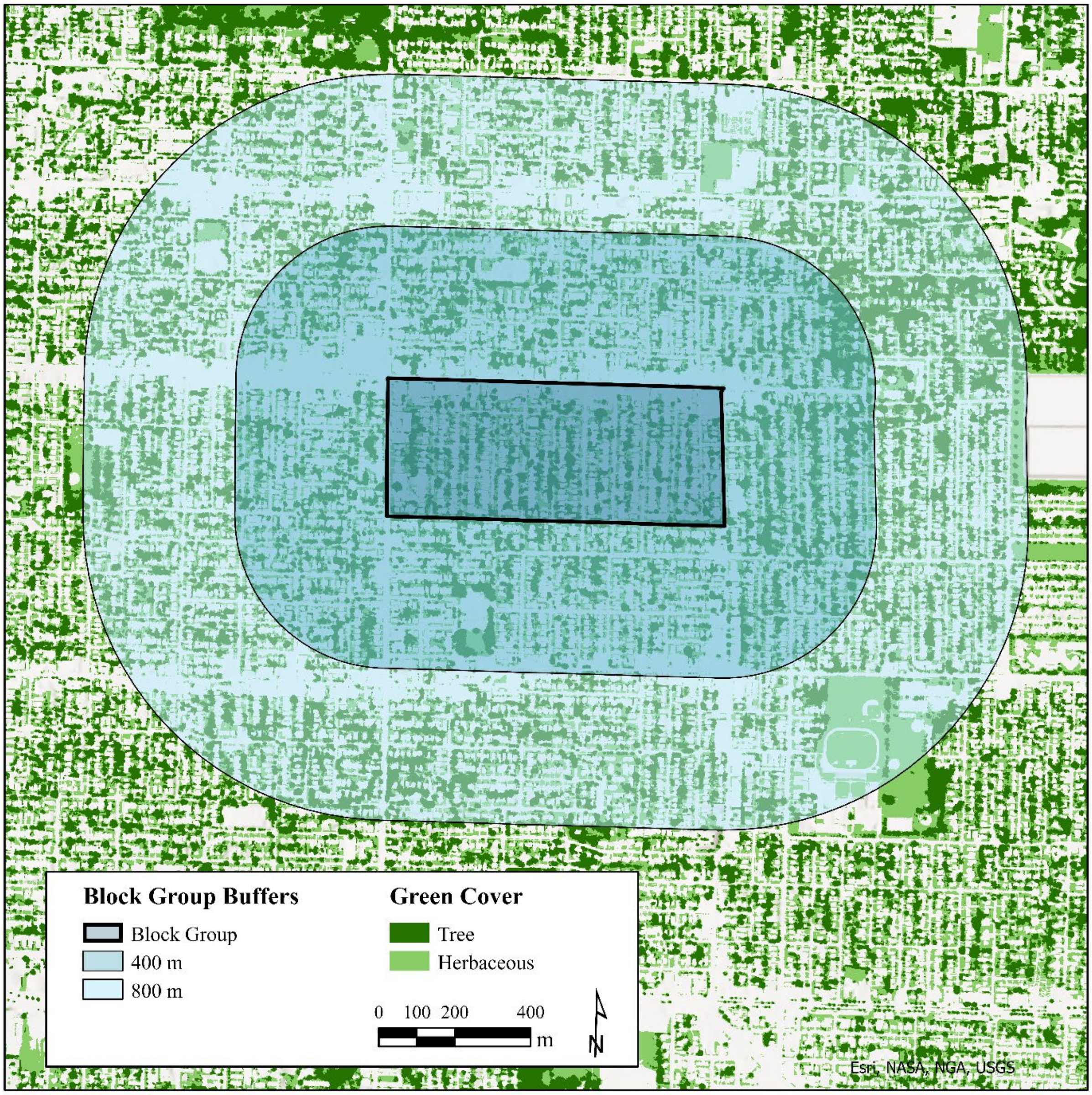

Figure C2. Green cover variables were defined as percent tree canopy cover and percent total vegetation (i.e., tree and herbaceous) within the block group boundary, within 400 m of block group boundary, and within 800 m of block group boundary

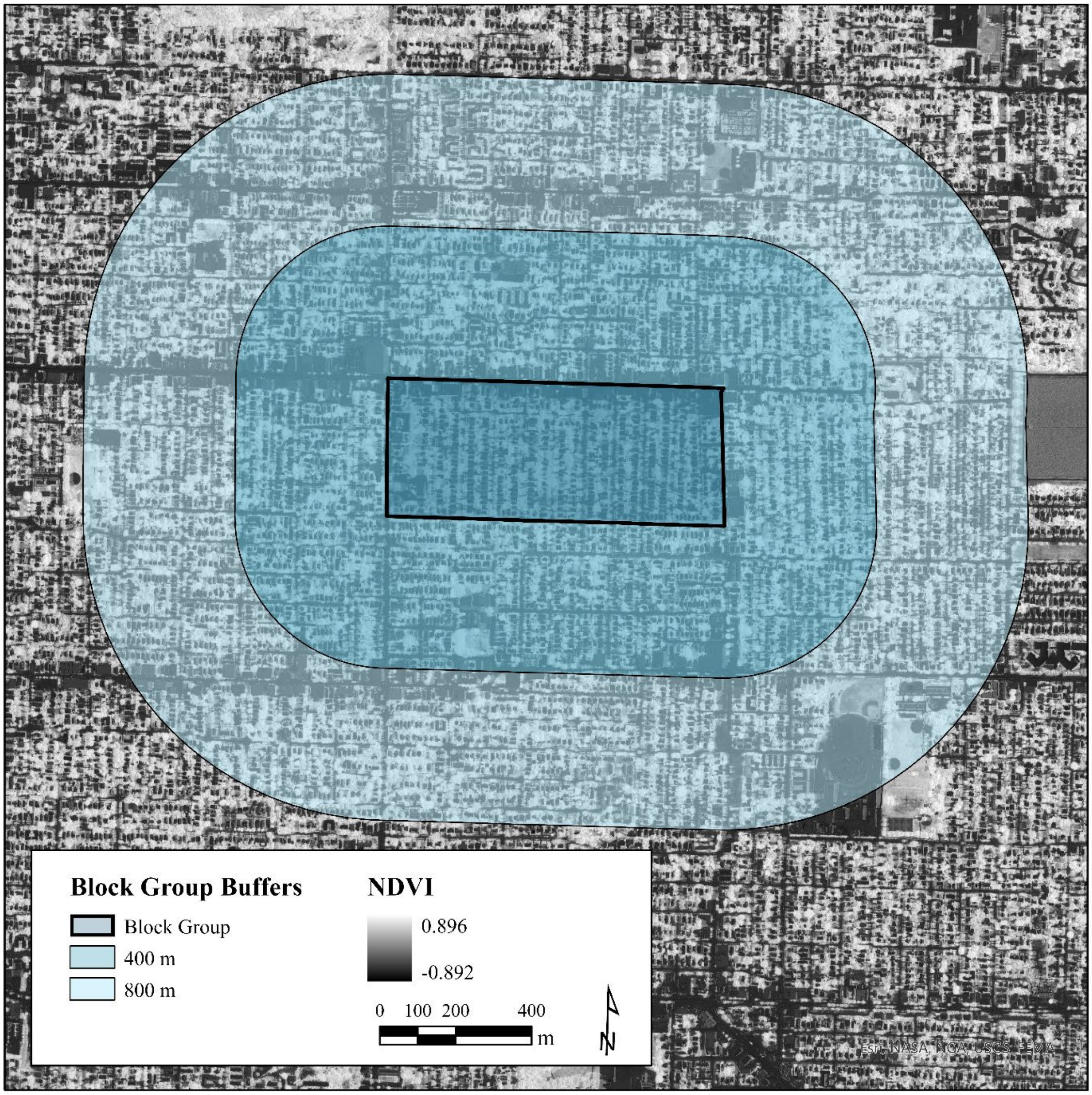

Figure C3. Cumulative normalized difference vegetation index (NDVI) was defined as the mean NDVI for all pixels within the block group boundary, within 400 m of block group boundary, and within 800 m of block group boundary.

