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Greenspace Across the United States: Exploring Equity and Associations With Physical Activity, Obesity, and Health-Related Quality of Life

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GREENSPACE ACROSS THE UNITED STATES: EXPLORING EQUITY AND ASSOCIATIONS WITH PHYSICAL ACTIVITY, OBESITY, AND HEALTH-RELATED QUALITY OF LIFE

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DEDICATION

For Indiana and Macoy.

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ABSTRACT

Neighborhood greenspace is important for health and well-being but may not be equitably present in neighborhoods across the United States. Also, many adults are physically inactive, have obesity, and report poor health-related quality of life. Greenspace has been tied to these health conditions, but with mixed findings. The purpose of this study was to 1) use an environmental justice perspective to examine variations in 11 measures of greenspace by neighborhood race/ethnicity, income, and rurality in block groups across the contiguous United States and 2) examine 11 greenspace measures in connection to physical activity, obesity, and health-related quality of life in counties across the contiguous United States. Greenspace data from the National Land Cover database and Esri Parks were used to calculate the 11 measures of greenspace indicating the percent of a block group or county covered by five land cover, one tree canopy, and five park greenspace measures.

In United States block groups, global and local spatial autocorrelation was present for all 11 greenspace measures. Positive and significant Moran's I values indicated clustering. Spatial error models showed that the proportion of non-Hispanic White residents and median household income were positively and significantly associated with nine and seven of the 11 greenspace measures, respectively. Small-town rural block groups had more greenspace for nine of the 11 measures but had less local park coverage.

In United States counties, percent total land cover greenspace and percent tree canopy were associated with worse outcomes for all five health measures. Percent forest was associated with worse health-related quality of life, percent herbaceous with worse physical activity, and percent wetlands with worse obesity. Percent total parks, local parks, and national parks had a beneficial association with physical activity, obesity, and health-related quality of life. Local parks had the largest beneficial association with these health indicators.

Greenspace was not equitably present in block groups across the contiguous United States, and only parks were identified has have a beneficial relationship with health and well-being. Local government officials, city planners, and public health practitioners should consider their communities' unique demographic characteristics and greenspace needs to ensure equitable and beneficial neighborhood greenspace.

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LIST OF ABBREVIATIONS

ACS ..... American Community Survey

BMI ..... Body mass index

COVID-19 ..... Coronavirus disease of 2019

FIPS ..... Federal information processing standard

GIS ..... American Community Survey

GWR ..... Geographically weighted regression

MRLC ..... Multi-resolution land cover characteristics

NAIP ..... National Agriculture Imagery Program

NDVI ..... Normalized difference vegetation index

NLCD ..... National Land Cover Database

RUCA ..... Rural-urban communting area

UIC ..... Urban influence codes

USGS ..... United States Gelogical Survey

CHAPTER 1

INTRODUCTION

1.1 STATEMENT OF THE PROBLEM

Regular physical activity is associated with improved physical functioning, executive functioning, and quality of life; reduced depressive symptoms and acute and chronic symptoms of anxiety; and reduced risk for weight gain, obesity, certain cancers, several chronic conditions, and premature death.[1-3] The majority of Americans, however, do not meet physical activity recommendations.[4] Further, disparities in physical activity exist; racial/ethnic minority adults, lower-income adults, and adults living in rural areas are at greater risk for physical inactivity.[5-10]

Obesity has become a public health crisis, with four in ten adults having obesity.[3,11] Obesity increases the risk for many chronic diseases, include type 2 diabetes, hypertension, heart disease, stroke, and certain cancers.[5,12-17] It also increases the risk of severity for infectious disease, such as influenza and COVID-19.[18,19] In conjunction with physical inactivity, a rising obesity prevalence increases risk for poor population health.

Health-related quality of life – a measure of general, physical, and mental health – is also of concern for adults in the United States. About 10% of Americans report they are of fair or poor health; for adults aged 65 years and older, the number increases to 22%.[20] Compared to adults living in urban areas, rural adults, especially rural racial/ethnic minority persons, are more likely to report their health as fair or poor and

have obesity.[17,21,22] Also, nearly 19% of adults in the United States had a mental illness in the last year, and depression and anxiety are two of the most common mental health disorders.[23] Anxiety and depression have been associated with suicide,[24-26] which has increased steadily over recent decades and is a leading cause of death in the United States.[27]

The environment has been consistently linked with health, and one key component of the environment is greenspace.[28] Among adults, greater amounts of urban greenspace have been associated with improved physical activity participation.[29-34] Increased exposure to greenspace has also been associated with several positive physical health outcomes (e.g., better subjective general heath, reduced obesity risk) and mental health outcomes (e.g., lesser likelihood for depressive symptoms, improved self-esteem).[34-38] However, greenspace is often not equitably present and varies by neighborhood race/ethnicity, income, and rurality; low-income, minority, and rural adults are less likely to have access to greenspace.[39-46] These populations experience environmental injustice when their neighborhoods fail to contain health-promoting features such as greenspace.[47,48]

In addition to the health outcomes that were the focus of this study, greenspace plays a considerable role in environmental health.[28] As global climate changes, greenspace – particularly in urban areas – is important for absorption of pollutants, carbon dioxide storage and sequestration, and reducing air and surface temperature.[49,50] Further, as greenspace is associated with physical activity, greener areas may promote active transportation and thus reduce carbon emissions from vehicles.[49,51] Greening of cities can help alleviate the physical and mental stress caused by the urban heat island

effect by cooling urban spaces and mitigating stressors.[52] The amount of green space may prove even more essential as climate change accelerates and as urban areas continue to increase in population.[53,54]

Greenspace is a key component of health-promoting environments and has been linked to positive health behaviors and positive health outcomes.[55-57] Although considerable research has identified these beneficial relationships, several studies have produced mixed findings concerning greenspace and health.[58-61] Moreover, key gaps exist in this critical area of study. Many studies have examined greenspace only in urban areas, in a single city or county, or outside the United States, warranting research on overlooked (e.g., rural and suburban) and larger (e.g., region and national) areas.[62-64] A national study could aid in identifying both small- and large-scale areas most in need of additional examination, areas that require infrastructure assessment and planning, and areas that could benefit from funding, intervention, and policy efforts.[65]

1.2 SPECIFIC AIMS AND HYPOTHESES

To conduct a comprehensive analysis of greenspace, this study utilized several types of greenspace – land cover, tree canopy, and parks – to examine greenspace across the United States. Findings from this project contributed to the environmental justice literature by shedding light on disparities in access to health-promoting features of the environment, specifically greenspace. Moreover, this work added to the fields of health promotion, epidemiology, and environmental health sciences by incorporating the use of spatial analytic techniques to examine greenspace equity, assessing relationships between greenspace and health, and identifying populations or locations most in need of public health efforts.

Completion of the aims in this proposed dissertation research resulted in 1) descriptions of the spatial patterns of greenspace across the United States, 2) identifying the relationship between greenspace and race/ethnicity, income, and rurality and, 3) a identifying the relationship between greenspace, physical activity, obesity, and health-related quality of life for adults. Specifically, this study set out to:

Aim 1a: Explore global and local clustering of greenspace by census block groups across the United States.

Hypothesis 1a: Statistically significant global clustering will be identified within the United States and local spatial clusters will be identified and mapped.

Aim 1b: Analyze the prevalence of multiple types of greenspace by census block group race/ethnicity, income, and rurality across the United States.

Hypothesis 1b. Greenspace will be less prevalent in lower income, higher racial/ethnic minority, and rural block groups.

Aim 2a: Examine the relationship between greenspace and physical activity, obesity, and health-related quality of life by county across the United States.

Hypothesis 2a. Counties with more greenspace will have greater physical activity, lower obesity, and better health-related quality of life.

Aim 2b: Assess if type of greenspace differs in strength of relationship with physical activity, obesity, and health-related quality of life by county across the United States.

Hypothesis 2b. Type of greenspace will differ in strength of relationship with physical activity, obesity, and health- related quality.

Several steps were taken to complete these study aims, which are detailed in chapters two through six of this dissertation. Specifically, chapter two addresses the importance of physical activity, obesity, health-related quality of life, noting disparities in each of these importance health indicators. This chapter introduces greenspace and its relevance and benefit to public health. Also, chapter two highlights the significance and innovation of this dissertation work on greenspace equity and greenspace and health. Chapter three details the methodology used to examine greenspace equity and the relationship between health and greenspace. Chapter four presents the first of two manuscripts, which is focused on equitable presence of greenspace in block groups across the contiguous United States. Chapter five presents the second manuscript, which is focused on the relationship between physical activity, obesity, and health-related quality of life and greenspace in counties across the contiguous United States. Chapter six provides a summary of findings from this dissertation work and discusses these findings in connection to public health research and practice.

CHAPTER 2

BACKGROUND AND SIGNIFICANCE

2.1 BACKGROUND

Physical Activity in the United States

As efforts to improve public health through chronic disease prevention have grown, emphasis has been placed on studying the health impacts of physical activity; numerous benefits have been identified. Being physically active reduces the risk for high blood pressure, high cholesterol, type 2 diabetes, heart disease, stroke, some cancers, and premature death.[1-3,66-70] Physical activity is associated with weight management and reduced risk for overweight and obesity.[1,3,71] It also strengthens muscle and bones and protects against disability among older adults.[72-74] Adults who are physically active are more likely to sleep better[75] and to have more energy throughout the day.[76]

Also, physical activity is linked to brain health,[1] as it has been shown to increase brain growth factors and plasticity, contribute to learning and memory, protect from neurodegeneration, and improve cognition and brain function across the lifespan.[77-79] Physical activity has been linked with reduced risk for depressive symptoms, anxiety, and mood disturbance, while also serving as a buffer for stressful life events.[1,80,81]

In addition to a host of health risks, inadequate physical activity has been linked to 11.1% of health care expenditures in the United States,[82] or $117 billion dollars annually in health care costs.[4] Further, physical inactivity contributes to significant lost economic productivity.[83,84]

The Physical Activity Guidelines for Americans (Second Edition) recommend that adults get at least 150 minutes of moderate-to-vigorous or 75 minutes of vigorous aerobic activity every week, as well as at least two bouts of muscle strengthening activity each week.[4] However, most adults do not meet these recommendations. Relying on self-report data, it is estimated that 54.1% of adults meet aerobic guidelines, 27.7% meet muscle-strengthening guidelines, and 24.3% of adults meet both aerobic and muscle-strengthening guidelines.[85] However, accelerometer data suggest only 5% of adults get at least 30 minutes of physical activity per day,[86] indicating actual physical activity engagement may be much lower than estimated.

Disparities in physical activity are evident across race/ethnicity, income, and rurality. Regarding race/ethnicity, compared to White and Asian adults, Black adults are less likely to meet aerobic activity recommendations through leisure-time physical activity;[5] compared to White adults, Asian and Black adults are less likely to meet muscle strengthening activity recommendations.[5] Further, compared to Black and Hispanic adults, White adults are more likely to meet both aerobic and muscle strengthening recommendations.[5] Similarly, among middle-aged and older adults, White adults are more likely to be physically active compared to racial/ethnic minority adults.[6] Regardless of socioeconomic status (e.g., education, income, occupation, employment, and marital status), Black and Hispanic adults are less likely to engage in leisure-time physical activity compared to White adults.[7]

Regarding income, adults with incomes below the poverty line are less likely to meet aerobic activity recommendations; adults with higher incomes are more likely to meet muscle-strengthening recommendations.[5] Adults with incomes at least $50,000 have

a greater likelihood of meeting vigorous activity recommendations compared to those who earn less.[15] Compared to adults earning less than $20,000, those earning at least $75,000 are nearly twice as likely to meet physical activity recommendations.[8]

Regarding rurality, physical activity participation is higher among adults living in urban areas compared to adults living in rural areas, and the likelihood for engaging in no leisure-time physical activity is higher for adults in rural areas compared to urban areas.[9,10] Similarly, evidence indicates that adults living outside of a metropolitan area are less likely to meet aerobic, muscle strengthening, or both aerobic and muscle strengthening physical activity recommendations compared to adults living in a small or large metropolitan area.[5] Other research suggests there may not be differences in physical activity participation among urban and rural adults; however, urban adults may be more likely to participate in leisure-time physical activity.[87] Also, physical activity disparities exist by region, as adults living in the West are most likely to meet physical activity recommendations, whereas adults living in the South are least likely.[5] Moreover, the urban-rural disparity in meeting physical activity recommendations is most pronounced in the South.[9]

Obesity in the United Sates

In 2013-2016, 71.1% of adults had overweight or obesity;[20] in 2015-2016, 39.8% of adults had obesity.[11] This is a major threat to public health, as obesity is associated with many adverse health outcomes. Obesity increases the risk for type 2 diabetes, hypertension, sleep apnea, heart disease, stroke, certain cancers, and premature death.[12,20,88-90] Moreover, it is also associated with poor mental health, particularly depression,[91,92] as well as quality of life.[93] Adults with obesity are also at risk for obesity

bias and stigmatization, including workplace discrimination and health care discrimination[94-98] Further, there are economic consequences to obesity. Health care costs related to obesity increased nearly 50%, from $212.4 billion to $315.8 billion.[99,100] Researchers estimated that if all United States adults experienced a one-unit increase in body mass index (BMI), healthcare spending would increase $6 billion; however, if all current adults with obesity were to have a healthy BMI, healthcare spending would decrease $166 billion.[101] In addition, indirect costs like lost productivity, such as from absenteeism (i.e., time away from work) and presenteeism (i.e., reduced productivity while at work) contribute to considerable economic loss in the United States,[102] as it was estimated that between $3 and $6 billion is lost each year to indirect costs.[103]

The relationship between obesity and income is mixed. In general, from 2011 to 2014, obesity was most prevalent among lower-income adults compared to medium- and higher-income adults.[104] Obesity was least prevalent among higher-income women compared to medium- and lower-income women; obesity was most prevalent among middle-income men compared to low-income and high-income men.[104] However, increases in obesity prevalence over recent decades vary by income, sometimes with greater obesity increases in adults with higher income levels.[105] Obesity prevalence also varies by race/ethnicity. Non-Hispanic Asian adults have the lowest obesity prevalence (12.7%) compared to White (37.9%), Hispanic (47%), and non-Hispanic Black (46.8%) adults.[11] Among women, non-Hispanic Black women have the highest obesity prevalence (54.8%) and non-Hispanic Asian women have the lowest obesity prevalence (14.8%); among men, Hispanic men have the highest obesity prevalence (43.1%) and non-Hispanic Asian men have the lowest obesity prevalence (10.1%). Lastly, obesity is higher

among rural adults compared to urban adults,[10,22] regardless of race/ethnicity.[17] Rural women are significantly more likely to have obesity compared to urban or suburban women.[106] Obesity is also most prevalent in the South and Midwest regions of the United States.[107]

Health-related quality of life in the United States

In 2000, the Centers for Disease Control and Prevention defined health-related quality of life as "An individual's or group's perceived physical and mental health over time" (p.8).[108] Major national surveys, like the Behavioral Risk Factor Surveillance System, ask several core questions that are utilized to assess health-related quality of life.[109] Taking into account health-related quality of life is important for public health, as it gives a basic and relatively accurate assessment of population health and well-being, particularly with consideration for chronic disease burden, disability burden, and mortality risk.[110-113] Further, use of the health-related quality of life measure, which has demonstrated reliability and validity, can contribute to identifying disparities, distributing resources, and informing public policy, as this measure is easily understandable by the public, public officials, and researchers.[110,112,114,115]

In the United States, about one in ten adults and one in five older adults aged 65-years and older report poor or fair health.[20] Further, between the early 1990s and 2010 quality of life declined.[116,117] Adults with multiple chronic conditions are more likely to report fair or poor health compared to adults with no chronic conditions.[118] Further, adults who are physically active are more likely to report better health-related quality of life, [119,120] and adults who have had obesity for many years, but who are physically active, are more likely to report better health-related quality of life .[121]

Income inequality has been linked with self-rated health.[122,123] Adults living in states with higher income inequality compared to states with less income inequality are more likely to report poor or fair health.[124] Regarding race/ethnicity, compared to non-Hispanic White adults, non-Hispanic Black, non-Hispanic American Indian and Alaskan Native, and Hispanic adults are more likely to report poor or fair general health.[125,126] Among adults with chronic conditions (e.g., type 2 diabetes, coronary artery disease), Black adults are more likely than White adults to rate their health as poor or fair.[127] Regarding rurality, rural adults are significantly more likely than urban adults to have poor health and chronic health conditions.[128] Adults in rural areas are more likely to report poor self-rated health compared to adults living in urban areas.[129,130] Further, in rural areas, racial/ethnic minority persons are more likely to report poor or fair health compared to Whites.[21]

Mental health disorders are one of the leading causes of disability in the United States,[131] with evidence indicating mental health disorders contribute to the number of disability adjusted life years experienced by Americans.[132] As of 2014, approximately one in five adults experienced any mental illness and one in twenty experienced a severe mental illness in the last year.[133] Depression and anxiety are two of the most common mental health disorders.[23,133] In 2017, 7.1% of adults suffered a major depressive episode, with highest rates among young adults, women, and those reporting two or more race/ethnicities.[134] Approximately one in five adults experienced an anxiety disorder in the last year,[135] and, over a lifetime, nearly one in three adults will experience an anxiety disorder.[136] Depression and anxiety are risk factors for suicide, which is now one of the top ten leading causes of death in the United States. [24-27] Adults with mental health

impairments, compared to physical health or no health impairments, are more likely to report experiencing pain and physical distress and are also more likely to smoke and drink alcohol.[137] Further, recent research suggests that as the climate crisis worsens, stress and mental health is at risk, particularly for the most vulnerable populations.[138-141]

There are significant economic consequences of mental health disorders in the United States. As of 2010, the economic burden of major depressive disorder alone cost $210 billion, an increase of 21.5% from 2000.[142] This estimate accounted for medical costs, comorbidity costs, suicide-related mortality costs, and indirect workplace costs; mental health disorders are one of the most common causes for hospitalization in the United States.[143] A 2008 study estimated that mental health disorders resulted in approximately $193 billion in lost earnings alone every year,[144] with a total cost – including health care expenditures, loss of earnings, and disability benefits – estimated at $318 billion every year.[145]

Regarding income, disparities in mental health disorders, particularly for depression, have been observed by socioeconomic status; adults of lower income and socioeconomic status have greater risk of experiencing depressive symptoms.[146,147] With respect to race/ethnicity, non-Hispanic White adults have greater risk for mental health disorders compared to non-Hispanic Black and Hispanic adults.[148] For example, compared to non-Hispanic White, non-Hispanic Black persons have a lower lifetime risk for several mental health disorders, particularly mood, anxiety, and substance use disorders.[147,149] However, despite lower lifetime risk among Hispanic and non-Hispanic Black persons, compared to non-Hispanic White persons, these groups are more likely to have persistent mental health disorders.[149] Regarding urban-rural differences, findings are

somewhat mixed. A metanalysis of research on psychiatric disorders found that mood disorders, anxiety disorders, and any mental disorder are more prevalent in urban areas than in rural areas.[150] However, research has also found that depression prevalence is higher among rural adults compared to urban adults[151] Suicide rates among adults living in less urban areas are higher than adults living in more urban areas,[152] and men living in rural areas are at particular risk for suicide.[153]

The environment and human health

Unhealthy lifestyles and increasing rates of chronic diseases have sparked public health research and interventions, many of which have been aimed at altering behavior, such as increasing physical activity and encouraging a healthful diet.[154] However, individual-level interventions based on theoretical models and frameworks such as the theory of planned behavior or the theory of reasoned action have often proved unsuccessful or unsustainable.[154-157] While such models and frameworks may hold true in an isolated or controlled environment, a major fault in these models is that they fail to consider outside influences on individual behavior. People are not solely influenced by their own knowledge, attitudes, and skills, nor are they free to act with total autonomy, as they are constrained by systems in which they live.

Recognizing that people are nested within environments – physical, social, cultural, political – and that these environments change across the life course, researchers have utilized ecological approaches to health.[158] Bronfenbrenner proposed an ecological model that incorporated microsystems, mesosystems, exosystems, and macrosystems.[159,160] These systems account for the wide range of influences on human health and development. Building from Bronfenbrenner's pioneering work, McLeroy's

1988 ecological model posits five levels that should be considered in health promotion interventions: intrapersonal, interpersonal, institutional, community, and public policy (Figure 2.1).[161] These ecological models emphasize that individual and population health outcomes are a product of several levels of influence; accordingly, targeting levels outside of or in addition to the individual may prove most promising for maximizing public health efforts. Recognizing the need for better understanding of influences on health behaviors and outcomes, research has utilized an ecological approach to study greenspace and the built environment.[56,162-167]

Greenspace and theoretical frameworks

As a key aspect of the built and natural environment, greenspace has warranted considerable attention in recent decades because of its potential to positively influence human and environmental health.[28,168] Greenspace been defined and measured in several ways. For example, parks, opens spaces, and tree cover are considered greenspace and have been assessed for connections with various health outcomes.[36,55,57,58,169,170] Efforts to study and utilize greenspace to promote public health have gained traction; aspects of the environment, like greenspace, influence human health through multiple mechanisms and across several levels proposed in ecological models.

This study is informed by several ecological models and frameworks, both general and specific to greenspace. Ecological models by Bronfenbrenner[159,160] and McLeroy et al[161] emphasize that people (and their health behaviors and health outcomes) are nested within several different environmental and societal layers. Since Bronfenbrenner's and McLeroy's work in the 1970s and 1980s, adaptions to and developments of ecological models have been proposed. Schulz and Northridge address

fundamental (macrosystem level), intermediate (mesosystem/community level), proximate (micro/interpersonal level), and health and well-being (individual or population levels) in their model 'social determinants of health and environmental health promotion' (Figure 2.2).[171] In describing the model, the researchers emphasize health disparities and the environment: "In keeping with our emphasis here on social determinants of environmental health disparities, the model has been modified to specifically examine relationships between social inequalities, the built environment and social context, and environmental health disparities, drawing on Northridge and Sclar" (p. 457).[171] Accordingly, this model is influential to the current dissertation study, as it highlights the role of the natural and built environments, environmental and neighborhood stressors, social factors and inequalities, health behaviors, and health outcomes and well-being.

In addition to health disparities, ecological models have been adapted to accommodate specific behaviors or health outcomes under study. For example, a framework that is highly influential to this dissertation study is the socio-ecological framework for the relationship between greenspace and health created by Lachowycz and Jones (Figure 2.3).[172] This framework proposes mechanisms through which green space is related to and influences physical and mental health outcomes. It also addresses several levels of the social ecological model, such as individual-level behaviors like physical activity and environmental factors like rurality and safety. This framework provides rationale as to the value of greenspace and why it may be impactful on health.

Utilizing ecological models proposed by Bronfenbrenner, McLeroy et al., Schultz and Northridge, and Lachowycz and Jones, this proposed dissertation research aims to

examine greenspace disparities across the United States and to understand how greenspace (i.e., an environmental-level factor) influences health (i.e., individual/population level factors), specifically physical activity, obesity, and health-related quality of life.

Defining and measuring greenspace

Greenspace has been defined in a multitude of ways. Typically, greenspace refers to vegetation that is associated with nature and the built environment.[173] Definitions have ranged depending on focus and discipline. Greenspace has been defined as parks and vegetative cover, including open space, grass, shrub, and forest,[43] as well as urban green, agricultural green, forests, and nature conservation area.[174] Green infrastructure has been defined as "an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations" (p.5).[175]

With review and consideration of greenspace research that has been conducted in the last few decades, Taylor & Hochuli discuss the evolution of 'green space' to greenspace, where the latter is used to reflect the modern use greenspace in research and practice.[173] The authors also provided two broader interpretations of greenspace.[173] The first describes greenspace as "bodies of water or areas of vegetation in a landscape, such as forests and wilderness areas, street trees and parks, gardens and backyards, geological formations, farmland, coastal areas and food crops" (p. 29). And as considerable research has examined urban greenspace, the authors' second interpretation of greenspace "represents urban vegetation, including parks, gardens, yards, urban forests and urban farms − usually relating to a vegetated variant of open space" (p. 29). These two definitions include greenspace elements found in nature and the built environment and

encompass most aspects of greenspace that adults typically encounter. Undoubtedly, though, greenspace definitions vary by the field of study (e.g., epidemiology, psychology) and a multitude of methods have been used to measure and describe greenspace.[176]

As greenspace research of nature and the built environment has grown in recent decades, various methodologies have been utilized to assess greenspace.[57,177] Remote sensing methods and the use of geographic information systems (GIS) are popular methods for measuring greenspace.[177-181] The following paragraphs introduce four of the most commonly used greenspace measures.

Greenspace measures: Land cover

In a report by the Environmental Protection Agency, land cover is described as "the actual or physical presence of vegetation (or other materials where vegetation is nonexistent) on the land surface. Land cover is also often described as what can be seen on land viewed from above."[182] Land cover differs from land use, in that land cover indicates how much of an area is covered by vegetation, water, or impervious surfaces; land use indicates how people use an area, such as for development.[183]

In the United States, the National Land Cover Database (NLCD) is produced by the Multi-Resolution Land Cover Characteristics (MRLC) Consortium, which was formed by the U.S. Geological Survey (USGS) and is a collaboration of federal offices.[184-186] The MRLC works to create several national databases, including land cover, tree canopy, and impervious surface. Land cover provides national spatial and descriptive Landsat-based data at 30-meter resolution with an eight-category legend.[187] These eight categories are water, developed land, barren land, forest land, shrubland,

herbaceous land, plant/cultivated land, and wetlands. NLCD is a reliable tool for assessing vegetation in the United States. The NLCD has been examined for accuracy,[188,189] and for NLCD datasets created from 1996 to 2012, NLCD was found to accurately represent land cover, with NLCD and study reference data indicating a 71% to 97% agreement rate.[186]

Land cover has been used in several greenspace studies. For example, land cover was used to examine the association between greenspace and general health and mental health[165] and mortality[190] in the Netherlands. Further, land cover was used to determine greenspace and examine well-being in Germany[191] and physical activity in the United Kingdom.[192,193] In Washington state, NLCD was used to determine percent of surrounding greenspace and examine the association with general and mental health.[60] IN the United States, NLCD was used to examine greenspace and mental health[194] and physical activity and BMI.[195] A national study used NLCD to identify five types of greenspace and tie greenspaces to healthcare spending.[196] Other United States national studies examined prevalence of greenspaces across the country[43] as well as obesity and physical activity.[197]

Greenspace measures: Tree canopy

Tree canopy refers to the "layer of tree leaves, branches, and stems that provide coverage of the ground when viewed from above."[198] The NLCD Tree Canopy, a 30-meter raster geospatial dataset, is created by the MRLC and the United States Forest Service and contains percent tree canopy estimates for the conterminous United States.[199] Data for tree canopy comes from Landsat imagery as well as additional ground and ancillary information. Values in the tree canopy dataset range from 0% to 100% and each

value indicates the proportion of the 30-meter cell that is covered by tree canopy.[200] Early assessments of tree canopy data reported accuracy ranging between 78% and 93%.[201] The recent accuracy assessment of the NLCD also included tree canopy in its evaluation, indicating high accuracy with improvement to NLCD measurement methodology.[186]

Another method for determining tree cover uses the National Agriculture Imagery Program (NAIP) provided by the U.S. Department of Agriculture (USDA), which gathers aerial imagery of the United States during the agricultural growing season.[202,203] NAIP imagery is gathered at a one-meter ground sample distance that then corresponds to photo-identifiable ground control points, which are used for image inspection. The imagery contains four spectral bands, including red, green, blue, and near infrared. NAIP imagery can be used to determine both the normalized difference vegetation index (NDVI) as well as tree canopy cover. In addition, other methods like Google Earth (www.google.com/earth) and Google Street View (google.com/streetview) have also been used to examine greenspace, including tree cover.[204-206]

Several studies have utilized tree canopy or tree cover to examine greenspace prevalence or the connection between greenspace and health. For example, the relationship between tree canopy and mental health was analyzed in Wisconsin.[62] A study of 496 major cities in the United States used NDVI and tree canopy to examine the relationship between greenspace and obesity and mental health.[207] A national study of tree cover and adults living in nursing homes assessed greenspace and depression.[208] Environmental justice studies have also used tree canopy/cover to evaluate greenspace prevalence.[209-213]

Greenspace measures: Parks

Parks are a commonly researched form of greenspace and have been examined for correlations with health outcomes and with an environmental justice lens. Parks can be defined as a national park or forest, state park or forest, county park, regional park, or local park; gardens have also been considered parks.[214] Some studies utilize GIS to examine park size, acreage, and location, whereas others consider park features, such as playgrounds, trails, and safety; many studies have incorporated both, and these park characteristics are often connected to health outcomes.[32,215-217] Moreover, parks are often examined by type, location, and quantity. For example, there have been studies and reviews focused on urban parks and rural parks; single or multiple parks; and parks in a city, county, state, region, or across the United States [43,181,218,219] Further, parks are often studied by category, as local, state, and national parks have been examined.[220-223] Lastly, perceptions of parks are often examined and used as the predictor of a health outcome.[224] There has been substantial research on parks, but methodologies vary considerably between studies, undoubtedly as the goal of each varies too.

National, state, and local entities compile GIS park data. For example, the National Park Service[225] and USGS[226] provide GIS data on parks (e.g. park boundaries, park types). Purdue University hosts an online Data Guide listing GIS files for all 50 states and Washington DC, many of which include park and recreation data.[227] Esri supplies a national parks file named USA Parks that contains data from large national parks to small local parks for the United States.[214]

Considerable research has been conducted on parks, health, and environmental justice; many of these studies have utilized geospatial methodologies. Parks have been

linked to physical activity,[218,228,229] for example, in Los Angeles,[230] Tampa and Chicago,[231] and Kansas City.[32] Parks have been studied with a focus on chronic disease,[232] obesity,[233] and mental health.[234] International research has also examined the relationship between parks and stress in Taiwan,[235] physical activity in Canada,[236] and obesity in the United States and Australia.[237] Also, parks have been a popular focus of environmental justice research.[42,43,46,181,221,238-241]

Greenspace measures: Normalized difference vegetation index

NDVI is a technique used to measure the amount of greenspace using remote sensing.[242] Greenspace – plants, trees, etc. – reflect certain wavelengths of infrared light; as density or size of greenspace increases, so does the amount of light reflected back into space. NDVI methodology measures this reflected light to determine the amount of greenspace in an area. When more near-infrared light is detected compared to visible light detected, this indicates an area under study may be very green; in contrast, if near-infrared light and visible light are similar in amount, this indicates the area may have little or no greenery. Specifically, NDVI is calculated by dividing near-infrared radiation minus visible radiation by near-infrared radiation plus visible radiation.[242] NDVI values range between -1 and 1, where values near -1 indicate water (e.g., lakes, snow), values near 0 indicate no greenery (rocks, barren land), values near .2-.3 indicate moderate greenery (e.g., shrubs, meadows), and values near .6 to .9 indicate the greatest density of greenery (e.g., forests).[242,243]

NDVI is a valuable tool for measuring greenspace: it is free and publicly available from several different government sources, including the USDA,[202] National Oceanic and Atmospheric Administration,[244] National Aeronautics and Space Administration,[245] and

USGS.[246] These data can be utilized to create both small- and large-scale measures of greenspace (e.g., neighborhood, county, country), to identify varying types of greenspace (e.g., forests, grasslands), and to compare findings between studies relatively easily. Further, NDVI has been shown to be accurate in determining area greenness, as Rhew at el. wrote: "Because of the high correlation with experts' ratings of greenness, it appears that NDVI accurately reflects the amount of neighborhood greenness that can be observed directly by humans from the ground." (p.5)[247] These aspects of NDVI make it a valuable method for measuring greenspace, particularly when used a summary or total measure of greenspace in an area.

Many studies have utilized NDVI to examine greenspace prevalence or the connection between greenspace and health. For example, NDVI has been used to examine residential surrounding greenness and general health in Spain,[37] cycling in Hong Kong,[248] overweight and physical activity in the Netherlands,[249] physical functioning in the United Kingdom,[250] mortality in Canada,[251] and weight status in Australia.[252] In the United States, NDVI has been used to determine surrounding greenness as well to examine the association with adolescent and adult mental health.[253] Further, a study of 496 major United States cities examined NDVI and several health outcomes, including general mental health and obesity.[207] Environmental justice studies have used NDVI to identify how greenspace is associated with demographic characteristics of study participants or a geographic area.[40,207,254] For example, a study of 10 urban United States cities used NDVI to classify areas as mixed or woody vegetation and examined the correlation with education, income, race/ethnicity, and other demographic variables.[41]

Greenspace measures: Subjective

Objective measures of greenspace are essential to understanding greenspace availability and its connection with health. However, perceptions of greenspace within one's environment are also important for gathering a more complete understanding of the role of greenspace in human health. Therefore, many studies have utilized subjective methodology to examine the connection between greenspace and several different health outcomes. For example, a study in the United Kingdom found that perceived greenspace quality was more important than objectively measured greenspace quality in predicting park use.[193] A study in England found that greenspace was often more accessible in deprived areas, however residents in those areas had more negative perceptions of accessibility and had a lower likelihood of using greenspace.[255] A study of adults in the Netherlands found that residents who had positive perceptions of their environment, which included an aspect of greenspace, were more likely to be physically active.[256]

Greenspace and health: Physical activity

Several reviews have been conducted on the relationship between greenspace and physical activity. In a review of greenspace and health outcomes, although the authors identified some studies that showed a null or negative association between greenspace and physical activity, several showed a positive relationship; they concluded that greenspace likely promotes physical activity.[55] A review of five smart growth principles, mixed land use and levels of open space (in addition to other non-greenspace related variables) were positively associated with physical activity.[257] Another review of the greenspace literature identified 50 studies related to greenspace and physical activity; 20 showed a positive relationship, whereas 15 showed a null relationship, 13 showed a

mixed relationship, and only two showed a negative relationship.[58] Further, a review of 68 studies conducted in several countries on urban greenspace interventions found that, overall, greenspace was positively associated with physical activity.[34]

These relationships are borne out in diverse individual studies. Florida greenspaces (e.g., parks, forests, conservation areas) at the county level were associated with moderate-to-vigorous physical activity.[258] For park users in the City of Los Angeles, distance to parks predicted park use and physical activity within parks; further, park users reported engaging in physical activity most often in parks.[230] In a national study of non-metropolitan counties in the United States, natural amenities (e.g., forest vegetation) were correlated with physical activity.[259] Also, in a national study of 135 counties within metropolitan areas across the United States, researchers found that vegetative cover, specifically forest, shrubland, and herbaceous vegetation, was related to physical activity.[195]

Such findings have been documented worldwide. Distance to and quality of urban greenspace has been linked with greater physical activity in adults living in Turkey.[33] In England, urban adults living near greenspace, specifically parks, had an increased likelihood for meeting physical activity recommendations.[260] Among a large sample of United Kingdom adults, visiting the countryside and urban greenspaces was correlated with physical activity of greater intensity compared to visits to coastal areas; however, visits to coastal areas resulted in greater energy expenditure because of more time spent in these areas.[261] Another United Kingdom study of adults found that greater perceived neighborhood greenness, compared to objectively measured greenness, better predicted the number of visits to greenspaces.[193] Also, in this study, the likelihood of meeting

physical activity recommendations was significantly greater for those visiting greenspaces compared to those who did not. For older adults residing in the United Kingdom, greater neighborhood greenness was associated with greater overall physical activity as adults aged.[192] A study of United Kingdom older adults also produced similar findings: greater neighborhood greenness was linked to a slower decline in walking speed over a 10-year period.[250]

A study in Canada found that greater park area within 1 km of participants' homes was associated with greater amounts of moderate-to-strenuous physical activity and greater likelihood of meeting physical activity recommendations (i.e., 150 minutes).[29] In a New Zealand study, less access to greenspace was linked to walking 30 minutes or less weekly.[59] Another New Zealand study found that physical activity was positively correlated with living in a greener neighborhood, as adults living in the greenest areas were more likely to meet physical activity recommendations compared to adults living in the least green areas.[262] A Danish study found that adults living near greenspace were more likely to be physically active in greenspaces, and adults living within 300 m of greenspace were more likely to engage in moderate-to-vigorous physical activity during leisure time compared to those living 300 m to 1 km away.[30]

Some findings on the relationship between greenspace and physical activity are mixed. A review of parks and physical activity in the United States identified 20 studies; five studies reported a positive association with physical activity, six studies had mixed findings, and nine studies found no association.[228] An Australian study found that greenspace and physical activity were linked with better health outcomes; however, greenspace and physical activity were not significantly related to one another.[263] Another

Australian study identified a relationship between distant greenspace and moderate-to-vigorous physical activity, but not between distant greenspace and adequate physical activity; further, no relationship was observed between local greenspace and moderate-to-vigorous physical activity or adequate physical activity.[264]

In a study of older adults in Finland, participants with a higher amount of biodiversity in large natural areas, compared to those with lower biodiversity, were more likely to be physically active; however, this finding did not hold for older adults in the study with walking difficulties.[265] A Dutch study found no significant relationship between greenspace and meeting physical activity recommendations (30 minutes of physical activity five times per week), and adults with more greenspace had less leisure time walking and cycling.[266] Another Dutch study found that outdoor physical activity was correlated with greenspace, but varied in relationship significance by type of greenspace measured.[249] For example, in this study, distance to the closest park was not significantly associated with either overweight or physical activity; however, overall surrounding greenness was associated with reduced risk for being overweight and increased physical activity. For women from many different neighborhoods in Ottawa, Canada, greenspace, specifically park area, was positively linked to greater leisure time physical activity; this relationship was not observed among men.[267]

A study in Scotland found no relationship between neighborhood greenspace and overall physical activity or physical activity within greenspaces among urban adults.[268] For adults residing in a city in the Netherlands, greenspace was not related to physical activity; however, more urban greenspace was linked to bicycling and sports and more rural greenspace was linked to gardening.[269]

Greenspace and health: Obesity

In comparison to physical activity, there is considerably less research on the relationship between greenspace and obesity. Moreover, findings on the relationship between greenspace and obesity are mixed.[55,58] Some studies have revealed a positive relationship between greenspace and obesity. In a national study of greenspace in the United States, forest land was associated with reduced BMI.[220] Another national study found that varying types of greenspace (e.g., connections between forests and developed areas, shrubland) were significantly correlated with having a healthy BMI.[195] A study of 67 metropolitan areas in the United States found a significant association between park density and weight status; areas with the greatest density of parks compared to the lowest density had reduced risk for overweight and obesity.[233] United States women living in areas with the greatest amounts of greenspace compared to the least amount of greenspace were less likely to have obesity.[197] Among United States and Australian women, a higher number of parks close to home was linked to lower BMI.[237]

Greater neighborhood greenness and greater variation in neighborhood greenness was associated with lower risk for overweight/obesity and obesity for adults in a large Australian city.[252] A New Zealand study found that in neighborhoods with lower greenspace access, residents were more likely to have overweight or obesity.[59] Further, a study of New Zealand women found that greater access to greenspace was associated with a lower likelihood for obesity.[270] A Dutch study found that for residents living in areas with high surrounding greenness, their risk for overweight was lower compared to those living in areas with low surrounding greenness.[249] A Danish study found that residents living closer to greenspace (300 m vs 1 km) had a lower risk for obesity.[30]

Living near greenspace, specifically a park, was associated with lower likelihood for overweight and obesity for adults in England.[260]

In a review conducted by Lachowycz and Jones , the authors identified 13 studies from the United States, Canada, and Europe related to greenspace and weight status; three of those studies reported a negative association with BMI and six studies reported mixed or weak associations.[58] In a study in Ohio, the relationship between various types of greenspace (e.g., parks, cemeteries) and health varied by age and gender. For example, parks were negatively associated with BMI among older women, but parks and conservation land was positively associated with BMI among younger women; tree canopy was associated with increased BMI among younger men.[271] In a Canadian study, greenspace was found to be significantly related to higher risk for overweight and obesity in men but lower risk for women.[272] In a study of New Zealanders, greenspace availability was not significantly correlated with overweight.[262]

Some studies have identified a negative association between greenspace and obesity. A study in England found that from 2000 to 2003, residents with the greenest areas were more likely to have overweight or obesity; in contrast, from 2004-2007, residents in the greenest areas were less likely to have overweight or obesity, but these findings were nonsignificant.[273] A study in Canada found that more park area was linked to greater risk for overweight and obesity in women.[267]

Greenspace and health: Health-related quality of life

Greenspace research has identified several positive physiological health benefits. A review of greenspace literature focused on greenspace quantity and quality found a strong link between greenspace and all-cause mortality, as well as a moderate link with

perceived general health.[274] A meta-analysis of 140 greenspace studies found that greenspace is linked to lower salivary cortisol, heart rate, HDL cholesterol, type 2 diabetes, and mortality, among other benefits; greenspace was also linked to improved self-reported health.[36] A meta-analysis of greenspace literature on mortality found that greenspace is associated with a lower risk for cardiovascular disease morality; evidence also suggested a weaker link between greenspace and all-cause mortality.[170] A review of interventions conducted on urban greenspaces found that greenspace was associated with reduced risk for mortality, high heart rate, and violence.[34]