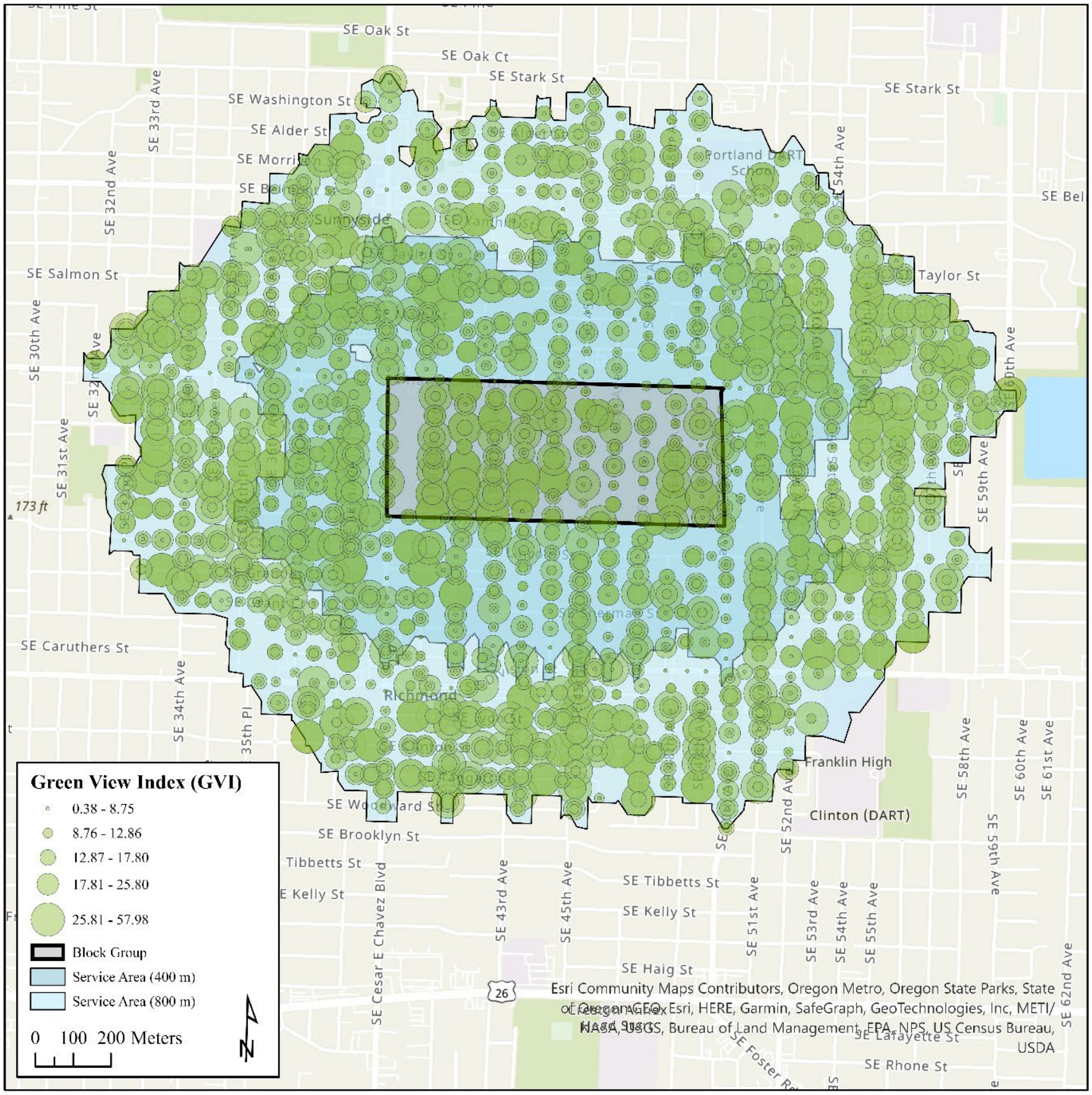

Figure C4. Green view index (GVI) was defined as the mean GVI for all points within the block group boundary and within 400 and 800 m walking distance from the block group boundary based on road network.

C2. Spatial Distribution and Local Moran's I Maps

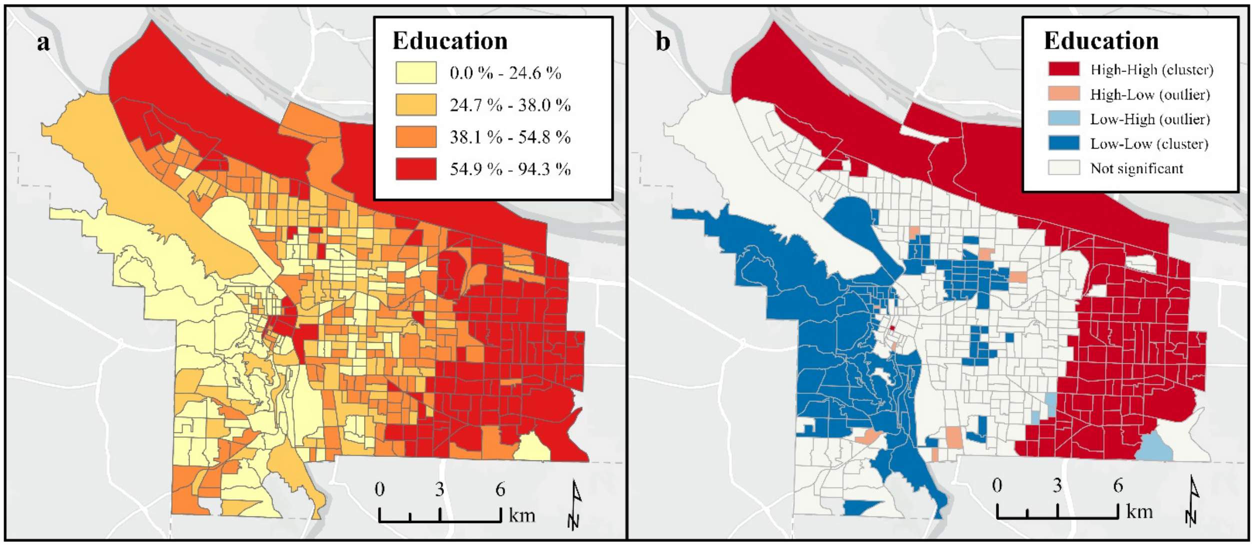

Figure C5. a) Percent of block group population with no postsecondary education grouped in quartiles (n=497); b) cluster analysis using Local Moran's I to identify clusters of block groups with high and low proportion of their populations with no postsecondary education.

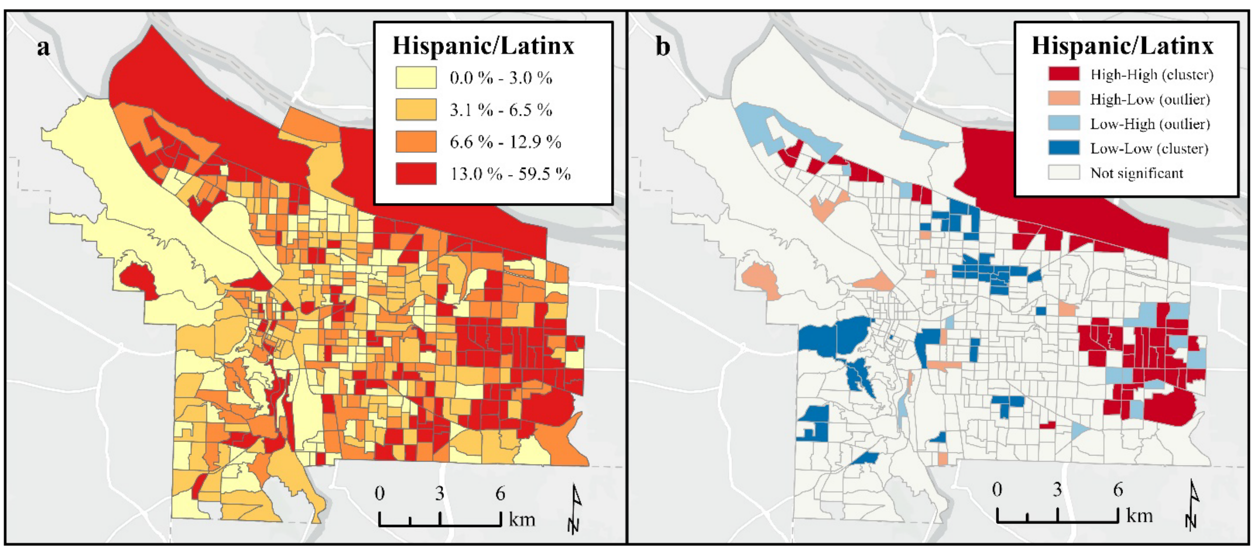

Figure C6. a) Block group percent Hispanic/Latinx grouped in quartiles (n=497); b) cluster analysis using Local Moran's I to identify clusters of block groups with high and low proportions of Hispanic/Latinx populations.