Several studies in the United States have examined greenspace and general health. In a study in Missouri, middle-aged adults that did not have greenspace, specifically a park, within a half mile of their residence had greater risk for having at least two chronic health conditions.[232] A study in Ohio found that older adults who use parks report significantly better physical health compared to older adults who do not use parks; moreover, older adults with a park within walking distance had better physical health compared to those who did not.[223] An examination of greenspace and general health in New York found that type of greenspace was important for predicting health; residents were more likely to report better general health when living in areas with the greatest amount of tree canopy whereas no relationship was observed between grass and general health.[275]

Studies from outside the United States have found comparable results. A study in Spain found that neighborhood surrounding greenspace and perceived neighborhood proximity to greenspaces, specifically parks, were positively associated with better subjective general health, and these relationships were partly mediated by mental health,

perceived social support, and physical activity; interestingly, however, objectively measured neighborhood proximity to greenspace was not a significant predictor of subjective general health.[37] Another Spanish study found that greenspace was correlated with better perceived general health; this relationship was stronger for surrounding greenspace compared to access to greenspace.[276] A study in Sweden found that perceived greenspace quality was associated with increased physical activity and better general health, where the connection between greenspace and general health was mediated by physical activity and neighborhood satisfaction.[277] A study in Australia found that increased access to greenspaces was correlated with decreased risk for mortality in a longitudinal study of older adult men.[38] Another Australian study found that people with high perceptions of neighborhood greenness were more likely to have better physical health, and this relationship was mostly explained by physical activity.[278]

An analysis of greenspace in Turkey found that distance to urban greenspace was correlated with more physical activity, and more physical activity was associated with improved physical health; large and open urban greenspaces were independently associated with improved physical health.[33] A study of Dutch adults reported a positive relationship between self-reported health and greenspace, as well as fewer chronic disease symptoms with more greenspace.[165] Among Dutch adults diagnosed by a physician, living in greener neighborhoods was correlated with having a lower risk for 15 of 24 morbidities (e.g., heart disease, asthma).[190] Another study of adults from the Netherlands found that more neighborhood greenspace was associated with better perceived general health; when analyzed by type of green space, the researchers found that agricultural green and natural green were linked to better perceived general health.[174]

Other research has identified a mixed or null relationship between greenspace and physical health.[279] A United States national, longitudinal study of parks found that in 1991, park use and use of park programming was not linked with self-rated health; in contrast in 2015, people who used parks and park programming often had greater likelihood of better self-rated health.[280] An analysis of greenspace in Washington state found that aggregated greenspace was not associated with general health.[60] A study among Scottish adults found that activity in natural areas was not significantly associated with better wellbeing; in contrast, use of non-natural areas for physical activity was linked with better wellbeing.[281]

As the study of greenspace has grown, considerable research has been devoted to examining the relationship between greenspace and mental health. A review of greenspace interventions and various health outcomes in urban areas found a positive relationship between greenspace and cognitive functioning and emotion, specifically attention and mood.[34] An analysis of literature on wildland and health found that greater exposure to wildland areas was linked to better mental health, including better self-esteem and reduced stress.[282] Also, a review of controlled trials found that engaging in physical activity outdoors, compared to indoors, increases the likelihood of improving mental health (e.g., reduced tension, depression), feelings of revitalization, and positive engagement.[169]

In Los Angeles, researchers found that living closer to a park was associated with better mental health; living more than a quarter of a mile from a park was linked to worse mental health scores, and living more than a half mile away was linked to the worst mental health scores.[234] In a unique study of adult twins, researchers found that

neighborhood greenspace may reduce risk for symptoms of depression, anxiety, and stress in adults; however, when comparing within twin pairs, only depressive symptoms remained associated with greenspace.[64] In a study of several thousand nursing homes in the United States, older adults may were at reduced risk for depression when living in facilities surrounded by more greenspace, specifically tree cover.[208]

For British adults residing in urban areas, increased greenspace was related to improved mental health and well-being.[283] In the United Kingdom, adults reported feeling happier when spending time in green or natural areas compared to spending time in urban areas.[284] Another study conducted in the United Kingdom found that, for pregnant women, living in greener areas was associated with a reduced risk for reporting depressive symptoms, particularly for women with less education or who were physically active.[285] Also, for United Kingdom adults who are regularly physically active and are considered healthy, exercising in green areas was associated with better mental health, specifically improved self-esteem and reduced anger, confusion, depressive symptoms, and anxiety.[286] In an analysis of a United Kingdom city with higher than average deprivation, researchers found that amount of greenspace was correlated with cortisol (a physiological indicator of stress); similarly, when using a self-reported measure of stress, greenspace was again found to be significantly and positively correlated with reduced perceived stress.[287] For Scottish adults, being regularly physically active in natural environments was linked to better mental health, particularly activity in open spaces, parks, woods, and forests.[281]

Dutch adults reported a positive relationship between mental health and greenspace,[165] and greenspace may serve as a buffer to stressful life events, as greenspace

was found to moderate the relationship between a stressful life event, health complaints, general health, and mental health.[288] Another Dutch study found that for adults diagnosed by a physician, living in greener neighborhoods was correlated with having a lower risk for morbidity, including depression and anxiety. [190]

A Canadian photovoice study found that for adults, access to parks and wilderness has restorative benefits that positively influence health and well-being.[289] For adults in Taiwan, park proximity predicted park use; moreover, park use was found to mediate the relationship between park proximity and stress.[235] A study conducted in four European cities found that commuting through natural environments (e.g., greenspace, blue space) is associated with improved mental health, particularly among adults using active transportation.[35] For Australian adults who had high perceptions of neighborhood greenness, the likelihood of better mental health was higher, and physical activity partly explained this relationship.[278] Another analysis of Australian adults found that an increased number of parks and greater park area was associated with better mental health; recreational opportunities and nature spaces within parks were also linked with better mental health.[290] When living in the greenest neighborhoods, adults from a New Zealand study had reduced risk for poor mental health.[262]

An analysis of greenspace in Washington state found that aggregated greenspace was not associated with mental health, anxiety, or depression; however, when examining type of greenspace, researchers found that forest was associated with better mental health.[60] Further, in urban areas, greenspace was correlated with better mental health.[60] Among adults in California, greater greenspace was not associated with reduced risk for serious psychological distress; however, when analyzing by age group, greater

greenspace was associated with reduced risk for serious psychological distress among older adults. [253]

A multi-county European study found that greenspace exposure was not significantly correlated with mental health; however, greenspace contact was linked to better mental health.[61] A longitudinal study of British adults found that, from 1996 to 2004, greenspace in urban areas was correlated with improved mental health among men but not among women; however, when considering age, greenspace was correlated with better mental health in young adult men and for women over the age of 40.[291] In a study of Scottish adults, objectively measured greenspace was linked to lower stress in men but not women, and greenspace was not correlated to mental health; however, perceptions of greenspace quantity were associated with better mental health and perceptions of greenspace quality were associated with better general health and reduced stress.[292] An analysis of several types of greenspace and mental health among Canadian adults found no significant relationship between any type of greenspace and depression, general mental health, or psychological distress; however, greenspace may serve as a mediator to better mental health and foster social connectedness.[293]

Greenspace and environmental justice

Environmental justice has been defined as "the fair treatment and meaningful involvement of all people (regardless of race, ethnicity, income, national origin, or educational level) in the development, implementation, and enforcement of environmental laws, regulations, and policies."[294,295] The environmental justice movement gained momentum in the early 1980s after events in Warren County, North Carolina, where residents of a low-income, minority community fought to prevent a toxic

landfill from being built in their community. Community members' efforts garnered national attention and help from well-known civil rights activists.[47,296] The following decade, in 1994, executive order 12898 was passed, which states that: "each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations."[297]

Prior to this, many environmental justice efforts were focused only on environmental hazards (e.g., contaminated water, location of waste facilities). With executive order 12898, environmental justice was expanded to ensure that natural resources were equitably managed and distributed by income and race/ethnicity.[47,164,296-298] With growing attention on the equitable distribution of health-promoting features of the environment, research has been conducted on the availability of and access to greenspace.[43,48,164,299-302]

Greenspace disparities

Greenspace can promote healthy behaviors and positive health outcomes, as well as benefit environmental health; however, it is often not equitably prevalent by neighborhood race/ethnicity, income, and rurality. Mixed findings have been reported on studies of park prevalence; in some areas, parks have been found to be more prevalent in underserved neighborhoods, whereas in more advantaged areas, parks are often less prevalent but of better quality. For example, a review of parks literature focused on proximity, acreage, and quality identified mixed findings for park proximity; however, low socioeconomic status and race/ethnicity were strongly correlated with less park

acreage, fewer parks per person, and poor park quality and were correlated with fewer park amenities and parks with more safety concerns.[181] A study of 99 of the largest United States cities by population found that cities with lower median incomes and more racial minority residents had lower Trust for Public Land ParkScores; predominantly Latino cities were worse off than Black cities, and both Latino and Black were worse off than White cities.[42] An examination of Baltimore parks found that although Black residents had greater park access compared to White residents, White residents had greater park acreage.[238] In Los Angeles, the largest urban park that was designed to serve underserved communities was found to most often have visitors that were White, higher income, and resided close to the park.[221] Also, another study of parks in Los Angeles found that minority and low-income residents were more likely to live near parks that are more congested (i.e., less park space available to a greater number of residents).[241]

An analysis of six states within the United States found that high minority areas had lowest availability of parks and recreation facilities, whereas low-income areas had greater access to parks.[44] In comparison, a national study of greenspace and parks found that areas with greater concentrations of Black and low-income residents had greater park proximity.[43] However, smaller scale analyses of parks have found that although low-income and high-minority areas may have equal or greater park access, parks in such neighborhoods are more likely to be smaller in size and of poorer quality.[45,239] For example, a study of parks in a large Southern county found that although neighborhood socioeconomic disadvantage was not related to park availability, it was correlated with park incivilities (e.g., litter, noise).[46] Moreover, a study in Kansas City found that lower

income and higher minority neighborhoods surrounding parks had a greater number of incivilities and unhealthy food outlets.[240]

An analysis of 10 major urban cities found that vegetation cover was positively associated with higher income, more education, proportion of White residents, and age; a similar but weaker relationship was found for parks, however, in some cities, more education, greater proportion of White residents, and age were negatively associated with park availability.[41] Similarly, a study of seven major urban cities across the country found that income was positively associated with urban tree canopy cover, but minority race/ethnicity was only negatively associated in two cities and null in the remaining five.[211] A national analysis of tree cover found that, although findings varied by state, tree cover was more prevalent in urban areas than in rural.[303]

In Portland, Oregon, areas with greater population density, older homes, and lower incomes had the lowest levels of mixed and of woody vegetation cover; areas with older homes and residents with less educational attainment had the greatest distance to parks and greenspaces.[40] In contrast, residents who were White, Asian, or "other race" or who had more education had greater mixed vegetation cover.[40] A study of 25 major cities in the United States examined vegetation and tree canopy, and researchers found that low-income Hispanic neighborhoods had the least amount of vegetation and tree canopy whereas high-income White neighborhoods had the most amount of tree canopy; low-income Black neighborhoods had the most vegetation.[210] In Tampa, Florida, an analysis of street trees found that neighborhoods with more minority residents, low-income residents, and renters had less tree cover.[213] Likewise, in Durham and Chapel Hill, North Carolina, the presence of street trees was negatively associated with racial/ethnic

minority residents.[212] Further, for urban areas across the United States, racial/ethnic minority persons were more likely to have less tree canopy cover and more impervious surface, referred to as heat risk-related land cover, compared to White residents.[304]

Using greenspace, health, and mortality data for the population of England, researchers found that adults with greater greenspace exposure were more likely to live in less deprived areas. Moreover, income deprivation and mortality varied by amount of greenspace; higher mortality was correlated with less greenspace.[305] A study of British adults found that adults who were of lower socioeconomic status, identified as a racial/ethnic minority person, or lived in deprived neighborhoods with less green space (in addition to several other demographic characteristics) were less likely to visit parks and other natural areas.[306] Further, among English adults, living in areas of higher deprivation was associated with living closer to greenspaces; however, residents' park use, park safety, and perceived park access were low.[255] An analysis of diverse cities in England found that for Black and minority racial/ethnic residents, greenspace access, use, satisfaction, and safety were associated with general health; for White residents, greenspace was not associated with general health, but social aspects of the neighborhood were (e.g., isolation).[307]

An examination of greenspace in the United Kingdom found that urban greenspace was linked to neighborhood deprivation; street trees were more heavily prevalent in areas with minority residents and lower socioeconomic status whereas areas with more White and higher socioeconomic status residents were more likely to have access to public greenspaces like parks and gardens.[209] In a city in Portugal, greenspace was found to be unequally spread across urban areas; the researchers estimated that at

least 25% of a neighborhood should be composed of greenspace to prevent residents from having to travel outside their neighborhood to utilize greenspace.[39]

A study of greenspace in Poland found an interesting relationship between greenspace and length of time living in one's neighborhood; greenspace was not related to residential duration in higher income areas, whereas a lack a greenspace was related to shorter residential duration; the authors raise the issue of place attachment and that lower income residents are less able to develop a relationship with their place of living based on greenspace availability.[308]

Recently, research has surfaced that acknowledges that although greenspace is beneficial for health, there are potential issues with gentrification and environmental justice when improving green infrastructure in deprived areas. For example, Wolch et al. discussed how greening of areas may be paradoxical, as more greenspace may encourage gentrification; the authors discuss the need to make cities "just green enough" where local residents benefit from greenspace but efforts are put into action to prevent gentrification.[309] Other studies focused on trails and greenways have observed similar issues with gentrification. For example, homes along the developing Atlanta Beltline, which was 22 miles long and provides access to trails, parks, and retail, have increased in value from approximately 18-22%; this may make living along the Beltline unaffordable for low-income residents. Ultimately, gentrification that accompanies greenspace improvements could perpetuate environmental injustice by contradiction the original greenspace investments that were intended to ameliorate it.

2.2 SIGNIFICANCE AND INNOVATION

Significance

Although there is research on greenspace availability and its connection with health, mixed findings and gaps in the literature obscure the potential importance of greenspace for public health.[55,58,60,61,220,271,293] Examining multiple types of greenspace across the United States is key to 1) understanding the spatial nature of greenspace, 2) identifying if greenspace is equitably present by race/ethnicity, income, and rurality, and 3) identifying the relationship between greenspace and physical activity, obesity, and health-related quality of life. As many Americans are physically inactive, have obesity, and have poor health-related quality of life,[310] it is critical to identify and better understand elements of nature and the built environment, such as greenspace, that can promote population health and reduce health disparities.[279,309]

Research on ehe influence of nature and the built environment on various health behaviors and outcomes has gained traction in recent decades, with evidence indicating the importance and impact of the environment on human health.[279,311,312] Of the many environmental factors linked to health, greenspace has been positively tied to several health outcomes.[58,170,274] However, greenspace may not be equitably present across the United States, and better understanding of the spatial prevalence of greenspace is needed.[241,302] As such, it is necessary to investigate where greenspace is present across the United States, as well as relationship between greenspace and health.

This study shed light on the spatial nature of greenspace, including identifying if geographic clustering exists, which is important for determining how greenspace is present across the United States.[41,43,313] A goal of this study was to not only map

greenspace prevalence, but also to identify if greenspace is clustered or dispersed, and, if so, where this spatial autocorrelation exists. Using GIS, generating these maps was key for improved understanding of greenspace coverage in the United States.[314] Moreover, such maps could provide researchers, practitioners, and policy makers a valuable tool for advocating for health-promoting environmental features, like greenspace, to promote healthy behaviors and reduce chronic disease risk across the United States.[315-317]

Environmental justice research broadened its approach when it incorporated study of health promoting features of the environment in addition to study of environmental hazards.[298,299] Examination of greenspace in relation to underserved communities garnered attention for the importance and value of greenspace equity in environmental health research.[210] For example, studies have found that underserved groups may live in areas with less greenspace compared to their more advantaged peers, and unequal availability of greenspace in underserved areas may perpetuate health disparities.[41,42,48,305] It is clear that an environmental justice approach is useful for greater understanding of greenspace and health disparities in the United States.[43]

However, there are gaps in the environmental justice literature. For example, much of the greenspace environmental justice literature has focused on parks.[42,43,45,46,181,221,238,241] Considerably fewer studies have examined tree canopy or different vegetation types.[211,213,303] Further, only one study was identified that examined greenspace – parks and percent vegetation coverage – nationally that compared prevalence by race/ethnicity, income, and rurality.[43] Most studies have examined major urban cities across the United States or conducted local/city assessments of greenspace prevalence.[41,210,211,238] Ultimately, greenspace may not be equitably prevalent across

race/ethnicity, income, and rurality, as low-income, minority, and rural adults may least likely to have access to greenspace.[39-46,48,305] And although substantial greenspace research has been conducted in the United States,[36,55,56,170,282] considerably fewer studies have used an environmental justice approach.[42,46,181,238,309]

This study contributed to the environmental justice literature by determining, at a national scale, if greenspace is equitably present in the United States. Moreover, identifying which demographic characteristics were tied to greenspace, such as race/ethnicity, income, and rurality, provided public health and environmental health professionals useful information on greenspace prevalence and the ability to identify underserved areas that lack greenspace.[181,314] Use of this information could be impactful for local, state, and national public health and urban planning efforts for creating healthy communities.[302,317] Further, findings from this study could advance not only public health, geography, and environmental health sciences literature, but also contribute to environmental justice efforts and to accurately focusing public health interventions where they are most needed to reduce health disparities.[302,314]

Physical activity has been linked with a host of health benefits, including improved cognitive functioning, better mental health, and reduced risk for obesity, certain cancers, and premature death.[1-3,68,70] However, few adults in the United States engage in adequate amounts of physical activity, with self-report estimates around 50% of Americans and objectively measured estimates of only 5% of Americans meeting physical activity recommendations.[1,4,85,86] Moreover, in part due to inadequate physical activity, obesity rates in the United States have risen significantly in recent decades, as approximately 40% of adults have obesity.[3,11,104] Obesity is associated with poor health

outcomes and chronic diseases, including an increased risk for type 2 diabetes, heart disease, and stroke.[5,12-17] In addition to inadequate physical activity and obesity, between 10% and 22% of adults report their health as fair or poor.[20] Also, about 19% of adults report experiencing a mental illness within the last year.[133] Depression and anxiety are two of the most common mental illnesses, and both are associated with risk for suicide, which is a leading cause of death in the United States.[23-26 27]

Further, considerable disparities exist in physical activity, obesity, and health-related quality of life (i.e., general, physical, and mental health). For example, low-income, racial minority, and rural adults are less likely to be physically active and more likely to have obesity.[10,17,22] Rural adults, especially rural racial/ethnic minority persons, are more likely to report their health as fair or poor and to have obesity.[17,21,22] Low-income adults, adults in both rural and urban areas, and adults of different racial/ethnic backgrounds, have unique risks for mental health disorders.[146-148,150,151] Such disparities in health behaviors and outcomes exacerbate the health divide between more advantaged and underserved Americans.

The consequences of inadequate physical activity, high obesity rates, and poor general and mental health result in substantial individual, population, and economic burden.[84,100,145] For example, about half of United States adults have a chronic health condition,[318] and the cost of healthcare continues to rise.[20] Key factors linked to these phenomena, such as physical activity, obesity, and health-related quality of life, warrant additional study. Further, examining these health factors with regard to race/ethnicity, income, and rurality is needed, as health disparities persist. This study contributed to the knowledge base on physical activity, obesity, and health-related quality of life,

particularly with a focus on which types of greenspace may be associated with these important health indicators. Researchers, policy makers, and advocates can utilize findings on greenspace from this study to improve population health and reduce health disparities.[65,319]

Reviews of the literature often report diverse results, but generally tend to agree that greenspace positively influences health.[55,56,58,169,170,274,279] However, with specific focus on physical activity, obesity, and health-related quality of life, the relationship between these health outcomes and greenspace is sometimes unclear.[58-61] Further, much of the greenspace-health research has focused on physical activity and mental health, with some focus on obesity;[58,64,194,249,258,260,268,320] there is considerably less research examining the relationship between greenspace and health-related quality of life and general health.[37,63,275,321] For example, in a review of greenspace literature focused on perceived general health, mental health, and all-cause mortality, the authors did not identify any study that met their inclusion criteria conducted in the United States on perceived general health; only two studies were identified for both perceived mental health and all-cause mortality.[274] Health-related quality of life is a valuable indicator of population health and warrants additional study in connection to greenspace.[110-113] Therefore, with consideration of mixed findings and inadequate assessment of health factors key to population health, this study contributed to better understanding the connection between greenspace and physical activity, obesity, and health-related quality of life.