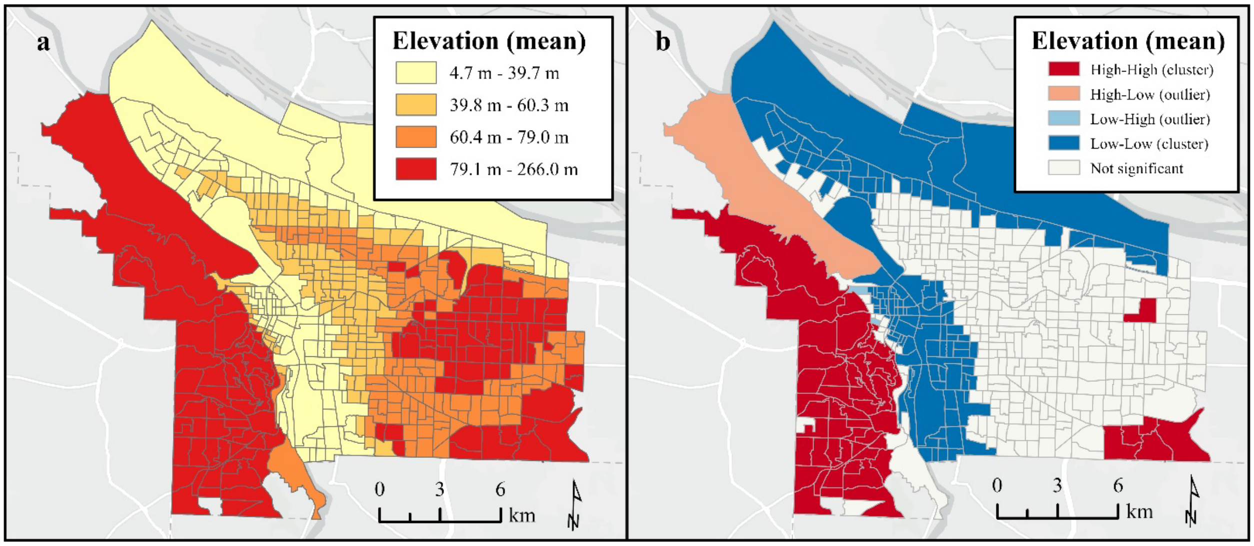

Figure C7. a) Block group mean elevation grouped in quartiles (n=497); b) cluster analysis using Local Moran's I to identify clusters of high and low mean elevation.

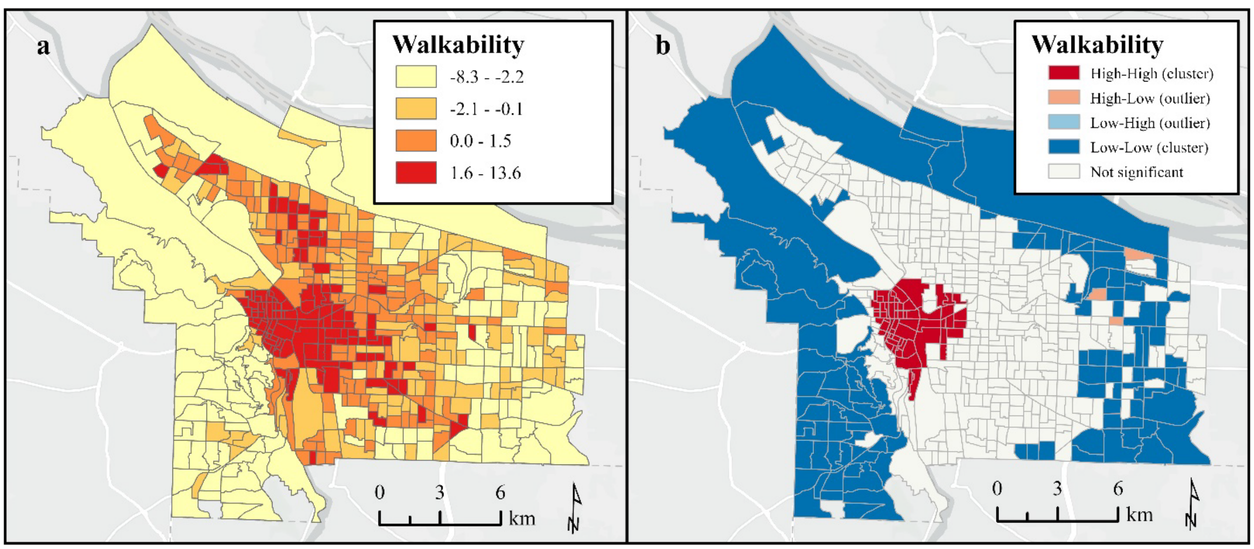

Figure C8. a) Block group neighborhood walkability index grouped in quartiles (n=497); b) cluster analysis using Local Moran's I to identify clusters of high and low neighborhood walkability indices.

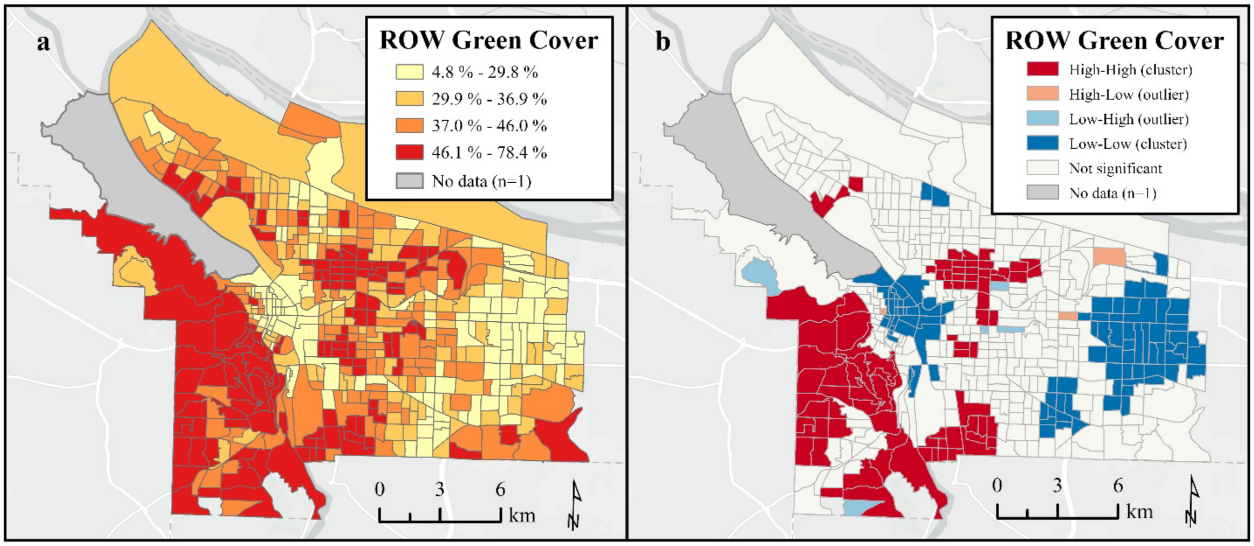

Figure C9. a) Block group percent right-of-way (ROW) green cover grouped in quartiles (n=496); b) cluster analysis using Local Moran's I to identify clusters of high and low right-of-way green cover.

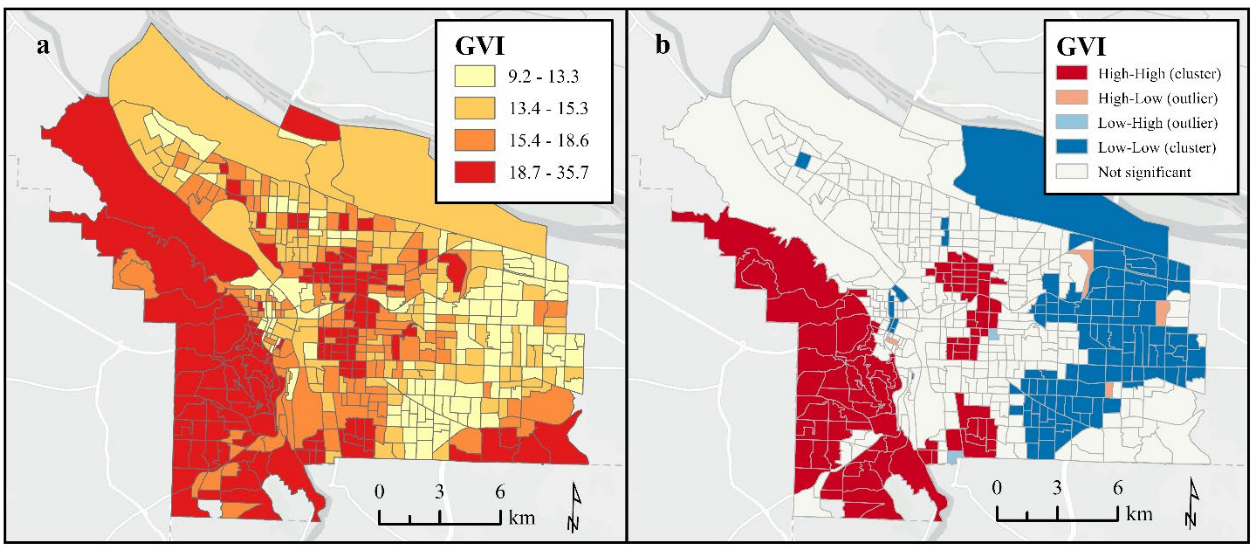

Figure C10. a) Block group Green View Index (GVI) grouped in quartiles (n=497); b) cluster analysis using Local Moran's I to identify clusters of high and low GVI.

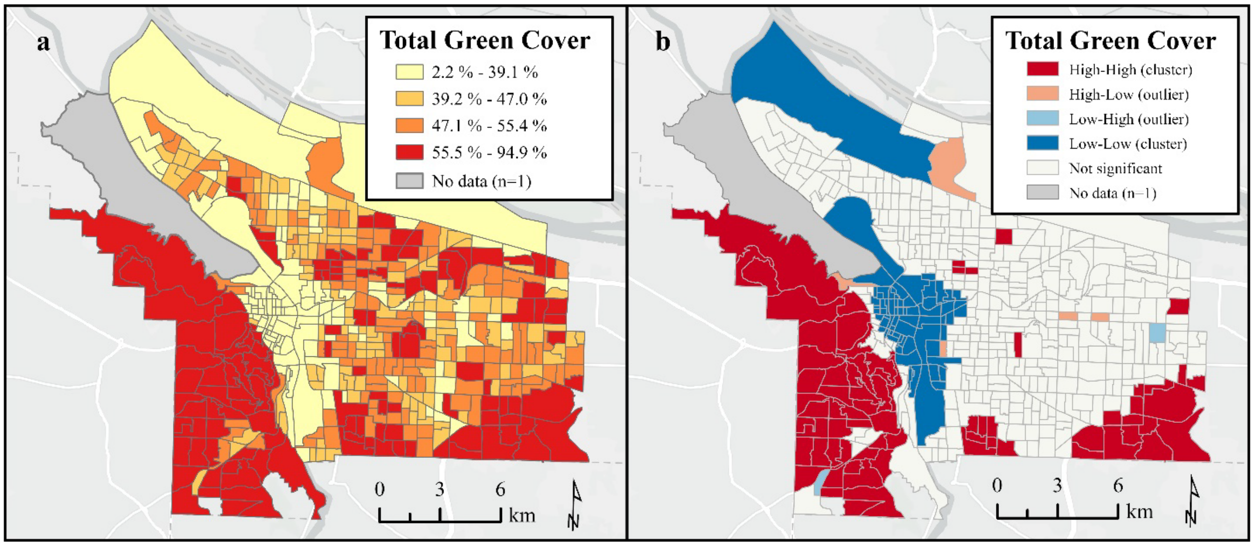

Figure C11. a) Block group percent total green cover grouped in quartiles (n=496); b) cluster analysis using Local Moran's I to identify clusters of high and low total green cover.

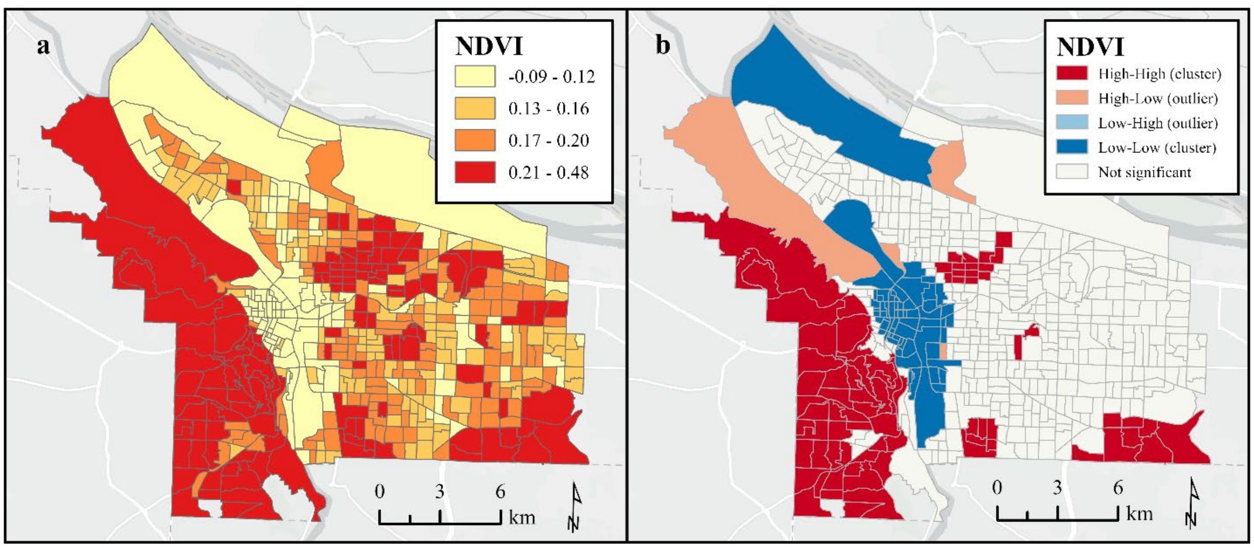

Figure C12. a) Block group percent normalized difference vegetation index (NDVI) grouped in quartiles (n=496); b) cluster analysis using Local Moran's I to identify clusters of high and low NDVI.

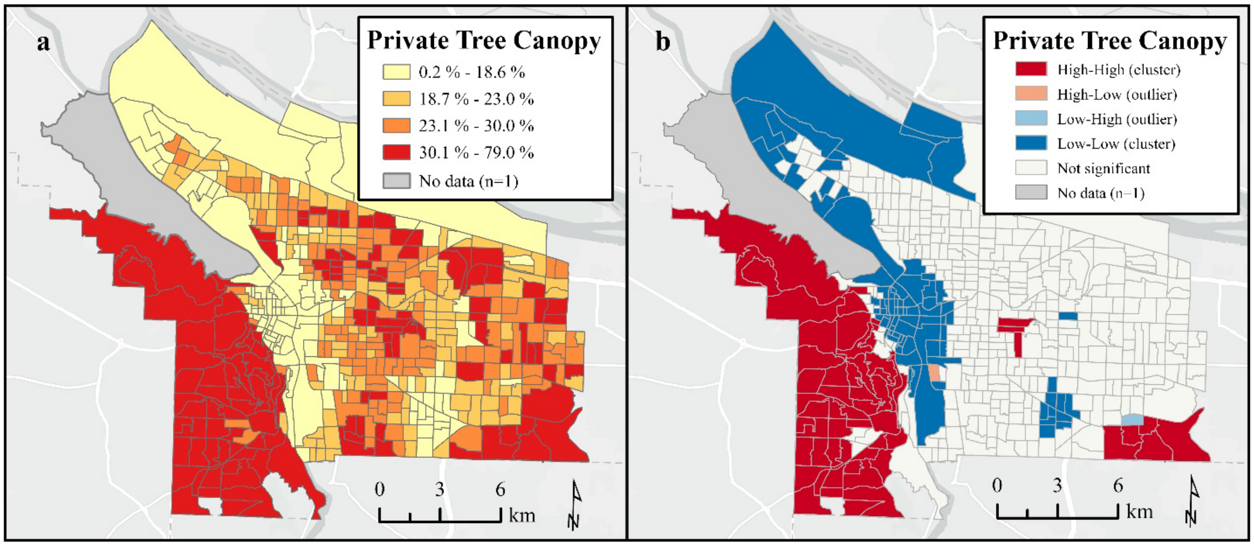

Figure C13. a) Block group percent private tree canopy cover, in quartiles (N=496); b) cluster analysis using Local Moran's I to identify clusters of block groups with high and low private tree canopy cover.