Although research has tied greenspace to health, many studies have only utilized one type of greenspace and have not taken into consideration how type of greenspace

may vary in strength of relationship to health.[64,192,253,291] This is an important gap in the literature, as studies that have utilized more than one type of greenspace have found differing results. For example, researchers have found that tree canopy may be more important for better mental health,[63] whereas forests and parks could be more important for obesity.[220] Despite this, only some studies have compared multiple types of greenspace concurrently.[60,249,271]

Ultimately, the relationship between physical activity, obesity, and health-related quality of life and greenspace is understudied. Accordingly, additional research was warranted to better understand the connection between multiple forms of greenspace and health, particularly health outcomes that are key to chronic disease prevention and management for United States adults. This study contributed to knowledge of how diverse types of greenspace are connected to health. This is essential, as identifying which types of greenspace are most strongly tied to different health outcomes will allow public health professionals, health practitioners, and policy makers to implement intervention and policy efforts focused on the most impactful forms of greenspace.[65,319]

Innovation

Researchers have highlighted the need for greenspace studies that use multiple forms of greenspace, are conducted in multiple locations, and use broad health indicators.[57,321] This study used multiple forms of greenspace, was conducted at the national level, and examined key variables related to chronic disease and overall health status. Moreover, this study provided the opportunity to promote population health, as it contributes to the fields of public health, environmental health sciences, and geography by exploring multiple forms of greenspace and multiple key health outcomes. Using

innovative methods, this study advanced understanding of how greenspace is present across the United States, as well as greenspace's connection to health behaviors, improved health-related quality of life, and chronic disease prevention.

Most greenspace research has been conducted at the local level, often within a single city, county, or state.[40,60,62,64,241,253,258,271,275] Moreover, much of the greenspace research has been conducted outside of the United States.[33,37,63,190-192,249,260,262,263,268,273] Studies examining one type of area (e.g., city) are valuable for assessing small scale relationships between health and greenspace, and studies outside the United States contribute to overall understanding of greenspace and health. However, these studies do not provide a comprehensive national assessment of health and greenspace. For example, in a review of urban greenspace literature, the authors found that many studies were conducted in single cities or small areas and that few studies assessed more than one area (national, use of multiple parks, etc.).[57] For this dissertation research, only two studies conducted nationally on greenspace prevalence or its connection to health were identified.[43,220] Of the studies that exist examining greenspace across the United States, many are limited to major urban cities,[41,194,207,210] use three or fewer types of greenspace,[41,197] and/or do not examine the connection between greenspace and health.[41-43] This study described greenspace across the United States, examined equity of 11 greenspace measures, and assessed the relationship between 11 measures of greenspace and five important health indicators; no prior studies have conducted such analyses before.

Urban greenspace has garnered considerable attention in recent decades, as urban greenery may promote health and have protective effects against the stressors unique to

urban living.[34,50,57,279] Moreover, a focus on urban areas is necessary due to urban population growth; about 31% of the United States population lives in highly urban area.[54,322] As expected, much of the United States greenspace literature is produced from studies conducted in urban areas.[40,213,221,271,300] Moreover, these studies often examine urban areas in some of the largest cities in the country.[41,194,210,275] While this is beneficial for major cities, it overlooks urban areas in smaller cities that are also key to the health of a sizeable proportion of the population.[54] This study was innovative in that in considers all areas across the United States; therefore, all types of urban areas (e.g., major metropolitan, micropolitan), in all locations in the contiguous United States were examined.

Although a focus on urban areas is important, suburban and rural areas also warrant attention. Suburban populations have grown in the United States within the last two decades – faster than urban areas – with 55% of Americans residing in suburban areas.[54] Rural populations are declining but consist of 14% of the population, and rural residents, particularly those who are part of minority groups, experience extreme health disparities.[54,323-325] Very few studies have focused either solely on rural greenspaces or made urban-rural comparisons.[62,219,273,303] With the majority of greenspace studies having been conducted in urban areas, suburban and rural areas have been largely overlooked. The pressing need to improve health among these populations – in part through greening of the environment – warranted research to identify areas most in need. Further, as there is little research about greenspace differences between urban and rural areas, it is vital to understand if type of greenspace impacts urban and rural residents differently.[62] For example, as Wen et al. wrote, "…most studies on park and green space access focused on

urban settings. The potential urban-rural differences in park and green space accessibility could differ widely across levels of urbanization, just like those often observed neighborhood effects on health" (p. S19).[43] This current study was innovative in that when examining greenspace at a national level, suburban and rural areas were included within analyses; no prior studies have focused on rurality in relation to greenspace, particularly at the national level.

Previous work has examined greenspace using many different measures, some of which has utilized only one measure at a time (e.g., parks and physical activity, tree cover and mental health).[208,230,233] Analyses of single types of greenspace limit the ability to assess differences in greenspace type and their connection to health. However, some studies have used multiple measures of greenspace.[63,210] For example, a study of nearly 496 major cities in the United States utilized tree canopy and NDVI and examined the association with several health outcomes.[207] A study in New York compared the relationship between tree canopy, grass, and mental health.[275] Some studies utilize the same data source, such as the USDA's NAIP or the NLCD, with different greenspace variables (e.g., non-tree vegetation, tree canopy, forests).[60,210] Few studies have used several data sources or greenspace measures.[62,194,271] For example, a study in Spain used residential surrounding greenness as measured by NDVI, proximity to parks, and access to major neighborhood greenspace to evaluate in relation to general health.[37] A study of nearly 300 counties in the United States utilized the NLCD to identify seven types of land cover and examined their relationship with mental health.[194]

Studies that have used different types of greenspace from a single dataset or multiple types from multiple datasets have found varying results, in that some greenspace

types or measurements are correlated with health whereas others are not.[60,196,210] For example, a study in Singapore found that vegetation cover, canopy cover, and park area showed different strengths of association with mental health; further, these associations varied by buffer distance.[326] A study in Australia concluded that urban tree canopy was more important for mental health than other types of greenspace,[63] and a study in New York City found that urban trees, but not grass, was associated with better general health among residents.[275]

Some researchers have utilized one or multiple greenspace measures and examined their relationship with a single health outcome.[194,210,220] While these studies are key for establishing a foundation for the relationship between greenspace and health, they do not allow for a more broad and comprehensive understanding of this relationship. However, some greenspace studies have examined physical activity, obesity, and health-related quality of life – or a combination thereof – simultaneously.[37,321] Of studies that have examined two or more health outcomes, they often compared a similar combination of health variables. For example, researchers have examined the relationship between greenspace, physical activity, and obesity,[197,259] greenspace, mental health, and general health, [63] and greenspace, physical activity, and mental health.[64] A comprehensive examination of these key health variables – physical activity, obesity, general health, physical health, and mental health – is lacking. For example, a study of greenspace, general health, mental health, and physical activity was conducted in Barcelona, Spain;[327] no similar study could be identified in the United States. Moreover, no national studies have been able to simultaneously compare the strength of relationship between the multiple greenspace types and multiple health outcomes. This study was innovative in

that it examines physical activity, obesity, and health-related quality of life (i.e., general heath, physical health, and mental health) simultaneously in connection to 11 diverse forms of greenspace.

In sum, this study was innovative in that it used 11 measures of greenspace in the analyses of greenspace equity and in the analyses of the connection between greenspace and health. Moreover, this study identified that some forms of greenspace showed larger correlations with health than others, which shed light on which forms of greenspace may be most beneficial to health.

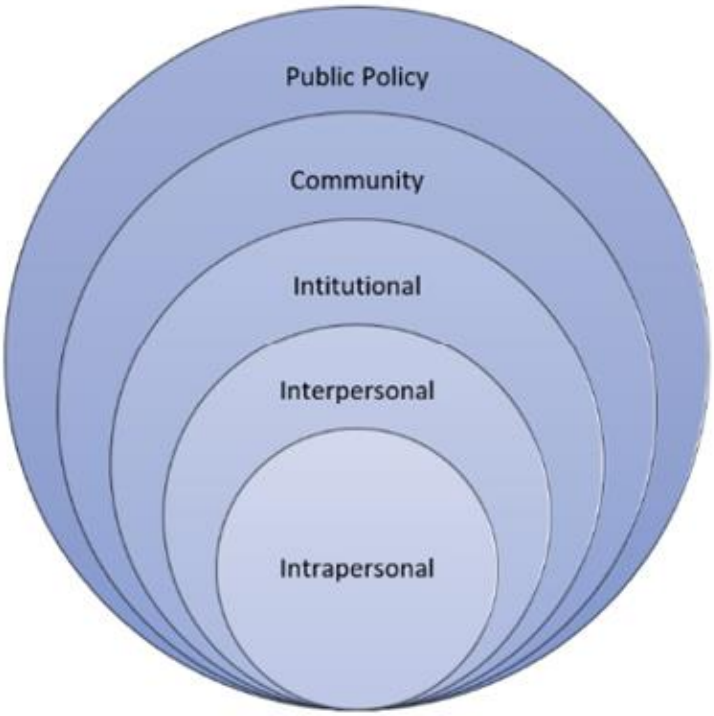

Figure 2.1 A visual interpretation of McLeroy et al.'s 'An ecological model for health promotion"[161]

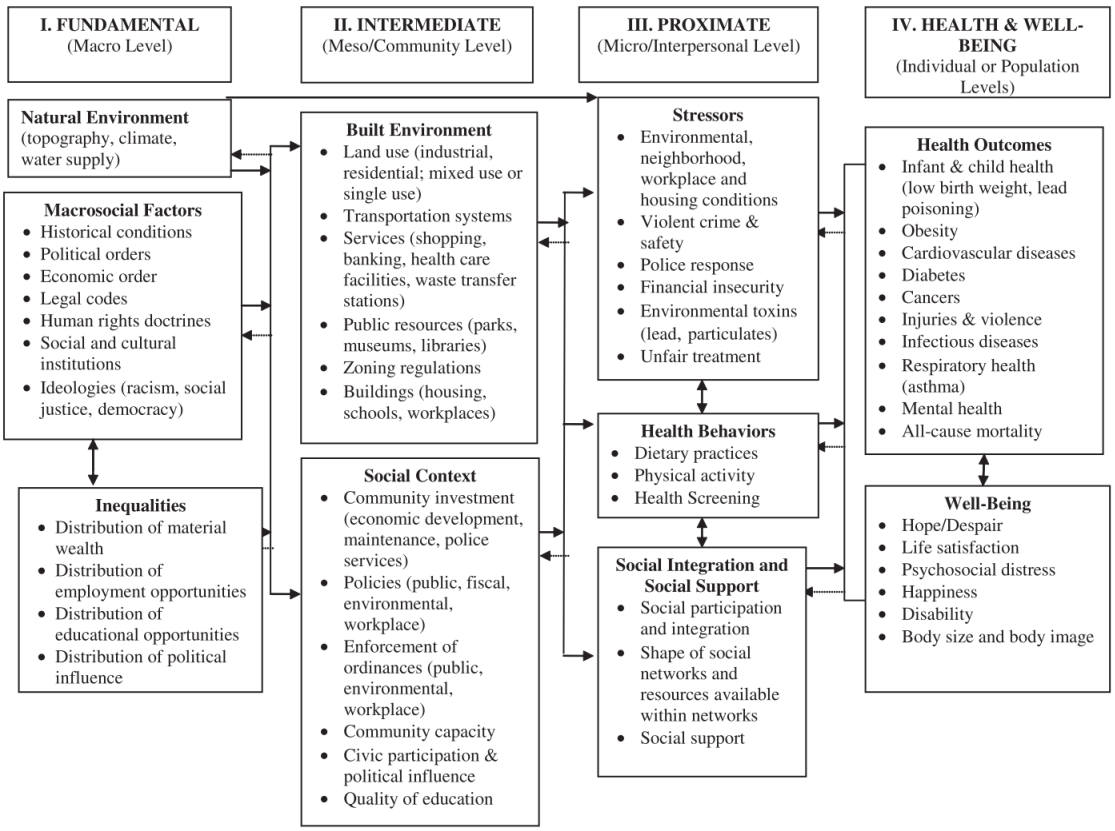

Figure 2.2 "Social determinants of health and environmental health promotion" by Schulz & Northridge[171]

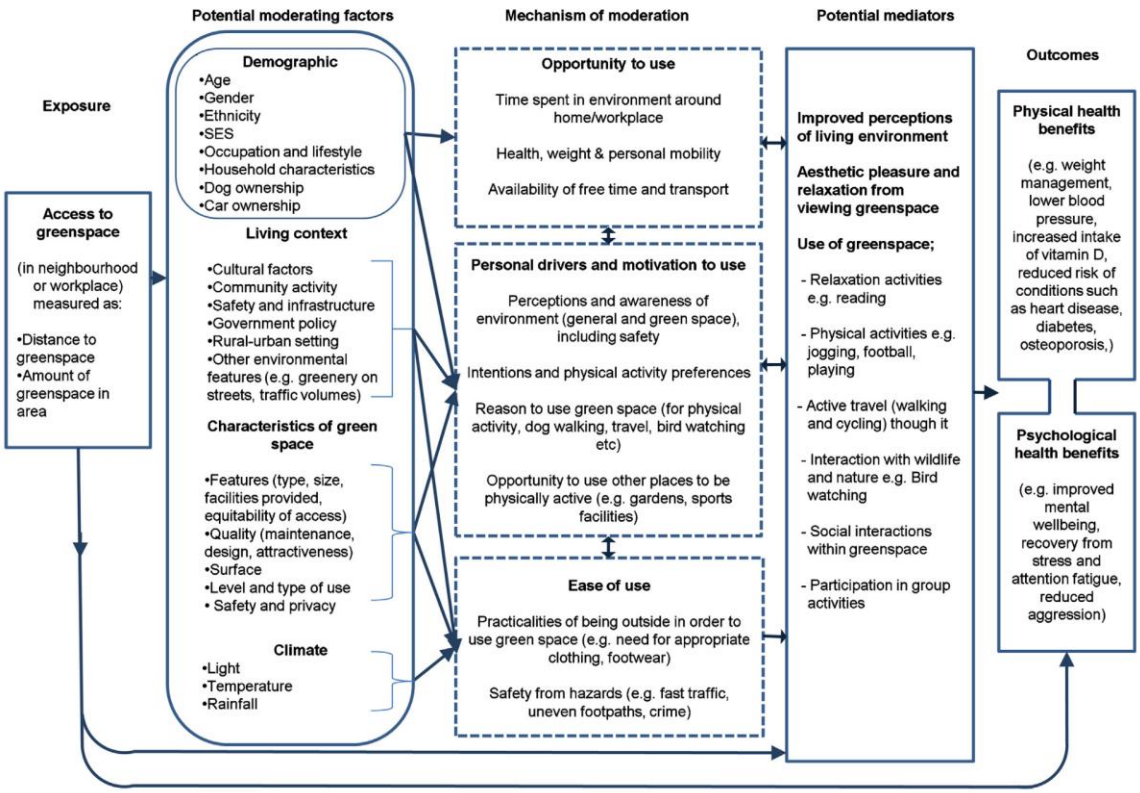

Figure 2.3 'Socio-ecological framework for the relationship between greenspace access and health' by Lachowycz & Jones[172]

CHAPTER 3

APPROACH

This dissertation research examined 11 measures of greenspace across the United States and assessed if race/ethnicity, income, and rurality were significantly associated with greenspace. In addition, this research assessed the relationship between each of the 11 greenspace measures and physical activity, obesity, and health-related quality of life. Completing the aims for this dissertation resulted in 1) descriptions of greenspace spatial patterns across the United States, 2) an equity analysis of greenspace by race/ethnicity, income, and rurality, and 3) novel insights into the relationship between greenspace and physical activity, obesity, and health-related quality of life.

3.1 CONCEPTUAL FRAMEWORKS

Ecological models by Bronfenbrenner[159,160] and McLeroy et al[161] propose that there are several levels through which individual and population health are influenced. Included within these levels are aspects of the environment, such as greenspace. Building off these ecological models, Shultz and Northridge[171] and Lachowycz and Jones[172] articulated the relationship between variables within various socioecological levels to explain the relationship between greenspace and health, in which reciprocal relationships exist. For example, an intermediate level factor, such as land use and greenspace, influences and interreacts with proximate level factors, such as physical activity and neighborhood safety; both intermediate and proximate factors ultimately influence individual and population health. This relationship continues across each level

– macrosystem, mesosystem, microsystem – in that each level has a reciprocal relationship with one another.

The models by Shultz and Northridge[171] and Lachowycz and Jones[172] highlight the intricate, multilevel relationship between greenspace and health that can be influenced by a host of factors. Because the present study was cross-sectional and utilized data about an exposure and outcome, simplified conceptual models informed by these more detailed models were used and are described below. These simplified models highlight the role of the intermediate and proximate levels for Aim 1 and the role of the intermediate, proximate, and individual/population levels in Aim 2.

The conceptual model for Aim 1 shows the proposed relationship between greenspace and demographic characteristics, where race/ethnicity, income, and rurality are associated with greenspace (Figure 3.1). Consideration of the reciprocal nature of varying levels of influence, as well as of previous research indicating persistent greenspace disparities, informed this proposed relationship. [42,171,172,207,211] For example, prior work indicates that greenspace is not equitably prevalent by race/ethnicity, income, or rurality; lower income, racial/ethnic minority, and rural adults are significantly less likely to have access to greenspace and to use greenspace.[42-44,62,181,303] Therefore, this model proposed that race/ethnicity, income, and rurality will play a significant role in the amount greenspace in neighborhoods across the United States.

Other neighborhood factors may influence whether greenspace is present. Median housing age is important consider, as older areas may be more condensed and walkable, with potentially more access to greenspace (e.g., pocket parks); moreover, older areas will have had more time to grow greenspace, such as tree canopy.[42,328] In contrast,

because of urban sprawl, more recent structures (e.g., homes) and other locations (e.g., parks) may be less accessible and less prevalent. Also, more recently built areas may have less dense greenspace and less time for greenspace to grow and develop. Similar to prior greenspace research, this study controlled for median housing age.[207,211] Also, the United States is heterogeneous in climate and topography, therefore the presence of greenspace varies across the country.[329] As such, U.S. Census region may be an important factor in the availability of greenspace in an area.

The conceptual model for Aim 2 proposed the relationship between greenspace and physical activity, obesity, and health-related quality of life (Figure 3.2). In this model, it is expected that the amount and type of greenspace will play a significant role in physical activity, obesity, and health-related quality of life, as evidence indicates that greenspace is connected to these health outcomes.[36,55,57,58,274] In previous research, physical activity has sometimes been treated as a mediating factor for the relationship between greenspace and health. However, research has produced mixed findings about this relationship. Some studies have identified physical activity as a mediator[277] whereas others have not;[263] some found that physical activity only partially or weakly mediated the relationship[37,285] or that physical activity mediated the relationship for some health variables but not others.[278] Therefore, this study did not use physical activity as a mediating factor.

This model incorporated sociodemographic factors that may influence the relationship between greenspace and health. Race/ethnicity, income, and rurality served as moderators, which are commonly used variables in greenspace and analyses.[210] These variables were treated as moderators because of the pervasive health inequalities

experienced by population groups across the United States.[21,125,324] Further, certain population groups typically have reduced access to greenspace.[42,44,181] Therefore, these three variables are expected to moderate the relationship between greenspace and health. As in the conceptual model for Aim 1, median housing age and region were included as influential factors.[42,328]

These simplified conceptual models highlight hypothesized relationship for greenspace and race/ethnicity, income, and rurality and for greenspace and physical activity, obesity, and health-related quality of life. However, it is imperative to recognize that these simplified models do not include all potential mediating factors in the relationship between greenspace and race/ethnicity, income, and rurality and greenspace and health.[172] For example, macro/fundamental factors, such as historical conditions, legal codes, ideologies, and inequalities, and intermediate/mesosystem factors, such as public policy, zoning regulations, and transportation systems, undoubtedly influence both the availability and use of greenspace as well as human health.[171,172] Because people and populations are nested within various levels of influence, it is impossible to entirely separate a person or population from the host of influences that dictate health;[158] similarly, aspects of the environment like greenspace are also determined by many difference sources of influence, from racism and inequality to policy and community capacity.[65,296,299,319,330]

3.2 SETTING

The total land area of the United States is 3,531,905.43 square miles, with a population density of 87.4 persons per square mile.[331] As determined by the U.S. Census Bureau, the United States is divided into four main regions: West, Midwest, Northeast,

and South. Further, divisions exist within each region. The Pacific and Mountain divisions comprise the West; the West North Central and East North Central divisions comprise the Midwest; the Middle Atlantic and New England divisions comprise the Northeast; and the West South Central, East South Central, and South Atlantic divisions comprise the South.[332]

Located on the continent of North America, the District of Columbia and the 49 states (excluding Hawaii) comprise the continental United States. In contrast, the lower 48 states and Washington DC comprise the contiguous United States, which is the area of focus for this study.[333] As determined by the U.S. Census Bureau, states contain counties, census tracts, block groups, and blocks, where counties are largest in population and blocks are smallest.[334].