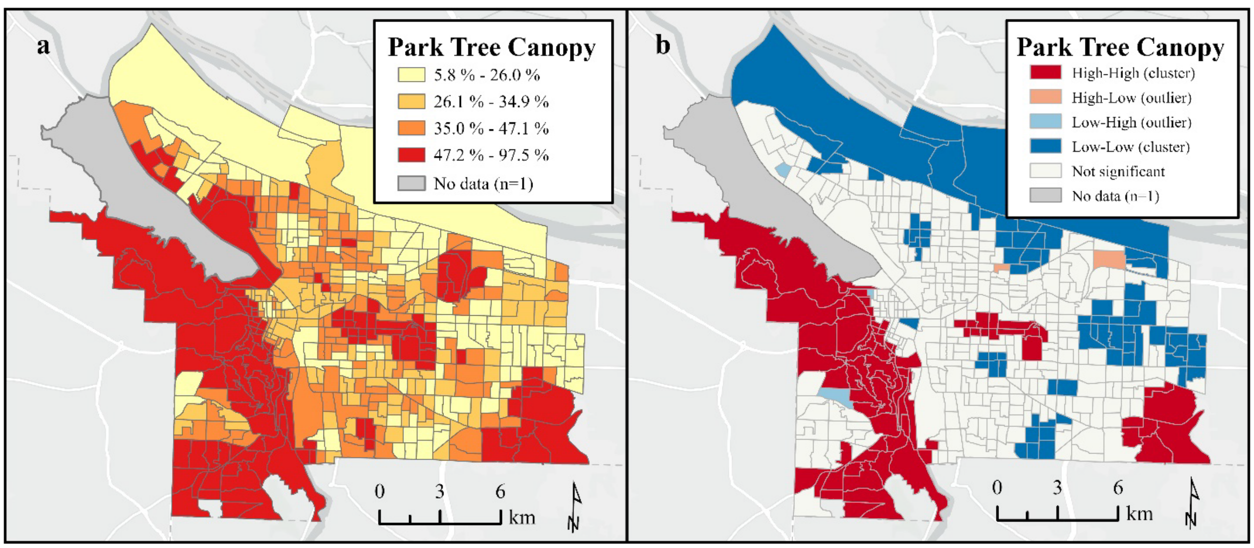

Figure C14. a) Block group percent parkland tree canopy cover, in quartiles (N=496); b) cluster analysis using Local Moran's I to identify clusters of block groups with high and low parkland tree canopy cover.

C3. Bivariate Spearman's Rank Correlation

Table C1. Summary of Spearman's rank correlation coefficients (r_s) between race and green space with, at minimum, moderate correlations ($|r_s|>0.3$).

Green Space Variable	**Race** *(Percent minoritized racial population)*	**Income** *(Median household income)*	**Education** (*Percent no postsecondary education*)	**Ethnicity** (*Percent Hispanic/ Latinx*)
ROW_Tree_800	-0.72	0.47	-0.69	-0.33
ROW_Tree_400	-0.73	0.48	-0.68	-0.34
ROW_Tree_BG	-0.68	0.46	-0.61	-0.33
ROW_Veg_800	-0.64	0.53	-0.47	-
ROW_Veg_400	-0.65	0.56	-0.49	-
ROW_Veg_BG	-0.61	0.56	-0.48	-0.33
GVI_800	-0.71	0.50	-0.63	-0.32
GVI_400	-0.71	0.50	-0.61	-0.34
GVI_BG	-0.65	0.48	-0.54	-0.32
Tot_Tree_800	-0.46	0.35	-0.31	-
Tot_Tree_400	-0.48	0.40	-0.32	-
Tot_Tree_BG	-0.43	0.43	-	-
Tot_Veg_400	-	0.36	-	-
Tot_Veg_BG	-	0.43	-	-
NDVI_800	-0.33	0.36	-	-
NDVI_400	-0.36	0.42	-	-
NDVI_BG	-0.33	0.46	-	-
Pri_Tree_400	-0.31	0.35	-	-
Pri_Tree_BG	-0.33	0.40	-	-
Pri_Veg_BG	-	0.36	-	-
Prk_Tree_800	-0.39	-	-0.33	-
Prk_Tree_400	-0.32	-	-	-
NEST_800	-	-	-0.31	-
NonNat_800	-	-	-0.34	-

ROW – right-of-way; GVI – green view index; Tot – total across all land uses; Pri – private land; Prk – parkland; NEST – Neighborhood Environment Scoring Tool (NEST) overall score; NonNat – Neighborhood Environment Scoring Tool (NEST) non-natural aesthetics domain; x_Tree – tree canopy cover; x_Veg – vegetation cover; x_BG – within block group; x_400 – within 400 m of block group boundary; x_800 – within 800 m of block group boundary

Table C2. Summary of Spearman's rank correlation coefficients (r_s) with moderate correlations ($|r_s|>0.3$) between green space, elevation, and neighborhood walkability index. [a]

Green Space Variable	Elevation *(mean)*	Neighborhood Walkability Index
Pri_Veg_800	0.79	-0.7
Pri_Veg_400	0.74	-0.7
Pri_Veg_BG	0.67	-0.73
Pri_Tree_800	0.74	-0.54
Pri_Tree_400	0.7	-0.56
Pri_Tree_BG	0.62	-0.57
Tot_Veg_800	0.72	-0.68
Tot_Veg_400	0.67	-0.67
Tot_Veg_BG	0.59	-0.68
NDVI_800	0.67	-0.59
NDVI_400	0.63	-0.58
NDVI_BG	0.57	-0.59
Tot_Tree_800	0.57	-0.4
Tot_Tree_400	0.55	-0.42
Tot_Tree_BG	0.48	-0.43

ROW – right-of-way; GVI – green view index; Tot – total across all land uses; Pri – private land; Prk – parkland; x_Tree – tree canopy cover; x_Veg – vegetation cover; x_BG – within block group; x_400 – within 400 m of block group boundary; x_800 – within 800 m of block group boundary

[a] only included correlations for green space variables that exhibited moderate or strong correlations with sociodemographic variables or met OLS model inclusion criteria

C4. Ordinary Least Squares Regression: One Census Variable

Table C3. Ordinary least squares (OLS) standardized regression coefficients (β) and adjusted-R^2 for models with one significant Census variable (p<0.05) and no spatial autocorrelation of residuals in spatial autoregressive modeling.

Green Space Variable	Census Variable	β_{CV}	β_{ELEV}	β_{UF}	Adjusted-R^2
ROW_Tree_BG [a]	Race	-0.58	0.17	-0.04	0.39
ROW_Tree_BG [a]	Education	-0.58	0.14	-0.10	0.38
ROW_Tree_BG [a]	Income	0.53	0.16	0.14	0.31
ROW_Tree_BG [a]	Ethnicity	-0.3	0.24	0.02	0.15
ROW_Veg_BG	Income	0.55	0.03	-0.17	0.40
ROW_Veg_BG	Race	-0.53	0.06	-0.34	0.40
ROW_Veg_BG	Ethnicity	-0.33	0.11	-0.3	0.23
GVI_BG [a]	Education	-0.54	0.15	-0.22	0.38
GVI_BG [a]	Income	0.54	0.15	0.00	0.36
GVI_BG [a]	Ethnicity	-0.31	0.23	-0.12	0.19
Tot_Tree_400	Race	-0.32	0.62	-0.20	0.70
Tot_Tree_BG [a]	Race	-0.3	0.47	-0.28	0.57
Tot_Tree_BG [a]	Income	0.29	0.46	-0.19	0.55
Tot_Tree_BG [a]	Education	-0.29	0.46	-0.31	0.55
Tot_Veg_BG	Ethnicity	-0.1	0.33	-0.54	0.61
NDVI_BG	Income	0.27	0.36	-0.38	0.63
NDVI_BG	Race	-0.2	0.39	-0.45	0.60
Pri_Tree_BG	Income	0.24	0.51	-0.30	0.70
Pri_Tree_BG	Race	-0.24	0.52	-0.37	0.70
Pri_Tree_BG	Ethnicity	-0.14	0.55	-0.35	0.66
Prk_Tree_800	Education	-0.33	0.42	-0.01	0.31
Prk_Tree_400	Race	-0.29	0.38	0.00	0.25
Prk_Tree_800	Income	0.21	0.45	0.11	0.24
Prk_Tree_800	Ethnicity	-0.18	0.47	0.05	0.24
NatAes_400	Education	-0.22	0.21	-0.07	0.11
Usability_800	Education	-0.25	-0.05	-0.22	0.07
Amenity_400	Income	0.2	0.04	0.23	0.06
Amenity_400	Race	-0.14	0.06	0.18	0.04

β_{CV} – standardized regression coefficient for Census variable

β_{ELEV} – standardized regression coefficient for mean elevation

β_{UF} – standardized regression coefficient for urban form

ROW – right-of-way; GVI – green view index; Tot – total across all land uses; Pri – private land; Prk_ – parkland; NatAes – Neighborhood Environment Scoring Tool (NEST) natural aesthetic domain; Usability – NEST usability domain; Amenity – NEST amenities domain; x_Tree – tree canopy cover; x_Veg – vegetation cover; x_BG – within block group; x_400 – within 400 m of block group boundary

[a] response variable transformed (square-root transformation)

C5. Spatial Autoregressive Models: One Census Variable

Table C4. Summary of spatial autoregressive (SAR) models with one Census variable (median household income) and no spatial autocorrelation of model residuals.