Between 2010 and 2018, the population of the United States increased by nearly 20 million people; in 2010, total population was 308,745,538, and in 2018, population was estimated at 327,167,434.[331] Approximately 22% of the population was aged 18 years and younger, 62% between 18 and 85 years, and 16% over aged 65 years; just over half the population was female (50.8%). About 77% of the population was White, and 60% is non-Hispanic White; 18% of the population was Hispanic, 13% was non-Hispanic Black, 6% was Asian, 1% was American Indian or Alaska Native, less than 1% was Native Hawaiian or Other Pacific Islander, and 3% report being of two or more races. Approximately 87% of adults had earned a high school diploma or higher and 31% had earned a bachelor's degree or higher. Median household income in 2017 dollars was $57,652, and about 12% of Americans live in poverty.[331]

Most of the United States land is categorized as rural; however, the majority of the population lived in either an urban (31%) or suburban (55%) area, whereas only 14% of the population lived in a rural area.[54] Between 2000 and 2012-2016, population growth had been predominately in suburban areas (16% increase) and urban areas (14% increase); rural populations increased by 3%, but most rural areas had more Americans moving out than moving in.[54] Rural areas contained more adults over the age of 65 years and are, on average, 79% non-Hispanic White. In contrast, urban and suburban areas are growing more racially diverse, with urban areas containing 44% non-Hispanic White persons and suburban areas containing 68% non-Hispanic White persons, and these areas also had a younger population.[54]

There are substantial health issues are present in the United States. Using self-report data, about half of Americans meet aerobic activity recommendations, under a third meet muscle-strengthening recommendations, and less than a quarter meet both.[85] However, objectively measured physical activity indicates that around 5% of the population meets physical activity recommendations.[86] Low-income, racial/ethnic minority, and rural adults are less likely to be physically active compared to higher-income, non-Hispanic White, and urban/suburban adults.[5-10,15,87] Also, in the United States, about four in 10 adults have obesity; seven in 10 adults have either overweight or obesity.[11,20] Obesity rates vary by income, but typically lower income adults are more likely to have obesity.[104] Also, obesity is most prevalent among racial/ethnic minority persons (with the exception of Asian adults) and rural adults.[10,11,22]

Among American adults, about one in 10 reported poor or fair health, with a decline in health-related quality of life in recent decades.[114,116,117] Greater income

inequality, identifying as a racial/ethnic minority person, and living in a rural area has been linked to worse self-rated health.[21,122-126,129,130] Further, each year about one in five adults experienced any mental illness and one in twenty experienced a severe mental illness.[133] Lower-income and lower-socioeconomic status adults and non-Hispanic White persons are at higher risk for mental illness, but the relationship between urban and rural adults and mental illness varies. [146-152]

Ultimately, the status of physical activity, obesity, general health, physical health, and mental health in the United States warrants additional research. This dissertation research examined greenspace and its connection with these health outcomes to better understand if and what types of greenspace may be important for protecting and improving public health.

3.3 SAMPLE: U.S. CENSUS BLOCK GROUPS AND COUNTIES

For this dissertation research, the sample was from the contiguous United States, which was selected for two reasons: 1) the distinctive landscapes of Alaska and Hawaii would make comparing greenspace difficult to the contiguous United States,[43] and 2) the 2016 NLCD does not yet include data on Hawaii, Alaska, or Puerto Rico (i.e., the full continental United States).[329]

Aim 1 utilized an environmental justice approach to examine the presence of greenspace across block groups in the contiguous United States (N=216,330). As is described further below, data were obtained from the 2016 American Community Survey (ACS) 5-year estimates to determine demographic characteristics of these block groups.[335,336] Rurality was determined by rural-urban commuting area (RUCA) codes.[337]

Greenspace data – land cover, tree canopy, and parks – was obtained using the NLCD and Esri's USA Parks.[184,214]

Aim 2 assessed the relationship between greenspace and adult physical activity, obesity, and health-related quality of life (i.e., general, physical, and mental health). The sample for Aim 2 was all counties in the contiguous United States (N=3,108). As is described further below, data were obtained from the 2012-2016 ACS 5-year estimates to determine demographic characteristics of these counties.[335,336] Rurality was determined by Urban Influence Codes (UIC).[337] Adult physical activity, obesity, and health-related quality of life data were collected from County Health Rankings.[338] Greenspace data – land cover, tree canopy, and parks – was obtained using NLCD and Esri's USA Parks.[184,187,214]

3.4 DATA COLLECTION AND MEASURES

Data collection and measures: Aim 1

The focus for Aim 1 was all block groups in the contiguous United States (N=216,330). Determined by the U.S. Census Bureau, block groups are the smallest geographical unit for which population information is collected. Block groups typically range in population from 600-3,000 people and share similar demographic characteristics.[339] Block group spatial data were obtained from the U.S. Census Bureau for 2016 and includes the block group Federal Information Processing Standard (FIPS) codes, boundary, and area of the block group.[340]

Three categories of greenspace data were utilized for this study: land cover, tree cover, and parks.[184,187,200,214] These sources for greenspace were selected for this dissertation research because between types of greenspace found within these data

sources, nearly every objectively measurable type of greenspace is included. For example, land cover data from the NLCD distinguishes between many types of greenspace, such as shrub, grassland, and forests.[184,187,341] The NLCD also provides percent tree canopy cover across all of the contiguous United States.[200] The Esri parks data provides detail on park size and park type, such as local, state, and national parks.[214] Moreover, these datasets were utilized because they provide greenspace data for the contiguous United States; no other publicly available datasets provide such comprehensive information on greenspace in the United States. Further, land cover, tree canopy, and parks – specifically from the NLCD and Esri parks – have been widely used as greenspace measures in past research about greenspace accessibility and in connection with many health outcomes.[60,62,194-197,208]

The NLCD is produced by the MRLC Consortium, which was formed by the USGS and is a collaboration of several federal offices.[184-186] Land cover provides national spatial and descriptive Landsat-based data at 30-meter resolution with a eight category legend.[187] These eight categories are water, developed land, barren, forest, shrubland, herbaceous, plant/cultivated, and wetlands. NLCD is a reliable tool for assessing vegetation in the United States. NLCD has been examined for accuracy,[188,189] and for NLCD datasets created from 1996 to 2012, NLCD was found to accurately represent land cover, with NLCD and study reference data indicating a 71% to 97% agreement rate.[186]

Land cover data were assimilated from the MLRC website for the 2016 NLCD.[329] The land cover data are produced as a raster surface, a file type that can be managed and manipulated in GIS for spatial and statistical analysis.[342,343] Specifically, a raster surface is a stored image that is made up of equally sized pixels or cells that are organized into a

grid (rows and columns). Some raster surfaces that are a rectangular table have cells that contain a value and reference a geographic coordinate; for other raster surfaces that are images, the stored numbers within a cell correspond to the assigned colors or also reference a geographic coordinate.[343]

Within the eight categories of land types within the NLCD, four were used in this study.[341] These four categories had vegetative characteristics: forest (deciduous forest, evergreen forest, and mixed forest), shrubland (shrub, scrub), herbaceous (grasslands, herbaceous), and wetlands (woody wetlands, emergent herbaceous wetlands). Table 3.3 provides descriptions of these types of greenspace. A fifth measure was created by creating a composite variable of the four land cover greenspace types. For each of the five types of greenspace used from the NLCD, percent of land cover type per block group was calculated (range 0-100).

The NLCD tree canopy dataset, a 30-meter raster geospatial dataset, is created by the MRLC and the United States Forest Service and contains percent tree canopy estimates for the contiguous United States. [199] Data for tree canopy came from Landsat imagery as well as additional ground and ancillary information. Values in the tree canopy dataset ranged from 0% to 100% and each value indicated the proportion of the 30-meter cell that is covered by tree canopy.[200] Early assessments of tree canopy data reported accuracy ranging between 78% and 93%.[201] The recent accuracy assessment of the NLCD also included tree canopy in its evaluation, indicating high accuracy with improvement to the NLCD measurement methodology.[186]

Tree canopy was retrieved from the MLRC website, which hosts the NLCD for the United States.[199] Data were downloaded for the contiguous United States for the year

2016. Tree canopy data were also produced as a raster surface,[343] where cells values range from 0% to 100%. For the tree canopy variable, average percent tree canopy coverage was calculated for each block group (range: 0-100).

For this study, parks data were retrieved from Esri's USA Parks, a layer package that contains data on parks and forests within the United States; this data is provided by Esri, the National Park Service, and TomTom.[214] This file provided the park name, park type, and park size. This data source was selected as it was the only park data available that is supplied at a national level; further, these data distinguished between park type, which is useful for understanding if park type is important in its connection to health. At the time of this study, this dataset had been downloaded over 14,000 times by GIS users. Prior studies related to greenspace and the built environment have utilized this data.[41,344,345]

Park types included in this dataset are national park or forest, state park or forest, county park, regional park, and local park.[214] Using these five park types, a composite total park variable was created. However, regional parks were excluded from individual analysis, as there were relatively few comprising little total area. Parks in this map layer were available for the continental United States and were edited to include only parks in the contiguous United States. This file was last updated in June 2019 before being retrieved in July of 2019. A limitation of the USA Parks data is that it does not identify or discriminate by park greenspace; therefore, for example, a local park in the file could have a relatively small amount of greenspace compared to paved areas (e.g., basketball courts).[41] For the six parks variables, the percent of park area per block group was calculated (range: 0-100).

Sociodemographic and geographic variables for Aim 1 were race/ethnicity, income, and rurality. Race/ethnicity and income data were collected from the 2012-2016 ACS 5-year estimates; the 5-year estimates were selected for use as only ACS 5-year estimates contain data for smaller geographic areas like block groups.[335] Income was measured as 'median household income,' which is based off the income distribution of all households in one area; the distribution is sorted to where one-half is above the median and one-half below the median.[346,347] Regarding race/ethnicity, the ACS reports the number of persons identify as Hispanic or Latino and Non-Hispanic or Latino; within these two categories, there are eight possible race/ethnicity response options. For this study, the percent of non-Hispanic White adults per block group was calculated; the total number of non-Hispanic White persons per block group was divided by the total number of people to generate the percent non-Hispanic White variable. Both median household income and percent non-Hispanic White are commonly used variables when examining sociodemographic characteristics in greenspace research.[42,43,207,210]

Rural-urban continuum (RUCA) codes were used to determine block group rurality. RUCA codes use population density, urbanization, and daily commuting patterns to categorize census tracts in the United States into 10 primary and 33 secondary classification schemes. RUCA codes are designated for census tracts, one geographical unit larger than block groups. Therefore, block groups housed within a census tract were ascribed their parent census tract secondary classification value. Next RUCA codes were aggregated to four classification schemes: urban (secondary codes 1.0, 1.1), suburban (secondary codes 2.0, 2.1, 3.0), large rural (secondary codes 4.0, 4.1, 4.2, 5.0, 5.1, 5.2,

6.0, 6.1), and small-town rural (7.0, 7.1, 7.2, 7.3, 7.4, 8.0, 8.1, 8.2, 8.3, 8.4, 9.0, 9.1, 9.2, 10.0, 10.1, 10.2, 10.3, 10.4, 10.5, 10.6).[348]

Median housing age is important to consider, as older and younger areas may differ in access to and amount of greenspace.[42,328] To account for area age, median housing age was controlled for.[346] This variable was calculated by using the median years structures were built, where half of the values above the median year and half fall below. The year provided was subtracted from the ACS survey year (2016) to get the median housing age. Also, the United States is heterogeneous in climate and topography, therefore the presence of greenspace varies across the country, data for region were retrieved from the U.S. Census.[329]

Data collection and measures: Aim 2

The focus for Aim 2 was counties in the contiguous United States (N=3,108); counties were selected as the unit of analysis for Aim 2 because this was the smallest geographical unit for which health data could be accurately provided at the national level. Determined by the U.S. Census Bureau, counties are the third smallest geographical unit for which population information is collected.[339] Counties are considerably less uniform than block groups, as they can range in population from less than 100 residents (located in Hawaii) to more than 10 million residents (located in California).[349] The 143 most populous counties in the United States have a median population of 821,725 residents; the least populous counties have a median population of 23,999 residents.[349] County spatial data were obtained from the U.S. Census Bureau for 2016 and included the county geo-identifier (i.e., FIPS code), boundary, and area.[340]

Eleven greenspace measures calculated at the block group level were presented in Aim 1. Aim 2 uses the same data sources and methods to generate the same 11 measures of greenspace but at the county level.

Health data were collected from the 2016 County Health Rankings.[338] Although originating from the Behavioral Risk Factor Surveillance Survey, data were collected from County Health Rankings because it has undergone complex modeling to provide more stable estimates for counties with a small number of survey respondents.[350] Further, County Health Rankings have been widely used in health and greenspace research.[194,196,351] Data were on five variables: physical inactivity, obesity, general health, physical health, and mental health. Demographic data, with county identifiers, were collected from the 2016 County ACS 5-year estimates and the United States Census Bureau.[336,340] Data were merged so that each county had spatial and descriptive (i.e., demographic) data. As in Aim 1, income was measured as median household income and race/ethnicity was measured as percent non-Hispanic White.[346] As in Aim 1, greenspace may be dependent on the age of a structure and location in the United States, therefore median housing age and United States Census region were controlled for.[328,329]

To determine rurality, the most recent Urban Influence Codes created in 2013 were used. Urban Influence Codes were created by the Economic Research Service and assign counties one of 12 categories depending on size and location. Specifically, urban influence codes "form a classification scheme that distinguishes metropolitan counties by population size of their metro area, and nonmetropolitan counties by size of the largest city or town and proximity to metro and micropolitan areas."[337] There are two categories assigned to metropolitan areas: metropolitan areas of at least 1 million residents and

metropolitan areas of less than 1 million residents. There are three categories assigned to micropolitan areas (with an urban core of at least 10,000 residents) based on size and adjacency to metro areas (large, small, no adjacency). There are seven categories assigned to noncore areas (i.e., without an urban core of at least 10,000) also based on size (more or less than 2,500 residents) and adjacency to a metropolitan or micropolitan area.[337]

For this study, the original 12 categories were aggregated into five categories. These five categories retained the original two metropolitan categories, as a considerable proportion of the population reside in these two distinct areas. The 10 nonmetropolitan categories were aggregated into three categories: one micropolitan category and two noncore categories. The two noncore categories (2,500+ population and <2,500 population) were kept separate to distinguish between urban-rural mixed areas (2,500+ residents) and rural areas (<2,500 residents). [352-354]

3.5 ANALYTIC APPROACH

Aim 1. Explore global and local clustering of greenspace by census block groups across the United States. Assess the relationship between block group race/ethnicity, income, and rurality and 11 measures of greenspace.

Aim 1 called for an analysis of the spatial prevalence of greenspace. To achieve this, Global Moran's I was used to identify if there was spatial autocorrelation across the entire study area. Specifically, it tested for dispersion, clustering, or randomness of the greenspace measures.[355] Global Moran's I is a frequently used tool for detecting spatial autocorrelation.[211,356] This test was used because it is assumed that greenspace was not randomly prevalent across the United States, which has implications for which statistical

analyses are appropriate for use.[41,43,187,357] Global Moran's I determined if block group-level greenspace was clustered, dispersed, or randomly prevelent across the contiguous United States, which is indicated through the Moran's I value and the z-score and p-value.[355] Moran's I values range from -1 to 1, where a more negative Moran's I value indicated dispersion and a more positive Moran's I value indicates clustering. Findings from this test indicated only if spatial autocorrelation existed and do not identify where spatial autocorrelation occurred. A test for Global Moran's I was run for each type of greenspace.

If global clustering was detected when examining each type of greenspace, the Anselin local Moran's I test was utilized.[358,359] Local Moran's I identified and mapped spatial autocorrelation of the greenspace measures by block group across the United States. The Anselin local Moran's I test is a commonly used spatial analysis that identifies clustering and outliers by comparing the average area value in an area to the total area average across the entire study area.[356,360]

When using the Anselin local Moran I analysis in GIS, a new feature class (i.e., map layer) was produced that displayed where spatial autocorrelation is present; a Local Moran's I index value, z-score, p-value, and cluster/outlier type were also produced.[360] The z-scores and p-values (95% confidence interval) were used to reject the null hypothesis that the features are randomly prevalent. Higher positive z-scores indicated that an area had surrounding areas with similar values: high values surrounded by other high values (i.e., high-high) or low values surrounded by other low values (i.e., low-low).[360] Lower negative z-scores indicated a spatial outlier: a high value surrounded by low values (i.e., high-low) or a low value surrounded by high values (i.e., low-high). If an

area did not fall within one of these four categories, it was non-significant and no spatial autocorrelation was detected.

Univariate statistics for all block groups were calculated for demographic characteristics (e.g., race/ethnicity, income, rurality) and the 11 measures of greenspace. Then, the results from the spatial autocorrelation analyses were used. If spatial autocorrelation was non-significant, multilevel regression models would be compiled with race/ethnicity, income, and rurality as the independent/predictor variables and greenspace types as the dependent/outcome variables; median housing age and region were controlled for. Census tracts would serve as the level two indicator in the multilevel modeling.

If significant global spatial autocorrelation was found when conducting clustering analysis in GIS, simultaneous autoregressive models, specifically spatial error models, were run in GeoDa™.[361,362] Controlling for spatial autocorrelation allowed for the measurement of the effect of the independent variable on the association with the dependent variable without similarities in the dependent variable confounding the results. Simultaneous autoregressive models, including spatial error models, account for the spatial autocorrelation of greenspace, and are often used when conducting greenspace spatial analyses.[41,207,211,213]

Within GeoDa™, spatial error models were run for of the 11 greenspace measures (dependent variable) and race/ethnicity, income, and rurality (independent variables); median household age and region were controlled for. A spatial weights matrix was used in the regression analysis, which allowed for the creation of spatially explicit variables.[361] A queen spatial weight matrix was used within this study, as this type of matrix

accounted for block groups that share borders and vertices; the queen contiguity was appropriate for use of block groups, as the shape of block groups likely do not reflect the spatial nature of the data.[363] A queen spatial weight matrix provided structure to the data that identifies relationships between block group, so that neighboring block group values were taken into account; the error term is weighted according to neighboring values in the spatial error model.[364]

Aim 2: Examine the relationship between greenspace and physical activity, obesity, and health-related quality of life by county across the United States. Compare the strength and direction of the relationships between the 11 measures of greenspace and the five health outcomes.

Univariate statistics for all counties were calculated for demographic variables (e.g., race/ethnicity, income, rurality), health outcomes (physical activity, obesity, general health, physical health, and mental health), and the 11 measures of greenspace.

The goal of this aim was to determine if greenspace is significantly associated with health. A global clustering analysis – Global Moran's I – was conducted in Aim 2 as proposed in Aim 1; however, these tests was at the county level rather than the block group level.[355] Further, in contrast to Aim 1, each health outcome (i.e., dependent variables) was tested using the Global Moran's I statistic. If spatial autocorrelation is non-significant, multilevel regression models would be compiled with each type of greenspace serving as an independent variable and physical activity, obesity, general health, physical health, and mental health serving as dependent variables. Race/ethnicity, income, rurality, median housing age, and region would be controlled for. In these multilevel models, states would serve as the level two indicator.

If significant clustering of the health variables was identified when conducting clustering analysis in GIS, spatial error models were run to test the relationship between the 11 greenspace measures and physical activity, obesity, general health, physical health, and mental health; race/ethnicity, income, rurality, median housing age, and region were controlled for. Findings from the spatial error model analyses were compared by greenspace type and by health outcome. Positive and negative significant associations were noted; among these associations, the parameter estimates for the greenspace measures were compared.