	ROW Tree Canopy [ab]	**ROW Vegetation** [b]	**GVI** [ab]	**Total Tree Canopy** [ab]	**NDVI** [b]	**Private Tree Canopy** [b]	**Park Tree Canopy** [d]	**NEST Amenities** [c]
Intercept	0.37**	6.04***	0.96***	3.48***	0.01*	11.49***	1.39	7.85***
Median household income ($10k)	0.07***	0.98***	0.03***	0.05***	4.0e-03***	0.45***	0.27*	0.30*
Elevation (mean)	6.90E-05	-0.01	-1.70E-05	0.01***	3.4e-04***	0.15***	0.03*	0.01
Urban form	-3.30E-03	-0.47***	-9.90E-03	-0.09***	-5.4e-03***	-1.21***	-0.17	0.48*
Pseudo-R^2	0.64	0.60	0.61	0.66	0.73	0.76	0.66	0.29
SAR Type (SEM or SLAG) [d]	SLAG	SLAG	SLAG	SEM	SLAG	SEM	SLAG	SLAG

* *p*<0.05; ** *p*<0.01; *** *p*<0.001

NDVI – normalized difference vegetation index; ROW – right-of-way; GVI – green view index; NEST – Neighborhood Environment Scoring Tool

[a] response variable transformed (square-root transformation)

[b] measured within block group boundaries

[c] measured within 400m of block group boundaries

[d] measured within 800m of block group boundaries

[e] SEM – Spatial error model; SLAG – spatial lag model

Table C5. Summary of spatial autoregressive (SAR) models with one Census variable (percent racial minority) and no spatial autocorrelation of model residuals.

	ROW Tree Canopy [ab]	ROW Vegetation [b]	Total Tree Canopy [c]	Total Tree Canopy [ab]	NDVI [b]	Private Tree Canopy [b]	Park Tree Canopy [c]	NEST Amenities [c]
Intercept	1.89***	23.23***	19.25***	4.50***	0.12***	21.52***	38.25***	35.84***
Race (percent racial minority)	-0.03***	-0.30***	-0.12***	-0.02***	-8.4e-04**	-0.21***	-0.39***	-0.17*
Elevation (mean)	6.80E-04	-5.30E-03	0.13***	0.01***	9.8e-04***	0.15***	0.14***	0.03
Urban form	-0.03*	-0.81***	-0.56***	-0.1***	-8.0e-03***	-1.33***	-0.95*	0.64*
Pseudo-R^2	0.64	0.58	0.88	0.66	0.72	0.76	0.47	0.29
SAR Type (SEM or SLAG) [d]	SLAG	SLAG	SEM	SEM	SEM	SEM	SEM	SEM

* p<0.05; ** p<0.01; *** p<0.001

NDVI – normalized difference vegetation index; ROW – right-of-way; NEST – Neighborhood Environment Scoring Tool

[a] response variable transformed (square-root transformation)

[b] measured within block group boundaries

[c] measured within 400m of block group boundaries

[d] SEM – Spatial error model; SLAG – spatial lag model

Table C6. Summary of spatial autoregressive (SAR) models with one Census variable (percent with no postsecondary education) and no spatial autocorrelation of model residuals.

	ROW Tree Canopy [ab]	**GVI** [ab]	**Total Tree Canopy** [ab]	**Park Tree Canopy** [d]	**NEST Useability** [d]	**NEST Natural Aesthetics** [c]
Intercept	1.64***	1.48***	4.17***	7.15***	6.29***	15.70***
No postsecondary education (percent)	-0.01***	-5.5e-03***	-7.6e-03**	-0.07**	-0.02*	-0.05*
Elevation (mean)	4.50E-04	1.40E-04	0.01***	0.03*	-3.10E-03	0.03
Urban form	-0.04**	-0.02***	-0.10***	-0.32	-0.12	-0.12
Pseudo-R^2	0.63	0.59	0.65	0.66	0.52	0.38
SAR Type (SEM or SLAG) [e]	SLAG	SLAG	SEM	SLAG	SLAG	SLAG

* p<0.05; ** p<0.01; *** p<0.001

NDVI – normalized difference vegetation index; ROW – right-of-way; GVI – green view index; NEST – Neighborhood Environment Scoring Tool

[a] response variable transformed (square-root transformation)

[b] measured within block group boundaries

[c] measured within 400m of block group boundaries

[d] measured within 800m of block group boundaries

[e] SEM – Spatial error model; SLAG – spatial lag model

Table C7. Summary of spatial autoregressive (SAR) models with one Census variable (percent Hispanic/Latinx) and no spatial autocorrelation of model residuals.

	ROW Tree Canopy [ab]	**ROW Vegetation** [b]	**GVI** [ab]	**Total Vegetation** [b]	**Private Tree Canopy** [b]	**Park Tree Canopy** [c]
Intercept	0.89***	12.91***	1.00***	38.1***	15.69***	5.07***
Ethnicity (percent Hispanic/Latinx)	-0.02***	-0.27***	-8.7e-03***	-0.10*	-0.08*	-0.16**
Elevation (mean)	6.60E-04	-3.50E-03	1.60E-04	0.14***	0.16***	0.03*
Urban form	-0.03	-0.70***	-0.02***	-1.89***	-1.33***	-0.28
Pseudo-R^2	0.61	0.55	0.58	0.70	0.75	0.66
SAR Type (SEM or SLAG) [d]	SLAG	SLAG	SLAG	SEM	SEM	SLAG

* p<0.05; ** p<0.01; *** p<0.001

NDVI – normalized difference vegetation index; ROW – right-of-way; GVI – green view index

[a] response variable transformed (square-root transformation)

[b] measured within block group boundaries

[c] measured within 800m of block group boundaries

[d] SEM – Spatial error model; SLAG – spatial lag model

C6. Ordinary Least Squares Regression: Two Census Variables

Table C8. Ordinary least squares (OLS) regression models with two census variables (CV_1 and CV_2) where standardized regression coefficients of both census variables (β_{CV1} and β_{CV2}) were greater (in magnitude) than standardized regression coefficients of both mean block group elevation (β_{ELEV}) and urban form (β_{UF}).

Green Space Variable	Census Variable (CV_1)	Census Variable (CV_2)	β_{CV1}	β_{CV2}	β_{ELEV}	β_{UF}	Adjusted-R^2	LM
ROW_Tree_400	Race	Income	-0.44	0.32	0.22	0.07	0.53	SLAG
ROW_Tree_400	Education	Income	-0.46	0.26	0.21	0.01	0.51	SLAG
ROW_Tree_BG [ab]	Race	Income	-0.44	0.28	0.13	0.02	0.44	SLAG
ROW_Tree_BG [a]	Education	Income	-0.42	0.25	0.12	-0.02	0.41	SLAG
ROW_Veg_400	Race	Income	-0.39	0.33	0.07	-0.25	0.53	SLAG
ROW_Veg_400	Education	Income	-0.30	0.35	0.07	-0.26	0.48	SLAG
ROW_Veg_BG [b]	Race	Income	-0.34	0.36	0.01	-0.26	0.48	SLAG
GVI_800	Race	Income	-0.46	0.28	0.21	-0.04	0.53	SLAG
GVI_400 [a]	Race	Income	-0.44	0.29	0.18	-0.05	0.52	SLAG
GVI_400 [a]	Education	Income	-0.42	0.26	0.18	-0.10	0.48	SLAG
GVI_BG [ab]	Race	Income	-0.39	0.32	0.12	-0.10	0.46	SLAG
GVI_BG [a]	Education	Income	-0.35	0.31	0.12	-0.13	0.43	SLAG

LM - Lagrange Multiplier spatial dependence test to select spatial lag model (SLAG) or spatial error model (SER)

GVI – green view index; ROW – right-of-way; x_Tree – tree canopy cover; x_Veg – vegetation cover; x_BG – within block group; x_400 – within 400 m of block group boundary; x_800 – within 800 m of block group boundary

[a] response variable transformed (square-root transformation)

[b] best-fit spatial autoregressive model

Table C9. Ordinary least squares (OLS) regression models with two census variables (CV_1 and CV_2) where standardized coefficient of one census variable (β_{CV1} or β_{CV2}) is greater (in magnitude) than standardized regression coefficients of both mean block group elevation (β_{ELEV}) and urban form (β_{UF}).