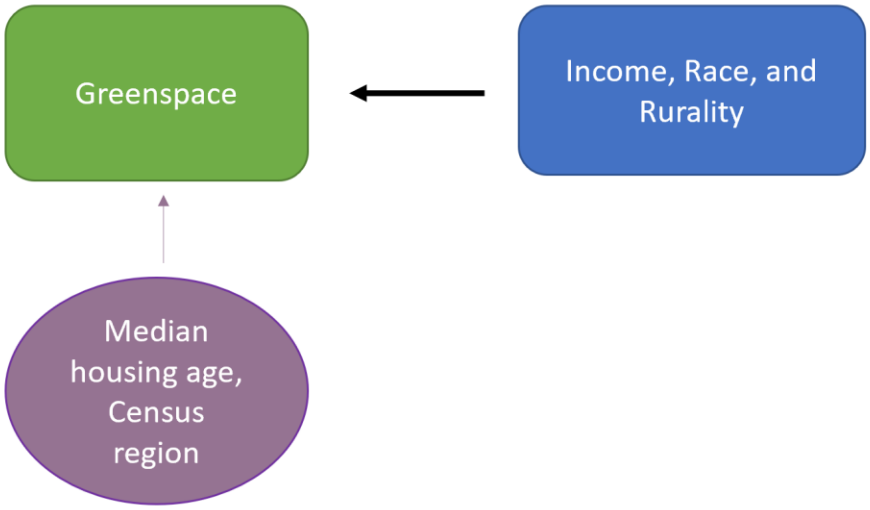

Figure 3.1 Aim 1 conceptual model: Race/ethnicity, income, and rurality in relation to greenspace

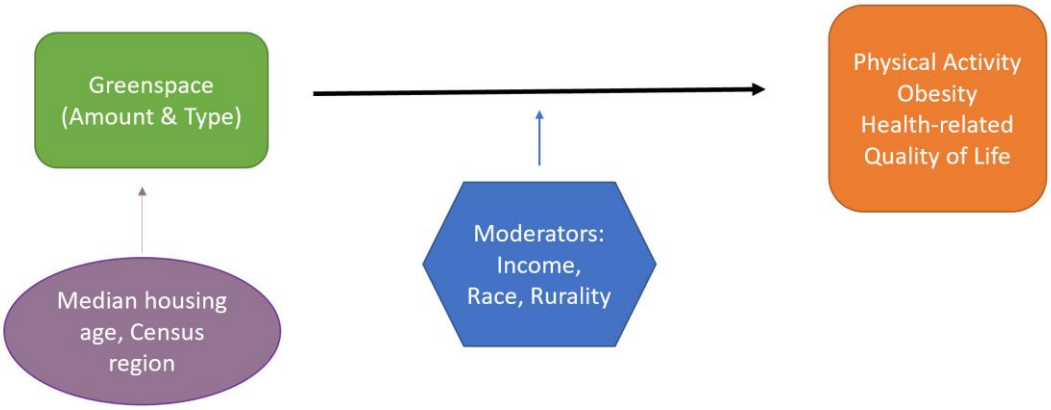

Figure 3.2. Aim 2 conceptual model: Greenspace in relation to physical activity, obesity, and health-related quality of life

Table 3.3 National Land Cover Database greenspace definitions[341]

Land Use Category	Land Use Type	Definition
Forest	Deciduous Forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
	Evergreen Forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
	Mixed Forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland	Shrub/Scrub	Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions
Herbaceous	Grassland/ Herbaceous	Areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing.
Wetlands	Woody Wetlands	Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water
	Emergent Herbaceous Wetlands-	Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water

CHAPTER 4

AN ENVIRONMENTAL JUSTICE APPROACH TO EXAMINING GREENSPACE: ASSOCIATIONS BY RACE/ETHNICITY, INCOME, AND RURALITY ACROSS THE UNITED STATES[1]

[1]Ellen W. Stowe, S. Morgan Hughey, Courtney Monroe, Dwayne Porter, Andrew T. Kaczynski. To be submitted to *Landscape and Urban Planning.*

4.1 ABSTRACT

Neighborhood greenspace is tied to health and well-being but may not be equitably present in neighborhoods across the United States. This study used an environmental justice approach to examine variations in greenspace coverage across the contiguous United States by neighborhood race/ethnicity, income, and rurality. Greenspace data from the National Land Cover database and Esri USA Parks were used to calculate percent block group (n=187,809) coverage of 11 measures of greenspace: five land cover, one tree canopy, and five parks. Race/ethnicity and median household income data were collected from 2016 American Community Survey five-year estimates. Rural-urban commuting area codes from 2010 determined rurality. Global and local tests for spatial autocorrelation were conducted. Spatial error models using a queen spatial weights matrix examined the association between race/ethnicity, income, and rurality and the 11 greenspace measures. Global and local spatial autocorrelation was present for all greenspace measures. Positive, significant Moran's I values indicated clustering. Spatial error models showed that the proportion of non-Hispanic White residents and median household income were positively and significantly associated with nine and seven of the greenspace measures, respectively. Small-town rural block groups had more greenspace for nine of the measures but had less local park coverage. Greenspace was not equitably present in block groups across the contiguous United States. Local government officials, city planners, and public health practitioners should consider their communities unique demographic characteristics and greenspace needs to ensure equitable and beneficial neighborhood greenspace.

4.2 INTRODUCTION

The built and natural environments have substantial influence on human health.[56,163,274] One key component of these environments is greenspace. Greenspace encompasses many types of vegetated areas and land uses on both developed and undeveloped land, including tree canopy, forest, parks, and recreational areas.[173] Greenspace has been associated with better health, particularly greater amounts of physical activity, lower obesity prevalence, and improved physical health, mental health, and overall well-being.[34,233,274] For example, a study of metropolitan areas in the United States found significant associations between park density, physical activity, and weight status; specifically, areas with the greatest density of parks compared to the lowest density had positive associations with physical activity and negative associations with overweight and obesity.[233]

Efforts to ensure equitable access to healthful environments have grown considerably over the last several decades, particularly through initiatives related to environmental justice. The Environmental Protection Agency defines environmental justice as "the fair treatment and meaningful involvement of all people (regardless of race, ethnicity, income, national origin, or educational level) in the development, implementation, and enforcement of environmental laws, regulations, and policies."[295] Early environmental justice efforts focused on environment hazards (e.g., contaminated water, location of waste facilities).[298] However, in the mid-1990s, environmental justice expanded to ensure that natural resources were equitably managed and prevalent by income and race/ethnicity.[164,296,298] With growing attention on the equitable distribution of health-promoting features of the environment, research has been conducted on the

availability of and access to greenspace by populations of varying sociodemographic characteristics.[43,48,299,300,302]

Greenspace has often been found to be inequitably present in varying locations across the United States. Neighborhoods and communities with lower income, with a higher percentages of racial/ethnic minority residents, and that are located within rural areas may be less likely to have access or exposure to greenspace.[39-46] For example, a review of parks literature found that people of low socioeconomic status and racial/ethnic minority residents had access to less park acreage, fewer parks per person, and poorer park quality.[181] A study of 99 of the largest United States cities by population found that cities with lower median incomes and more racial minority residents had lower Trust for Public Land ParkScores.[42] Finally, a national analysis of tree cover found that, although findings varied by state, tree cover was more prevalent in urban areas than in rural areas.[303]

There are several limitations to existing greenspace literature. First, although substantial research about greenspace and health has been conducted in the United States,[56,170] considerably fewer studies have adopted an environmental justice approach to examine greenspace equity, particularly outside of urban areas or the field of parks and recreation.[42,46,181,238] Second, most greenspace studies have focused on populous urban areas to the exclusion of rural areas and smaller communities.[41,181,233,365] Third, many studies have been conducted as small-scale, local assessments of greenspace in a single city.[41,211,232,238,274,366] Fourth, much of the greenspace equity research has been limited to parks or to only one measure of greenspace.[42,43,45,46,181,238] This is an important gap in greenspace research, as studies that have utilized more than one type of greenspace

reported differing results. For example, researchers have found that tree canopy may be more important for better general health and mental health, whereas forests and parks could be more important for obesity.[63,220,275] Despite this, only some studies have compared multiple types of greenspace concurrently.[60,249,271] Further, even fewer studies have examined multiple greenspace measures with an environmental justice lens.[211,213,303] Lastly, only some greenspace research has adequately accounted for the spatial nature of greenspace.[367] Failing to do so can result in biased, inconsistent, or inefficient parameter estimates, biased standard error estimates, and type 1 errors.[357]

Ultimately, greenspace may not be equitably prevalent by neighborhood race/ethnicity, income, and rurality.[39-46,48] However, there is a major gap in understanding the prevalence of many types of greenspace in neighborhoods of differing sociodemographic characteristics across the entire United States. Therefore, the purpose of this study was to examine if race/ethnicity, income, and rurality were significantly associated with 11 measures of greenspace – five land cover, one canopy, and five park measures - in census block groups across the contiguous United States.

4.3 METHODS

Study Sample

The eligible study sample was composed of census block groups in the contiguous United States (N=216,330). Block groups were selected as the unit for analysis because they are the smallest geographical unit for which demographic data are available, they have a similar number of residents, are often homogenous in resident makeup, and they most closely reflect neighborhoods that people reside in. Block groups were excluded from analysis if they were composed solely of water (i.e., no land area; n=532). Block

groups missing data for race/ethnicity (n=469), median household income (n=5959), median housing age (n=21,437), or rural-urban commuting area (RUCA) secondary code (n=66) were also excluded from analysis, resulting in a final analytic sample of 187,809 block groups that spanned 48 states and the District of Columbia.

Outcome Measures

In this study, greenspace was conceptualized as areas that were covered in vegetation in both natural and human-made environments. Greenspace measures fell within three categories: land cover, tree canopy, and parks.[187,200,214] In total, there were 11 greenspace measures – five land cover measures, one tree canopy measure, and five parks measures, which are described in the following paragraphs.

Data from the Multi-Resolution Land Characteristics (MRLC) Consortium's National Land Cover Database (NLCD) were used to create five land cover greenspace measures indicating the percentage of a block group covered by the greenspace type: percent forest, percent shrubland, percent herbaceous, percent wetlands, and percent total land cover greenspace (i.e., sum of all land cover greenspace types).[185] The 2016 land cover raster file was obtained from the NLCD, which provided national spatial and descriptive Landsat-based land cover data at 30-meter resolution. Within ArcGIS Pro (Esri, v2.6), the 'Tabulate Area' tool was used analyze the land cover raster surface to determine area in square meters of each specific land cover greenspace type within a block group, and the areas of these four land cover greenspace types were summed to get total land cover greenspace area per block group. Land cover greenspace area was divided by total block group area to get percent land cover greenspace coverage per block

group for the four land cover greenspace measures and for the total land cover greenspace measure.

Tree canopy data from 2016 were obtained from the MLRC.[185] A raster surface contained cell values ranging from 0% to 100% representing the percent of the area of a 30-meter cell covered by tree canopy. Within ArcGIS Pro, the 'Zonal Statistics' tool was used to determine percentage of a block group covered by tree canopy.

Data from Esri's USA Parks were used to create five park measures indicating the percentage of a block group covered by different park types: percent national parks or forests, percent state parks or forests, percent county parks, percent local parks, and percent total parks (i.e., sum of all park types). Parks data were obtained in July 2019 from USA Parks, a layer package that contains data on United States national parks or forests (n=1990), regional parks (n=447), state parks or forests (n=5362), county parks (n=1394), and local parks (n=40,601).[214] Because there were relatively few regional parks and they comprised a small total area, this park type was not examined individually but was included in the total parks measure. Within ArcGIS Pro, the 'Summarize Within' tool was used to determine area of each specific park type within a block group, and the areas of these four park types were summed to get total park area per block group. Park area in square meters was divided by total block group area to get percent park coverage per block group for each individual park type and for the total park measure.

Geographic and demographic characteristics

Data for race/ethnicity (percent non-Hispanic White) and median household income (dollars) for each block group were obtained from the 2012–2016 American Community Survey (ACS) 5-year estimates.[346,347] RUCA codes were used to determine

block group rurality. RUCA codes use population density, urbanization, and daily commuting patterns to categorize census tracts in the United States into 10 primary and 33 secondary classification schemes. RUCA codes are designated for census tracts, one geographical unit larger than block groups. Therefore, block groups housed within a census tract were ascribed their parent census tract secondary classification value. Next RUCA codes were aggregated to four classification schemes: urban (secondary codes 1.0, 1.1), suburban (secondary codes 2.0, 2.1, 3.0), large rural (secondary codes 4.0, 4.1, 4.2, 5.0, 5.1, 5.2, 6.0, 6.1), and small-town rural (7.0, 7.1, 7.2, 7.3, 7.4, 8.0, 8.1, 8.2, 8.3, 8.4, 9.0, 9.1, 9.2, 10.0, 10.1, 10.2, 10.3, 10.4, 10.5, 10.6).[348]

Additionally, shapefiles obtained from 2016 United States Census data provided geographic data for block groups (total area, polygons, i.e., block group borders) and for United States Census Region (North, Midwest, South, and West). Data on median housing age were obtained from the 2012-2016 ACS 5-year estimates. Consistent with previous greenspace research, median housing age served as a covariate, as it has been associated with greenspace; older areas may be more walkable and thus have greater access to specific greenspace types (e.g., parks) and have had more time for greenspace to grow (e.g., tree canopy).[42,207,328] The geography and climate of the United States also vary, which may impact the type of greenspace present; therefore, region was also included as a covariate.

Statistical Analyses

Descriptive characteristics of greenspace and sociodemographic data were calculated in Stata (version 17.0, College Station, TX). Using ArcGIS Pro (Esri, v2.9.0), Global Moran's I was used to determine if spatial autocorrelation was present for each of

the 11 greenspace measures.[355] This is a frequently used measure for detecting spatial autocorrelation[211,356] and was included because it was assumed that greenspace was not randomly present across the United States.[41,43,187] Global Moran's I assessed if block group-level greenspace was clustered, dispersed, or randomly present across the block).[355] Values could range from -1 to 1, where a more negative Moran's I value indicated dispersion and a more positive Moran's I value indicated clustering. Findings from this test indicated only if spatial autocorrelation exists but did not identify where the spatial autocorrelation occurred.

The Anselin local Moran's I tool was used to map local spatial autocorrelation of the greenspace measures.[358,359] Anselin local Moran's I is a commonly used spatial analysis tool that identifies clustering and outliers by comparing the average area value in an area to the total area average across the entire study area.[356,360] When using the Anselin local Moran's I analysis in GIS, a local Moran's I index value, z-score, p-value, and cluster/outlier type are produced.[360] Higher positive z-scores indicated that an area had surrounding areas with similar values: high values surrounded by other high values (i.e., high-high) or low values surrounded by other low values (i.e., low-low).[360] Lower negative z-scores indicated a spatial outlier: a high value surrounded by low values (i.e., high-low) or a low value surrounded by high values (i.e., low-high). If an area did not fall within one of these four categories, it was non-significant and no spatial autocorrelation was detected.

Within GeoDa™ (v1.20.0, Luc Anselin), spatial error models were used to test the relationship between race/ethnicity, income, and rurality and the 11 greenspace measures. Spatial error models use a spatially lagged error term in the regression model

that accounted for spatial dependence in the error terms.[357] A queen spatial weights matrix was used, as block groups are geographic boundaries that do not reflect the underlying spatial nature of the data.[363] This matrix applied structure to the data by identifying relationships among block groups, which influenced the weighting of the error terms in the spatial error models. [364] Also, in all regression analyses, median housing age and United States Census region were controlled for.

4.4 RESULTS

As shown in Table 4.1, across all block groups, mean percent of the population who was non-Hispanic White was 65.0% (SD=30.88), mean median household income was $60,741 (SD=$31,976), and mean median housing age was 42.4 years (SD=15.6). About 68.7% of block groups were urban, 11.2% were suburban, 10.2% were large rural, and 10.0% were small town/rural.

As shown in Table 4.2, all 11 greenspace measures had a significant, positive Moran's I value, which indicated clustering of greenspace. Accordingly, Anselin's local Moran's I analyses were conducted on the 11 greenspace measures. All variations of clustering and dispersion were observed (i.e., high-high, low-low, high-low, low-high, and non-significant). Two maps were selected to illustrate findings: Figure 4.4 shows the mapped results for total percent land cover greenspace, and Figure 4.5 shows the mapped results for percent local parks. The remaining maps are available upon request.

Nine of the 11 greenspace measures had a significant, positive association with race/ethnicity, in that as the percentage of non-Hispanic White residents in a block group increased, so too did the proportion of greenspace. As shown in Table 4.3, for every one percent increase in percent non-Hispanic White, percent total land cover greenspace

increased 0.07 (SE=0.002, p<.05), percent forest increased 0.04 (SE=0.002, p<.05), percent shrubland increased 0.004 (SE=0.001, p<.05), percent herbaceous increased 0.01 (SE=0.001, p<.05), percent wetlands increased 0.01 (SE=0.001, p<.05), percent tree canopy increased 0.05 (SE=0.001, p<.05), percent total parks increased 0.01 (SE=0.001, p<.05), percent state parks increased 0.004 (SE=0.001, p<.05), and percent national parks increased 0.01 (SE=0.001, p<.05). In contrast, as percent non-Hispanic White increased, percent local parks decreased 0.01 (SE=0.001, p<.05). There was no significant association between percent non-Hispanic White and percent county parks.

Seven of the 11 measures of greenspace had a significant, positive association with median household income, in that as block group income increased by $10,000, so too did the amount of greenspace. As shown in Table 4.3, for every $10,000 increase in median household income, percent total landcover greenspace increased 0.38 (SE=0.02, p<.05), percent forest increased 0.29 (SE=0.01, p<.05), percent shrubland increased 0.06 (SE=.01, p<.05), percent herbaceous increased 0.04 (SE=0.005, p<.05), percent canopy increased 0.43 (SE=0.01, p<.05), percent local parks increased 0.09 (SE=0.005, p<.05), and percent county parks increased 0.01 (SE=0.001, p<.05). There was no significant association between median household income and percent wetlands, percent total parks, percent state parks, and percent national parks.

Nine of the 11 greenspace measures were significantly lower in urban block groups compared to small-town rural block groups (Table 4.3). Urban block groups had less percent total landcover greenspace (B=-11.46, SE=0.30, p<.05), less percent forest (B=-5.56, SE=0.23, p<.05), less percent shrubland (B=-1.86, SE=0.11, p<.05), less percent herbaceous (B=-1.52, SE=0.09, p<.05), less percent wetlands (B=-2.11, SE=0.11,

p<.05), less tree canopy (B=-2.47, SE=0.20, p<.05), less percent total parks (B=-2.19 SE=0.16, p<.05), less percent state parks (B=-0.71, SE=0.07, p<.05), and less percent national parks (B=-1.08, SE=0.13, p<.05). Urban block groups had more percent local parks (B=1.34, SE=0.05, p<.05) compared to small-rural block groups. There was no significant difference for percent county parks.

Six of the 11 greenspace measures were lower in suburban block groups compared to small-town rural block groups; two measures were significantly higher (Table 4.3). Suburban block groups had less total landcover greenspace (B=-1.20, SE=0.26, p<.05), less percent shrubland (B=-0.37, SE=0.10, p<.05), less percent herbaceous (B=-0.54, SE=0.08), less percent wetlands (B=-2.11, SE=0.11, p<.05), less percent total parks (B=-0.77, SE=0.15, p<.05), and less percent state parks (B=-.17, SE=0.07, p<.05). Compared to small-town rural block groups, suburban blocks groups had significantly more percent tree canopy (B=0.69, SE=0.16, p<.05) and more local parks (B=0.24, SE=0.06, p<.05). There was no significant difference for percent forest, percent county parks, and percent national parks.

Six of the 11 greenspace measures were significantly lower in large rural block groups compared to small-town rural block groups; two measures were significantly higher (Table 4.3). Large rural block groups had less percent total landcover greenspace (B=-0.70, SE=0.28, p<.05), less percent shrubland (B=-0.24, SE=0.11, p<.05), less percent herbaceous (B=-0.29, SE=0.09, p<.05), less percent wetlands (B=-0.38, SE=0.11, p<.05), less percent total parks (B=-0.53, SE=0.17, p<.05), and less percent state parks (B=-0.25, SE=0.07, p<.05). Large rural block groups had more percent local parks

(B=0.23, SE=0.07, p<.05) and percent national parks (B=0.22, SE=0.12, p<.05). There was no significant difference for percent forest, percent canopy, or percent county parks.

4.5 DISCUSSION

This study examined the association between race/ethnicity, income, and rurality and 11 diverse measures of greenspace across 187,809 block groups in the contiguous United States. Findings indicate that greenspace is not equitably present and varies by race/ethnicity, income, and rurality. Block groups with a greater percent of the population identifying as non-Hispanic White had more greenspace for 9 of the 11 measures: total land cover greenspace, forest, shrubland, herbaceous, and wetland land cover; tree canopy; and total, state, and national park area. However, block groups with a greater percent of the population identifying as non-Hispanic White had less local park area. Block groups with higher median household income had more greenspace for 7 of the 11 measures: total land cover greenspace, forest, shrubland, and herbaceous land cover; tree canopy; and local and county park area.

These findings are consistent with previous research that has examined greenspace inequality in the United States. For example, a national study examining parks and greenspace accessibility at the census tract level using two measures of greenspace found that areas with a higher percentage of Black or Hispanic residents or low-income residents had less access to greenspace but greater access to parks, particularly in urban areas.[43] Also, an analysis of six states within the United States found that census tracts that were predominantly Hispanic had a lower probability of having a park or recreation center.[44] An analysis of 10 major urban cities found that higher income and more education were associated with urban vegetation and parks, but findings varied

by city for race/ethnicity; in some cities, a greater proportion of White residents was associated with less park area, whereas in others it was associated with less.[41] This study contributed to the greenspace and environmental justice literature by providing additional evidence for disparities in greenspace at the national level, which held true when examining by two composite and nine individual measures of greenspace that characterize almost all types of greenspace found in the contiguous United States.

Parks can be essential features of a neighborhood for health.[229,280] With consideration to environmental justice, findings from this study regarding race/ethnicity and previous studies regarding income indicate that racial/ethnic minority and low-income residents may have greater park acreage or park access may seem promising. However, parks in neighborhoods with more racial/ethnic minority residents, particularly parks in urban areas, may be of lesser quality (e.g., fewer amenities, less park maintenance, and reduced safety.[42,181] The lesser quality and quantity of greenspaces in these neighborhoods is in part a product of systemic racism, through mechanisms such as redlining.[368,369] Smaller scale (e.g., single city) analyses of parks have found that although areas with more racial/ethnic minority residents may have equal or greater park access, parks in such neighborhoods were more likely to be smaller in size and of poorer quality.[45,239] In addition, a study of parks in a large southern county found that although neighborhood socioeconomic disadvantage was not related to park availability, it was positively correlated with park incivilities, such as litter and noise.[46] Also, a study of parks in Los Angeles found that minority and low-income residents were more likely to live near parks that are more congested (i.e., less park space available to a greater number of residents).[241] Therefore, environmental justice efforts in neighborhoods with a greater

proportion of racial/ethnic minority residents or with lower incomes may need to focus on efforts to improve park features, such as access (e.g., adjacent sidewalks, crosswalks), facilities (e.g., playgrounds, courts), and safety and comfort (e.g., lighting, restrooms), rather than on overall presence of parks. However, actions to avoid gentrification will be required, as park improvements and the greening of neighborhoods can lead to increased property values and taxes and consequentially the displacement of the residents such improvements were intended to benefit.[309,370]

This study found that block groups that had a greater proportion of non-Hispanic White residents, higher income residents, or were located in suburban areas had greater tree canopy coverage. Previous studies examining tree canopy have found neighborhoods with a greater proportion of racial/ethnic minority residents have less tree canopy coverage.[371] For example, in Tampa, Florida, an analysis of street trees found that neighborhoods with more minority residents, low-income residents, and renters had less tree cover.[213] Likewise, in Durham and Chapel Hill, North Carolina, the presence of street trees was negatively associated with racial/ethnic minority residents.[212] In addition, tree canopy has been associated with income. In several urban cities, median household income was associated with tree canopy cover.[211] This study found similar results, not just in urban areas but across the entire contiguous United States.

Previous research on greenspace and rurality shows somewhat mixed findings. In a national examination of tree canopy, there was no significant variation in tree cover between urban and rural areas of the United States; however, differences were observed when examined by state.[303] This current study observed significantly less greenspace in urban areas compared to small-town rural areas; the only exceptions were greater tree

canopy in suburban areas and more local park area in urban, suburban, and large rural block groups. This is concerning, as the majority of Americans reside in urban areas, and tree canopy has been linked to positive health outcomes such as improved mental health.[275,372] Also, urban areas are more likely to experience extreme heat due to the heat-island effect, but tree canopy can mitigate this effect.[373] However , disparities in canopy coverage exist, as an analysis of heat risk-related land cover in connection to racial segregation found that in urban areas across the United States, compared to White residents, racial/ethnic minority residents were more likely to have less tree canopy cover and more impervious surface, placing them at greater heat risk.[304]

Environmental justice efforts must then consider the importance of tree canopy, particularly in urban areas, for both the promotion of health-promoting behaviors and protective features such as city cooling.[36,373] In contrast, when focused on rural areas, the lack of local parks may deprive rural residents of the multitude of benefits that come from local parks, including safe places to be active, safe and free/low-cost places for socializing, and a wide variety of programming that occurs in local parks. [374,375] While building more local parks may not be feasible in rural areas, use of existing facilities to promote healthy behaviors may be possible, such as adoption of shared-use agreements between schools and the larger community.[376,377]

This study provided a national assessment of greenspace by race/ethnicity, income, and rurality. Many of the 11 measures of greenspace were not equitably present in block groups across the country. From a national perspective, public health researchers and practitioners should take into consideration the overall inequitable presence of greenspace across the county. From a more local perspective, where most policy and

program are implemented, public health efforts to improve greenspace equity may benefit from small-scale, local analyses of greenspace. For example, geographically weighted regression (GWR) is a useful exploratory method for identifying how the relationship between greenspace and income, for example, may vary across towns, cities, and counties. A benefit of GWR is the variation in the strength of the relationship between greenspace and income is mapped, allowing city officials or community workers to advocate for changes in greenspace based on areas identified as most in need. Other future steps could include examining parks not as area relative to a neighborhood, but the number of parks present, as previous research indicates that the number of parks available is a key predictor of park use.[378]

Strengths and Limitations

This study conducted a national analysis of block groups across the contiguous United States. Examination at the block group level is advantageous, as block groups are the closest geographical unit available nationally with corresponding demographic characteristics that represent neighborhoods, and many health studies have utilized block groups as indicators of neighborhood.[46,379-381] This is important, as neighborhoods are strong predictors of health and well-being.[382] However, while block groups may reflect neighborhoods and have a similar number of residents within them, they are heterogenous and vary in size across the United States. A block group in a rural area may be many times the size of a block group in an urban city center, making the physical availability of greenspace greater in larger block groups. Consequently, this study attempted to account for this by using relative measures of greenspace (i.e., percent of a block group covered by greenspace) rather than absolute area.

In addition, because many block groups are relatively small, the likelihood of finding any of the 11 measures of greenspace within was low, therefore there was overdispersion in the greenspace data. Previous greenspace research and studies analyzing over-dispersed data have applied other modeling techniques, such as use of zero-inflated negative binomial models or geographically weighted negative binomial models to account for the overdispersion of greenspace data.[44,383] However, an analytic goal of this study was to account for the spatial nature of the data (i.e., spatial autocorrelation), and zero-inflated models do not. Geographically weighted regression is best suited for exploratory purposes rather than prediction, and therefore it was not used.[384] In this study, the large sample size provided adequate statistical power for use of spatial error models.[385]

Findings from this study were relatively consistent with previous greenspace research with an environmental justice or equity focus. However, differences in greenspace research may be, in part, a result of the variety of ways in which greenspace is conceptualized.[173] For example, definitions of greenspace vary widely and have included natural features of the environment (e.g., forests), human-focused areas (e.g., parks), or focused just on urban areas; moreover, many have been vague (e.g. “areas covered in vegetation”).[173] This study sought to overcome this limitation and was specific in how greenspace was assessed – 11 measures reflecting natural and built environment vegetated areas composed of vegetated land cover, tree canopy, and parks.

This study used the percent of the population identifying as non-Hispanic White to examine the relationship between greenspace and race/ethnicity. This group was used as evidence indicates that non-Hispanic White people often have greater access to

environmental and health resources like greenspace. However, this grouped all remaining racial/ethnic minority populations, which restricted the ability to determine the relationship between non-Hispanic Black, non-Hispanic Asian, Hispanic, and mixed-race people (among others) and greenspace. Evidence suggests that greenspace varies by race/ethnicity and future research would benefit from examining greenspace with additional racial/ethnic minority categories.

Similarly, differences in findings regarding rurality and greenspace may also be a result of varying definitions of urban and rural. Many different definitions of urban and rural are used by both government entities in the United States and by researchers, which can lead to contrasting results.[386] Also, dichotomizing urban-rural may mask the relationship between greenspace and rurality; therefore, this study used four categories to define urbanicity/rurality. Further, with the understanding that rural areas are at greatest risk for access to health-promoting resources, this study sought to delineate more populous rural areas from small-town rural areas with less than 2,500 residents to identify variations in greenspace by degree of rurality.

Conclusion

This study used block groups, the geographical unit that most closely reflects neighborhoods, to identify associations between race/ethnicity, income, and rurality and 11 measures of greenspace across the contiguous United States. Use of a variety of measures allowed for identifying disparities for most types of greenspace present in the contiguous United States. Percent non-Hispanic White and median household income were associated with nine and seven of the 11 greenspace measures, respectively. Small-town rural areas had more greenspace for nine of the measures; urban areas had more

local park area, and suburban areas had more tree canopy. Public health practitioners, city planners, and community organizations will need to consider neighborhood demographic composition and location when working toward ensuring equitable access to greenspace.

Table 4.1 Descriptive characteristics of block groups in the contiguous United States (n=187,809)

	Mean	SD
Greenspace measures		
Percent total landcover greenspace	23.3	27.9
Percent forest	14.5	21.5
Percent shrubland	2.6	9.6
Percent Herbaceous	2.3	7.7
Percent wetlands	3.9	8.9
Percent tree canopy	20.1	20.6
Percent total parks	3.2	11.8
Percent local parks	1.4	5.3
Percent county parks	0.1	1.3
Percent state parks	0.6	5.0
Percent national parks	1.2	9.5
Sociodemographic characteristics		
Percent non-Hispanic White	65.0	30.9
Median household income (dollars)	60,742	31,977
Median housing age (years)	42.4	15.6
	Frequency	Percent
Geographic characteristics		
Rurality		
Urban	129,102	68.7
Suburban	20,941	11.2
Large rural	19,074	10.2
Small-town rural	18,692	10.0
Region		
Northeast	31,021	16.5
Midwest	44,339	23.6
South	70,757	37.7
West	41,692	22.2

Note: percent greenspace indicates percent of a block group covered by the type of greenspace

Table 4.2 Results from Global Moran's I tests for spatial autocorrelation for block groups across the contiguous United States (n=187,809)

	Moran's I	z-score	p-value
Percent total land cover greenspace	0.37	1856.42	p<.01
Percent forest	0.43	2118.33	p<.01
Percent shrubland	0.36	1795.21	p<.01
Percent herbaceous	0.33	1633.85	p<.01
Percent wetlands	0.32	1579.18	p<.01
Percent tree canopy	0.56	2770.88	p<.01
Percent total parks	0.12	615.54	p<.01
Percent local parks	0.04	213.05	p<.01
Percent county parks	0.01	38.21	p<.01
Percent state parks or forests	0.11	526.13	p<.01
Percent national parks or forests	0.18	891.75	p<.01

Note: Percent greenspace indicates percent of a block group covered by the type of greenspace. Forest, shrubland, herbaceous, and wetlands comprised total land cover greenspace. Local, county, state, regional, and national parks comprised total parks.

Table 4.3 Spatial error models predicting 11 greenspace measures (percent area of a block group) in block groups across the contiguous United States (n=187,809)

	Total landcover greenspace (%)		Forest (%)		Shrubland (%)		Herbaceous (%)		Wetlands (%)		Canopy (%)	
	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE
Percent non-Hispanic White	0.07*	0.002	0.04*	0.002	0.004*	0.001	0.01*	0.001	0.01*	0.001	0.05*	0.001
MHHI ($10,000)	0.38*	0.02	0.29*	0.01	0.06*	0.01	0.04*	0.005	0.003	0.01	0.43*	0.01
Urban	-11.46*	0.30	-5.56*	0.23	-1.86*	0.11	-1.52*	0.09	-2.11*	0.11	-2.47*	0.20
Suburban	-1.20*	0.26	0.29	0.19	-0.45*	0.10	-0.54*	0.08	-0.37*	0.10	0.69*	0.16
Large Rural	-0.70*	0.28	0.13	0.21	-0.24*	0.11	-0.29*	0.09	-0.38*	0.11	0.35	0.18
Median Housing Age	-0.24*	0.003	-0.13*	0.002	-0.03*	0.001	-0.03*	0.00	-0.04*	0.001	-0.05*	0.002
Northeast	8.94*	0.58	8.73*	0.49	-3.16*	0.20	-0.94*	0.17	2.82*	0.18	12.71*	0.47
Midwest	2.42*	0.54	4.63*	0.46	-3.72*	0.19	-0.45*	0.16	1.70*	0.16	7.06*	0.45
South	10.49*	0.50	10.28*	0.43	-2.96*	0.17	-0.10	0.15	2.84*	0.15	17.03*	0.42
Spatial parameter (λ)	0.85*		0.87*		0.83*		0.83*		0.78*		0.89*	

*Indicates statistical significance at p<.05.
MHHI: Median household income (represented in $10,000 increments)
Percent greenspace indicates percent of a block group covered by the type of greenspace.
Forest, shrubland, herbaceous, and wetlands comprised total land cover greenspace.

Table 4.3 (cont'd) Spatial error models predicting 11 greenspace measures (percent area of a block group) in block groups across the contiguous United States (n=187,809)

	Total parks (%)		Local parks (%)		County parks (%)		State parks (%)		National parks (%)	
	B	SE	B	SE	B	SE	B	SE	B	SE
Percent non-Hispanic White	0.01*	0.001	-0.01*	0.001	0.000	0.000	0.004*	0.001	0.01*	0.001
MHHI ($10,000)	0.01	0.01	0.09*	0.005	0.01*	0.001	-0.002	0.004	-0.002	0.01
Urban	-2.19*	0.16	1.34*	0.05	0.02	0.01	-0.71*	0.07	-1.08*	0.13
Suburban	-0.77*	0.15	0.24*	0.06	-0.01	0.01	-0.17*	0.07	-0.06	0.11
Large Rural	-0.53*	0.17	0.23*	0.07	-0.01	0.02	-0.25*	0.07	0.22*	0.12
Median Housing Age	-0.01*	0.002	0.01*	0.001	-0.001*	0.000	-0.005*	0.001	-0.01*	0.00
Northeast	-0.81*	0.23	-0.48*	0.05	0.06*	0.01	0.76*	0.09	-0.04	0.25
Midwest	-0.68*	0.21	0.42*	0.05	0.04*	0.01	0.02	0.08	0.45	0.24
South	-0.86*	0.19	-0.34*	0.04	-0.01	0.01	0.05	0.08	0.23	0.22
Spatial parameter (λ)	0.72*		0.28*		0.21*		0.69*		0.85*	

*Indicates statistical significance at p<.05.
MHHI: Median household income (represented in $10,000 increments)
Percent greenspace indicates percent of a block group covered by the type of greenspace
Local, county, state, regional, and national parks comprised total parks

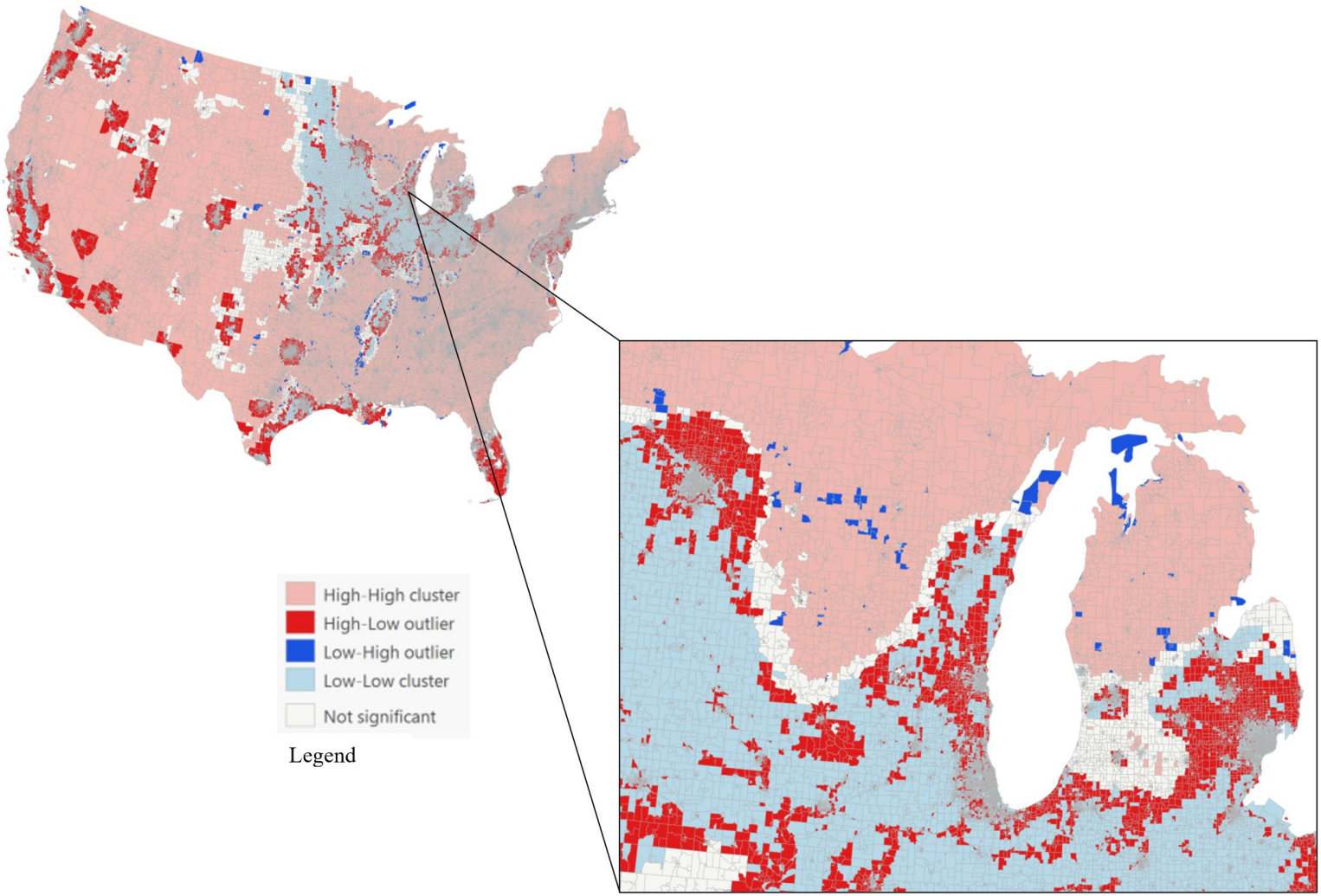

Figure 4.4 Spatial autocorrelation of percent total land cover greenspace (aggregate of forest, shrubland, herbaceous, and wetlands) in block groups across the contiguous United States (n=187,809)

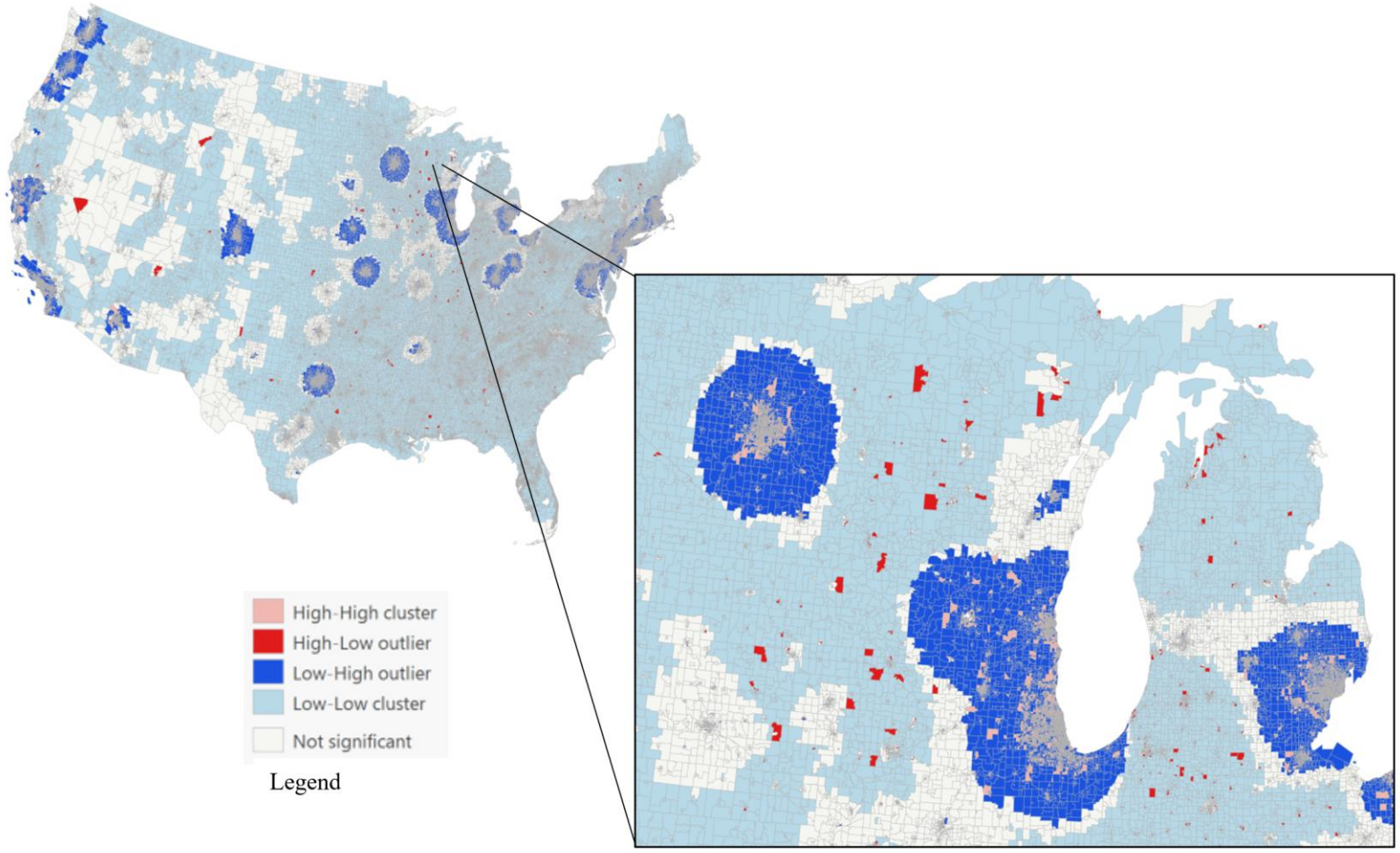

Figure 4.5 Spatial autocorrelation of percent local parks in block groups across the contiguous United States (n=187,809)

CHAPTER 5

EXAMINING THE RELATIONSHIP BETWEEN GREENSPACE AND PHYSICAL ACTIVITY, OBESITY, AND HEALTH-RELATED QUALITY OF LIFE ACROSS THE UNITED STATES[1]

[1]Ellen W. Stowe, S. Morgan Hughey, Courtney Monroe, Dwayne Porter, Andrew T. Kaczynski. To be submitted to *International Journal of Environmental Research and Public Health*

5.1 ABSTRACT

Many adults are physically inactive, have obesity, and report poor health-related quality of life. Greenspace has been tied to these health conditions, but with mixed findings. This study examined multiple greenspace measures in connection to physical activity, obesity, and health-related quality of life across counties in the contiguous United States. County data (n=3,101) on physical activity, obesity prevalence, and health-related quality of life (i.e., general, physical, and mental health) were obtained from 2016 County Health Rankings. Data from the 2016 National Land Cover Database and 2019 Esri's USA parks were used to create 11 measures of greenspace: five land cover, one tree canopy, five parks. American Community Survey 2016 5-year estimates provided race/ethnicity and income data. Urban Influence Codes from 2012 determined county rurality. Region was obtained from the U.S. Census. Separate spatial error models tested the relationship between the five health outcomes and 11 greenspace measures, controlling for race/ethnicity, income, rurality, and region. A queen spatial weights matrix was used in all analyses. Total land cover greenspace and tree canopy were associated with worse outcomes for all five health measures. Forest was associated with worse health-related quality of life, herbaceous with worse physical activity, and wetlands with worse obesity. Total parks had a beneficial association with physical activity, obesity, and health-related quality of life. Local and national parks had a beneficial association with physical activity, obesity, general health, and physical health. Parks may be one of the most beneficial forms of greenspace for health. Notably, local parks may be most important, as they showed the strongest positive association with physical activity, obesity, and health-related quality of life.