Green Space Variable	Census Variable (CV_1)	Census Variable (CV_2)	β_{CV1}	β_{CV2}	β_{ELEV}	β_{UF}	Adjusted-R^2	LM
ROW_Tree_800	Education	Income	-0.53	0.18	0.24	0.01	0.53	SLAG
ROW_Tree_800	Income	Ethnicity	0.50	-0.09	0.28	0.19	0.38	SLAG
ROW_Tree_400	Ethnicity	Income	-0.09	0.53	0.24	0.16	0.41	SLAG
ROW_Tree_BG [a]	Ethnicity	Income	-0.11	0.48	0.15	0.11	0.32	SLAG
ROW_Veg_800	Race	Income	-0.41	0.26	0.10	-0.26	0.51	SLAG
ROW_Veg_800	Education	Income	-0.36	0.26	0.10	-0.29	0.46	SLAG
ROW_Veg_800	Ethnicity	Income	-0.10	0.46	0.13	-0.18	0.40	SLAG
ROW_Veg_400	Ethnicity	Income	-0.10	0.51	0.09	-0.17	0.43	SLAG
ROW_Veg_400	Education	Ethnicity	-0.48	-0.10	0.10	-0.37	0.42	SLAG
ROW_Veg_BG	Education	Income	-0.27	0.37	0.01	-0.27	0.44	SLAG
ROW_Veg_BG	Ethnicity	Income	-0.13	0.49	0.02	-0.21	0.41	SLAG
ROW_Veg_BG	Ethnicity	Race	-0.11	-0.48	0.05	-0.35	0.41	SLAG
GVI_BG [a]	Education	Ethnicity	-0.50	-0.10	0.14	-0.23	0.39	SLAG
GVI_400 [a]	Ethnicity	Income	-0.11	0.50	0.20	0.03	0.39	SLAG
GVI_BG [a]	Ethnicity	Income	-0.12	0.49	0.14	-0.03	0.37	SLAG

LM - Lagrange Multiplier spatial dependence test to select spatial lag model (SLAG) or spatial error model (SER)

ROW – right-of-way; GVI – green view index; x_Tree – tree canopy cover; x_Veg – vegetation cover; x_BG – within block group; x_400 – within 400 m of block group boundary; x_800 – within 800 m of block group boundary

[a] response variable transformed (square-root transformation)

Table C10. Ordinary least squares (OLS) regression models with two census variables (CV_1 and CV_2) where standardized regression coefficients (SC) of mean block group elevation (β_{ELEV}) and/or urban form (β_{UF}) were greater (in magnitude) than standardized regression coefficients of both census variables (β_{CV1} and β_{CV2}).

Green Space Variable	Census Variable (CV_1)	Census Variable (CV_2)	β_{CV1}	β_{CV2}	β_{ELEV}	β_{UF}	Adjusted-R^2	LM
Tot_Tree_800	Race	Income	-0.24	0.11	0.65	-0.13	0.72	SLAG
Tot_Tree_800	Education	Income	-0.26	0.07	0.65	-0.17	0.72	SLAG
Tot_Tree_400	Race	Income	-0.24	0.16	0.59	-0.17	0.72	SLAG
Tot_Tree_400	Education	Income	-0.24	0.13	0.59	-0.20	0.71	SLAG
Tot_Tree_BG [ab]	Race	Income	-0.22	0.17	0.45	-0.25	0.58	SEM
Tot_Tree_BG [a]	Education	Income	-0.18	0.17	0.45	-0.26	0.57	SEM
Tot_Veg_BG	Education	Ethnicity	-0.07	-0.07	0.32	-0.55	0.62	SLAG
NDVI_800	Race	Income	-0.12	0.10	0.48	-0.39	0.69	SLAG
NDVI_400	Race	Income	-0.12	0.16	0.44	-0.39	0.68	SLAG
NDVI_BG [b]	Race	Income	-0.08	0.23	0.36	-0.40	0.63	SLAG
NDVI_BG	Education	Ethnicity	-0.15	-0.07	0.38	-0.47	0.60	SLAG
Pri_Tree_400	Race	Income	-0.17	0.10	0.61	-0.28	0.78	SLAG
Pri_Tree_400	Education	Income	-0.15	0.10	0.61	-0.29	0.77	SLAG
Pri_Tree_BG [b]	Race	Income	-0.17	0.14	0.50	-0.34	0.71	SEM
Pri_Tree_BG	Education	Income	-0.15	0.13	0.50	-0.35	0.71	SLAG
Prk_Tree_800 [b]	Ethnicity	Income	-0.12	0.16	0.44	0.08	0.25	SLAG

LM - Lagrange Multiplier spatial dependence test to select spatial lag model (SLAG) or spatial error model (SER)

Tot – total across all land uses; NDVI – normalized difference vegetation index; Pri – private land; Prk – parkland; x_Tree – tree canopy cover; x_Veg – vegetation cover; x_BG – within block group; x_400 – within 400 m of block group boundary; x_800 – within 800 m of block group boundary

[a] response variable transformed (square-root transformation)

[b] best-fit spatial autoregressive model

C7. Spatial Autoregressive Models: Two Census Variables

Table C11. Summary of right-of-way (ROW) green cover spatial autoregressive (SAR) models with no spatial autocorrelation of model residuals and at least one significant Census variable where at least one model with the same response variable has a higher Nagelkerke pseudo-r^2.

	ROW Tree Canopy [ab]	ROW Tree Canopy [ab]	ROW Vegetation Cover [a]	ROW Vegetation Cover [a]	ROW Vegetation Cover [a]
Intercept	0.53***	0.96***	8.76***	11.24***	23.28***
Median household income ($10k)	0.07***	0.06***	0.86***	0.8***	-
Race (percent racial minority)	-	-	-	-	-0.25***
Ethnicity (percent Hispanic/ Latinx)	-8.00E-03	-	-0.14**	-	-0.15**
Education (percent no postsecondary)	-	-6.9e-03**	-	-0.06*	-
Elevation (mean)	-2.40E-05	2.40E-05	-0.01	-0.01	-7.80E-03
Urban form	-7.90E-03	-0.02	-0.56***	-0.62***	-0.85***
Pseudo-R^2	0.64	0.65	0.61	0.6	0.59
SAR Type (SEM or SLAG)	SLAG	SLAG	SLAG	SLAG	SLAG

* p<0.05; ** p<0.01; *** p<0.001

SEM – Spatial error model; SLAG – spatial lag model

[a] measured within block group boundaries

[b] response variable transformed (square-root transformation)

Table C12. Summary of green view index (GVI), normalized difference vegetation index (NDVI), and total tree canopy spatial autoregressive (SAR) models with no spatial autocorrelation of model residuals and at least one significant Census variable where at least one model with the same response variable has a higher Nagelkerke pseudo-R^2.

	GVI [ab]	**GVI** [ab]	**GVI** [ab]	**Total Tree Canopy** [ab]	**NDVI** [a]
Intercept	1.24***	1.06***	1.49***	3.65***	0.06***
Median household income ($10k)	0.03***	0.03***	-	0.04***	-
Ethnicity (percent Hispanic/ Latinx)	-	-4.5e-03**	-5.4e-03**	-	-6.4e-04*
Education (percent no postsecondary)	-2.4e-03*	-	-4.5e-03***	-3.00E-03	-3.5e-04**
Elevation (mean)	-2.90E-05	-7.20E-05	6.00E-05	0.01***	3.5e-04***
Urban form	-0.01**	-0.01*	-0.02***	-0.09***	-6.6e-03***
Pseudo-R^2	0.61	0.61	0.6	0.66	0.71
SAR Type (SEM or SLAG)	SLAG	SLAG	SLAG	SEM	SLAG

* p<0.05; ** p<0.01; *** p<0.001

SEM – Spatial error model; SLAG – spatial lag model

[a] measured within block group boundaries

[b] response variable transformed (square-root transformation)

C8. Home Owner's Loan Corporation (HOLC) Analysis

Table C13. Results from Student's t-tests comparing Home Owner's Loan Corporation (HOLC) mortgage security grades with block group green cover conditions.

Green Space Variable	Comparison of HOLC A/B with C/D [a]			Comparison of HOLC A/B/C with D [b]		
	t-statistic	*p*-value	Difference in means	*t*-statistic	*p*-value	Difference in means
ROW_Tree_BG	8.1	4.7E-13	12.6	0.3	0.7	0.5
ROW_Veg_BG	10.3	3.5E-18	15.2	3.3	0.001	5.5
Tot_Tree_BG	7.9	1.2E-12	9.3	4.4	2.9E-5	5.0
Tot_Veg_BG	7.8	4.1E-13	9.7	6.3	4.0E-9	10.9
Pri_Tree_BG	6.9	1.3E-10	7.6	5.6	3.2E-7	6.4
Pri_Veg_BG	5.5	9.5E-08	7.2	5.7	4.6E-7	12.6

ROW – right-of-way; Tot – total across all land uses; Pri – private land; x_Tree – tree canopy cover; x_Veg – vegetation cover; x_BG – within block group; x_400 – within 400 m of block group boundary; x_800 – within 800 m of block group boundary

[a] block groups with centroids in HOLC "desirable" and "still desirable" grade areas (A and B, respectively) were compared to those with centroids in "definitely declining" and "hazardous" grade areas (C and D, respectively)

[b] block groups with centroids in A, B, and C grade areas were compared to those with centroids in D grade areas

C9. Park Improvement Lists

Table C14. List of parks, schools, and cemeteries (located within 400 m of block group boundary) for block groups with low natural aesthetic scores (i.e., lower quartile) and high percent population with low educational attainment (i.e., upper quartile).

Parks	Ankeny Plaza, Bloomington Park, Brentwood Park, Cherry Park, Flavel Park, Francis and Clare Commons, Gilbert Heights Park, Gilbert HydroPark, Glenwood Park, Gov. Tom McCall Waterfront Park, Hand in Hand (DART), Harney Park, Hazeltine Park, Knott Park, Laurelwood Park, Lents Park, Lincoln Park, Lownsdale Square Park, Merrifield Park, Mill Park, North Park Blocks, North Powellhurst Park, Parklane Park, Pioneer Courthouse Square, Simon and Helen Director Park, South Park Blocks, Springwater Corridor, Vera Katz Eastbank Esplanade, Verdell Burdine Rutherford Park, West Powellhurst Park
Schools	Alder Elementary, Alice Ott Middle, Arleta Elementary, BizTech High School of Business and Technology, Buckman Elementary, Creston Elementary, David Douglas High, Fir Ridge Campus, Gilbert Heights Elementary, Helensview High, Kelly Elementary, Lane Middle, Lent Elementary, Lincoln High, Lincoln Park Elementary, Lynch View Elementary, Marysville Elementary, Menlo Park Elementary, Mill Park Elementary, NAYA Early Learners, North Powellhurst School, Portland SD 1J (Wilcox School), Whitman Elementary, Woodmere Elementary
Cemeteries	Columbia Pioneer Cemetery, Kesher Israel Cemetery, Multnomah Park Cemetery, Shaarie Torah Cemetery

Table C15. List of parks, schools, and cemeteries (located within 800 m of block group boundary) for block groups with low parkland tree canopy within 800 m of block group boundary (i.e., lower quartile) and high Hispanic/ Latinx population (i.e., upper quartile).

Parks	Argay Park, Arleta Triangle, Beggars-tick Wildlife Refuge, Cherry Blossom Park, Cherry Park, Chimney Park, Clarendon Regional Early Learning Academy, Columbia Boulevard Community Trail, Columbia Children's Arboretum, Columbia Park, Cully Park, Delta Park, Earl Boyles Park, Essex Park, Farragut Park, Fernhill Park, Flavel Park, Floyd Light Park, Gilbert Heights Park, Glenwood Park, Gov. Tom McCall Waterfront Park, Harney Park, Jamison Square, Kelley Point Park, Kenton Park, Knott Park, Lents Park, Lincoln Park, Luuwit View Park, Lynchwood Park, McCoy Park, McKenna Park, Merrifield Park, Midland Park, Mill Park, Montavilla Park, Mt Scott Park, North Park Blocks, North Powellhurst Park, Northgate Park, Parklane Park, Peace Memorial Park, Peninsula Crossing Trail, Pier Park, Portland International Raceway, Portland SD 1J (Sacajawea Head Start), Powell Butte Nature Park, Raymond Park, Roseway Parkway, Sacajawea Park, SE Firland Parkway, Senn's Dairy Park, Smith and Bybee Wetlands Na, Smith and Bybee Wetlands Natural Area, Springwater Corridor, Stark Street Island, Tanner Springs Park, Trenton Park, University Park, Unnamed 10, Unnamed 13, Unnamed 14, Unnamed 15, Unnamed 25, Unnamed 46, Ventura Park, Vera Katz Eastbank Esplanade, Verdell Burdine Rutherford Park, Wellington Park, Zenger Farm
Schools	Alder Elementary, BizTech High School of Business and Technology, Centennial High, Cesar Chavez Elementary, Cherry Park Elementary, David Douglas High, Fir Ridge Campus, Gilbert Heights Elementary, Hand in Hand (DART), Joseph L. Meek Professional/Technical High, Kelly Elementary, Lincoln Park Elementary, Lynch View Elementary, Marysville Elementary, Menlo Park Elementary, Mill Park Elementary, NAYA Early Learners, North Powellhurst School, Parkrose High, Parkrose Middle, Peninsula Elementary, PPS Student Transportation, Prescott Elementary, Ron Russell Middle, Scott Elementary, Sitton Elementary, Unnamed School Property 3, Ventura Park Elementary, Vestal Elementary, Whitman Elementary, Woodmere Elementary
Cemeteries	Brainard Cemetery, Columbia Pioneer Cemetery, Historic Columbian Cemetery, Kesher Israel Cemetery, Multnomah Park Cemetery, Powell Grove Cemetery, Shaarie Torah Cemetery

Table C16. List of parks, schools, and cemeteries (located within 400 m of block group boundary) for block groups with low Neighborhood Environment Scoring Tool amenity domain scores (i.e., lower quartile) and high racialized minority population (i.e., upper quartile) or low median household income (i.e., lower quartile).

Parks	Berrydale Park, Campbell Fountain, Cherry Blossom Park, Cherry Park, Clatsop Butte Park, Collins Circle, Columbia Children's Arboretum, Essex Park, Flavel Park, Floyd Light Park, Frazer Park, Gilbert HydroPark, Glenhaven Park, Governors Park, Hancock Park, Harney Park, Harrison Park, Humboldt Gardens Pocket Park, Jenne Butte, Joseph Wood Hill Park, Kelly Butte Natural Area, Kelly Butte Reservoir, Laurelwood Park, Lincoln Park, Mallory Meadows Park, Midland Park, Mill Park, Portland State University, Powell Butte Nature Park, Providence Park, Rocky Butte Natural Area, Rocky Butte State Scenic Corridor, Roselawn Park, Rosemont Bluff Natural Area, SE Firland Parkway, Senn's Dairy Park, South Park Blocks, Springwater Corridor, Stark Street Island, Sumner-Albina Park, SW Hall & 14th, Two Plum Park, Unnamed 111, Unnamed 49, Ventura Park, West Powellhurst Park, Wilkes Creek Headwaters Natural Area, Wilkes Park
Schools	BizTech High School of Business and Technology, Bridger Elementary, Cherry Park Elementary, Creative Science School at Clark, Creston Elementary, David Douglas High, Fir Ridge Campus, Helensview High, Jason Lee Elementary, Jefferson High, King School Park, Lincoln High, Lincoln Park Elementary, Marysville Elementary, Mill Park Elementary, NAYA Early Learners, Parkrose High, Portland SD 1J (Wilcox School), PPS Student Transportation, Prescott Elementary, Ron Russell Middle, Unnamed School Property 2, Ventura Park Elementary, Whitman Elementary, Woodlawn Elementary, Woodmere Elementary
Cemeteries	Columbia Pioneer Cemetery, Kesher Israel Cemetery, Multnomah Park Cemetery, Powell Grove Cemetery, Shaarie Torah Cemetery

Table C17. List of parks, schools, and cemeteries (located within 800 m of block group boundary) for block groups with low Neighborhood Environment Scoring Tool usability domain scores (lower quartile) and high percent population without any postsecondary education (upper quartile).

Parks	Ankeny Plaza, Arleta Triangle, Brentwood Park, Cherry Blossom Park, Cherry Park, Clarendon Regional Early Learning Academy, Columbia Boulevard Community Trail, Floyd Light Park, Glendoveer Golf Course, Glenfair Park, Gov. Tom McCall Waterfront Park, Halsey HydroPark, Hancock Park, Hazeltine Park, Joseph Wood Hill Park, Kelly Butte Natural Area, Kelly Butte Reservoir, Kern Park, Laurelwood Park, Lincoln Park, Lownsdale Square Park, Luuwit View Park, Mallory Meadows Park, McCoy Park, Midland Park, Mill Park, Mt Hood Community College Head Start (Thompson Site), Mt Scott Park, North Park Blocks, North Powellhurst Park, Northgate Park, Parklane Park, Peace Memorial Park, Peninsula Crossing Trail, Pioneer Courthouse Square, Portland State University, Rocky Butte Natural Area, Rocky Butte State Scenic Corridor, Roselawn Park, SE Firland Parkway, Senn's Dairy Park, Simon and Helen Director Park, South Park Blocks, SW Hall & 14th, Thompson Park, Unnamed 10, Unnamed 111, Unnamed 14, Unnamed 15, Unnamed 25, Unnamed 46, Ventura Park, Vera Katz Eastbank Esplanade, West Powellhurst Park, Wilkes Creek Headwaters Natural Area, Wilkes Park
Schools	Arleta Elementary, Cherry Park Elementary, David Douglas High, Fir Ridge Campus, Glenfair Elementary, Helensview High, Jason Lee Elementary, King School Park, Lane Middle, Lincoln High, Lincoln Park Elementary, Margaret Scott Elementary, Marysville Elementary, Menlo Park Elementary, Mill Park Elementary, North Powellhurst School, Parkrose High, Parkrose Middle, Prescott Elementary, Ventura Park Elementary, Woodmere Elementary
Cemeteries	Columbia Pioneer Cemetery, Kesher Israel Cemetery, Multnomah Park Cemetery, Powell Grove Cemetery