5.2 INTRODUCTION

Many adults in the United States are physically inactive, have obesity, and report poor health-related quality of life, placing them at risk for acute and chronic health conditions.[1-4,11,20] For example, regular physical activity is associated with improved physical health, executive functioning, and quality of life; reduced depressive symptoms and acute and chronic symptoms of anxiety; and reduced risk for weight gain, obesity, certain cancers, several chronic conditions, and premature death.[1,2] The majority of American adults, however, do not meet minimum physical activity recommendations; only 26% of men and 19% of women meet the aerobic and muscle-strengthening guidelines.[4] As well, in part due to physical inactivity, obesity has become a public health crisis: more than four in ten adults have obesity.[3,11] Obesity increases the risk for type 2 diabetes, hypertension, heart disease, stroke, and certain cancers.[12] Lastly, health-related quality of life (i.e., perceived general, physical, and mental health), an indicator of overall health and a predictor of disease risk, is also of concern.[111] About 10% of American adults report they are of fair or poor health; for adults aged 65 years and older, the prevalence increases to 22%.[20] Further, about one in five adults lived with a mental illness in 2020, of which depression and anxiety were two of the most common disorders.[23] Both are associated with suicide, which has increased steadily over the last two decades and is a leading cause of death in the United States.[20,25,26]

The consequences of inadequate physical activity, high obesity prevalence, and poor health-related quality of life result in substantial individual, population, and economic burden.[84,100,145] For example, about half of United States adults have a chronic health condition, and one-quarter have two or more chronic conditions.[318] Average life

expectancy has declined, and the cost of healthcare has continued to rise.[20,387] Environmental factors or interventions that have the potential to impact these health behaviors and outcomes are of high priority, as they may result in significant and sustainable individual and population level benefit.[163,388,389] A key environmental factor that has been linked to all these health behaviors and outcomes is greenspace.[28] Greenspace is developed and undeveloped land that contains vegetation, including tree canopy, forest, parks, and recreational areas.[173]

Several studies and reviews have concluded that varying types of greenspace promote physical activity.[29,30,33,34,55,58] For example, greater amounts of or access to greenspace has been associated with more physical activity.[29,30,34] Increased exposure to greenspace has also been associated with several positive physical health (e.g., better subjective general heath, reduced obesity risk) and mental health (e.g., lesser likelihood for depressive symptoms, improved self-esteem) outcomes, as well as lower mortality risk.[34-36,38,55,195]A meta-analysis of 140 greenspace studies found that greenspace was linked to lower salivary cortisol, heart rate, high-density lipoprotein cholesterol, type 2 diabetes, and mortality, among other benefits; greenspace was also related to improved self-reported health.[36] Living closer to a park has also been associated with better mental health.[234]

Although considerable research has identified the benefits of greenspace on physical activity, obesity, and health-related quality of life, studies have reported mixed findings.[58-61] Moreover, key gaps exist in this critical area of study. Many studies have examined greenspace only in urban areas, in a single city or county, or outside the United

States, warranting research on overlooked (e.g., rural and suburban) and larger (e.g., regional and national) areas.[62-64]

Further, many studies have only considered one type of greenspace (e.g., parks) and have not taken into consideration how differing types of greenspace may be linked to health.[64,192,253,291] Previous research has shown that specific types of greenspace are associated with varying health outcomes (e.g., trees and mental health).[63,220] However, few studies have examined more than one or two greenspace types simultaneously.[60,249,271] Also, failing to account for the inherent spatial nature of both greenspace and health data during analysis can bias results.[357]

Accordingly, additional research is warranted using spatial methods to better understand the connection between multiple forms of greenspace and multiple types of health, particularly health outcomes that are key to chronic disease prevention and management for adults in the United States. Therefore, using spatial analytic methods, this study examined the relationship between physical activity, obesity, and health-related quality of life and 11 measures of greenspace – five park measures, five land cover measures, and one tree canopy measure – across counties within the contiguous United States.

5.3 METHODS

Study Sample

The eligible study sample was all counties in the contiguous United States (N=3,108). Seven counties were excluded from analysis because they were missing data for median housing age, resulting in a final analytic sample of 3,101 counties. County

spatial data (i.e., shapefiles with geographic boundaries) from 2016 were obtained from the U.S. Census Bureau.[340]

Health and greenspace measures

Five health variables were retrieved from the 2016 County Health Rankings to measure physical inactivity, obesity, and health-related quality of life.[338] This data originated from the 2016 Behavioral Risk Factor Surveillance Survey, which is a nationally representative survey of adults in the United States.[390] However, data were retrieved from County Health Rankings because it has undergone complex modeling to provide more stable estimates for counties with a small number of survey respondents.[350] County Health Rankings data have also previously been used in health and greenspace research.[194,196,351] Physical inactivity was measured as the percentage of adults age 20 and over reporting no leisure-time physical activity. Obesity was measured as the percentage of the adult population age 20 and older that reported a body mass index (BMI) greater than or equal to 30 kg/m. Three indicators were used to reflect health-related quality of life: the percentage of adults reporting fair or poor health, the percentage of adults with frequent physical distress (i.e., 14 or more days of poor physical health per month), and percentage of adults with frequent mental distress (i.e., 14 or more days of poor mental health per month).

A total of 11 greenspace measures were created: five greenspace land cover measures, one tree canopy measure, and five park measures. The five greenspace land cover measures indicated percent of county covered by forest, shrubland, herbaceous, wetlands, or total greenspace land cover (i.e., sum of the four greenspace land cover measures). A 2016 land cover raster surface was obtained from the Multi-Resolution

Land Cover Characteristics (MRLC) Consortium's National Land Cover Database (NLCD), which provided national spatial and descriptive Landsat-based land cover data at 30-meter resolution.[185] Within ArcGIS Pro (Esri, v2.6), the Tabulate Area tool was used analyze the land cover raster surface to determine the county area in square meters for forest, shrubland, herbaceous, and wetlands; the areas of these four measures were summed to get total greenspace land cover. Greenspace area was divided by total county area to get percent greenspace coverage per county for each of the five measures.

One tree canopy measure was created to indicate percent of a county covered by tree canopy. Tree canopy data from 2016 were also obtained from the MRLC. Data were contained in a raster surface where cell values range from 0% to 100%, indicating percentage of a 30-square meter area covered by tree canopy.[199] Using these cell values, within ArcGIS Pro, the Zonal Statistics tool was used to determine percent tree canopy coverage for each county.

Five park measures indicating percent of a county covered by a park were created: percent total parks (i.e., sum of all park types), percent local parks, percent county parks, percent state parks or forest, and percent national park or forests. Parks data were obtained in July 2019 from Esri's USA Parks, a layer package that contains data on United States local parks (n=40,601), county parks (n=1394), state parks or forests (n=5362), regional parks (n=447), and national parks or forests (n=1990).[214] Because there were relatively few regional parks with small total area, this park type was not examined individually but was included in the total parks measure. Within ArcGIS Pro, the Summarize Within tool was used to determine area of each specific park type within a county; the areas of these park types were summed to get total park area per county. Park

area was divided by total county area to get percent park coverage per county for total parks, local parks, county parks, state parks, national parks.

County demographic and geographic characteristics

Measures indicating county race/ethnicity, income, rurality, and region were selected as covariates as they are associated either the five health measures, the greenspace measures, or both.[5,11,41-44,46,123] Median housing age was also selected as a covariate because it has been associated with greenspace, as older areas may be more walkable and thus have greater access to specific greenspace types (e.g., parks) and have had more time for greenspace to grow (e.g., tree canopy).[42,328] Median household income (dollars), race/ethnicity (percent non-Hispanic White), and median housing age (years) were obtained from the 2016 American Community Survey (ACS) 5-year estimates. Region data was retrieved from the U.S. Census.

The U.S. Department of Agriculture Economic Research Service's 2013 Urban Influence Codes were used to determine urbanicity. The 12 Urban Influence Codes were aggregated into five categories: major metropolitan (in metropolitan areas of at least 1 million people; code 1), small metropolitan (in metropolitan areas of less than 1 million people; code 2), micropolitan (in areas both adjacent and not adjacent to metropolitan areas; codes 3, 5, and 8), large rural (noncore areas adjacent to metropolitan or micropolitan areas and contain a town of at least 2,500 people; codes 4, 6, 9, 11) and small rural (in areas both adjacent and not adjacent to small metropolitan or micropolitan areas and do not contain a town of at least 2,500 people or counties no adjacent to metropolitan or micropolitan areas not containing a town of at least 2,500 people; codes 7,10, 12).[337]

Statistical Analyses

Descriptive characteristics for the five health measures, 11 greenspace measures, and all county sociodemographic and geographic characteristics were calculated in Stata (version 17.0, College Station, TX).

Separate ordinary least squares (OLS) regression models were conducted for each of the five health measures with each of the 11 greenspace measures using GeoDa™ (v1.20.0, Luc Anselin). Results from the OLS analyses were reviewed to determine if spatial autocorrelation was present in the data as indicated by a statistically significant Moran's I value. When autocorrelation is present, values that are either more alike or more different than expected are found together, resulting in erroneous standard errors and increased risk for type 1 error. If autocorrelation was indicated, a spatial error model was applied. People of similar characteristics tend to cluster (e.g., people with high incomes live near other people with high incomes). When areas share characteristics that produce the clustering of a health behavior, a spatial error model is appropriate. Further, a spatial error model accounts for the inability to model all sources of spatial dependence, which results in spatial dependence in the error terms of neighboring areas, through a spatially lagged error term[357] In all regression analyses, a queen spatial weights matrix was used, which identified relationships between block groups and was used to weight the error terms in the spatial error models.[364] Also, race/ethnicity, income, rurality, median household age, and United States region were controlled for.

5.4 RESULTS

As shown in Table 5.1, the county average for the percent of adults who were physically inactive was 27.41% (SD=5.41), for percent of adults with obesity was

30.97% (SD=4.46), for percent of adults with fair or poor health was 16.94% (SD=4.97), for percent of adults with frequent physical distress was 11.56% (SD=2.45), and for percent of adults with frequent mental distress was 11.24% (SD=2.07).

As depicted in Table 5.1, the county average for greenspace coverage varied widely. Within the five land cover greenspace measures, the average for percent wetlands was lowest (mean=6.81%, SD=10.34) and the average for percent total greenspace land cover was the highest (mean=54.45%, SD=27.89). Average percent tree canopy coverage was 29.63% (SD=24.52). Within the five parks measures, the average for percent county parks was lowest (mean=0.03%, SD=0.18) and the average for percent total parks was highest (mean=8.29%, SD=17.14).

Finally, the county average for percent of the population who was non-Hispanic White was 77.42% (SD=19.69), for median household income was $47,785 (SD=$12,483), and for median housing age was 41.19 years (SD=11.02; Table 5.1). In addition, 13.83% of counties were categorized as major metropolitan, 23.48% were small metropolitan, 20.51% were micropolitan, 25.54% were large rural, and 16.64% were small rural.

Results from the OLS models indicated that for all five health measures, spatial autocorrelation was present: Moran's I values were significant ($p<.05$) and positive, indicating clustering of all greenspace measures. In all subsequent spatial error models, the spatial parameter (λ) was positive and significant, indicating an improvement in model fit compared to OLS. Summary findings from spatial error models for the relationship between the five health measures and 11 greenspace measures can be found in Table 5.2; full model results can be found in the Appendix, Table 5.3.

Percent total greenspace land cover had a significant positive relationship with all five health measures, in that as percent total greenspace land cover increased by 1%, percent physically inactive increased by 0.02 (SE=0.004, p<.01), percent obesity prevalence increased by 0.01 (SE=0.004, p<.01), percent fair or poor health increased by 0.01 (SE=0.002, p<.01), percent frequent physical distress increased by 0.004 (SE=0.001, p<.01), and percent frequent mental distress increased by 0.003 (SE=0.001, p<.01).

Percent forest had a significant positive relationship with three health measures, in that as percent total forest increased by 1%, percent fair or poor health increased by 0.01 (SE=0.003, p<.01), percent frequent physical distress increased by 0.01 (SE=0.002, p<.01), and percent frequent mental distress increased by 0.005 (SE=0.001, p<.01).

Percent shrubland was not significantly associated with the five health measures. Percent herbaceous had a significant positive relationship with one health measure, in that as percent herbaceous coverage increased by 1%, percent physical inactivity increased by 0.03 (SE=0.01, p<.01). Percent wetlands had a significant positive relationship with one health measure, in that as percent wetlands coverage increased by 1, percent obesity prevalence increased by 0.03 (SE=0.01, p<.01).

Percent tree canopy had a significant positive relationship with four health measures, in that as percent tree canopy coverage increased by 1%, percent obesity prevalence increased by 0.02 (SE=0.005, p<.01), percent fair or poor health increased by 0.01 (SE=0.003, p=0.01), percent frequent physical distress increased by 0.01 (SE=0.002, p<.01), and percent frequent mental distress increased by 0.01 (SE=0.002, p<.01).

Percent total parks had a significant inverse relationship with all five health variables, in that as percent total park coverage increased by 1%, percent physical inactivity declined by 0.02 (SE=0.005, p<.01), percent obesity prevalence declined by 0.02 (SE=0.004, p<.01), percent fair or poor health decreased by 0.01 (SE=0.002, p<.01), percent frequent physical distress decreased by 0.004 (SE=0.001, p=0.01), and percent frequent mental distress decreased by 0.002 (SE=0.001, p=0.03).

Percent local parks had a significant inverse relationship with four of the five health variables, in that as percent local park coverage increased by 1%, percent physical inactivity declined by 0.69 (SE=0.09, p<.01), percent obesity prevalence declined by 0.68 (SE=0.09, p<.01), percent fair or poor health decreased by 0.22 (SE=0.05, p<.01), and percent frequent physical distress decreased by 0.06 (SE=0.03, p=0.02).

Percent county parks and percent state parks or forests did not have significant associations with any of the five health measures. Percent national park or forests had a significant inverse relationship with four health variables, in that as percent national park or forest coverage increased by 1%, percent physical inactivity declined by 0.02 (SE=0.005, p<.01), percent obesity prevalence declined by 0.02 (SE=0.004, p<.01), percent fair or poor health decreased by 0.01 (SE=0.003, p=0.01), and percent frequent physical distress decreased by 0.003 (SE=0.001, p=0.03).

5.5 DISCUSSION

Summary of findings

This study examined the association between physical activity, obesity, and health-related quality of life (i.e., general, physical, and mental health) and 11 measures of greenspace – five land cover, one tree canopy, and five park measures – in 3,101

counties across the contiguous United States. Results varied by greenspace category. Land cover greenspace measures and tree canopy were associated with worse health outcomes. In contrast, parks measures were associated with better health outcomes.

Findings from this study indicate that parks may be the most beneficial form of greenspace for physical activity, obesity, and health-related quality of life. The total parks measure was associated with better outcomes for all five health measures; local parks and national parks were associated with better outcomes for physical activity, obesity, general health, and physical health. Similar findings have been reported in previous research.

For physical activity, a Canadian study found that more park area and greater number of parks within 1 km of residents' homes was associated with greater amounts of moderate-to-strenuous physical activity and greater likelihood of meeting physical activity recommendations (i.e., 150 minutes of activity).[29] For park users in the City of Los Angeles, distance to parks predicted park use and physical activity within parks; further, park users reported engaging in physical activity most often in parks.[230]

For obesity, a study of 67 metropolitan areas in the United States found a significant association between park density and weight status; areas with the greatest density of parks compared to the lowest density had reduced risk for overweight and obesity.[233] However, a study in Canada found that more park area was linked to greater risk for overweight and obesity in women.[267]

For health-related quality of life (i.e., perceived general health, physical health, and mental health), in a study in Missouri, middle-aged adults that did not have a park within a half mile of their residence had greater risk for having at least two chronic health conditions.[232] A study in Ohio found that older adults who use parks report significantly

better physical health compared to older adults who do not use parks; moreover, older adults with a park within walking distance had better physical health compared to those who did not.[223] A national longitudinal study of parks in the United States found that in 1991, park use and use of park programming was not linked with self-rated health; in contrast, in 2015, people who used parks and park programming often had greater likelihood of better self-rated health.[280] When analyzing adults living in Los Angeles, researchers found that living closer to a park was associated with better mental health.[234]

Through a variety of mechanisms, parks can positively impact health.[229] National parks provide benefits that may be unique to larger, less structured spaces. For example, an analysis of literature on wildland (e.g., national parks, national forests) and health found that greater exposure to wildland areas was linked to better mental health, including increased self-esteem and reduced stress.[282] A Canadian photovoice study found that for adults, access to parks and wilderness has restorative benefits that positively influence health and well-being.[289] Notably, however, local parks may be the most important type of park, as findings from this study showed that this measure had the strongest relationship with the health outcomes, with estimates ranging about 15-35 times larger than the total park measure and the national park measure. Local parks are the most prevalent and accessible park type, particularly in non-rural areas. Further, local parks provide both structured and unstructured places to be physically active, promote socialization among residents, have programming that both promotes park use and healthful behaviors among users, and can be restorative and help alleviate stress.[374,375] Interestingly, even residents of neighborhoods with parks, but who do not use parks, report benefits from local parks that are present in their neighborhoods.[375] Parks may also

benefit the environment through reducing air pollution and lowering surface temperature, thus improving human health.[28,391]

It is essential to note that park use and park quality are not equitable in the United States. In a national study of parks, researchers found that residents of low-income neighborhoods used parks less frequently.[374] A review of urban parks with an environmental justice focus concluded that people of low socioeconomic status and racial/ethnic minority residents often have less total park area, less park area per capita, and parks of worse quality, and parks with more safety concerns.[181] In addition, funding and resources for parks has declined, placing greater burden on low-income and underserved communities for gaining access to quality parks.[392] Efforts to create and ensure equitable access to health promoting features of neighborhoods like parks must consider neighborhood demographic characteristics as well as ways to maximize resources to improve park accessibility, quality, and safety.

In contrast to parks, the composite measure of all land cover greenspace was significantly associated with worse outcomes for all five health indicators. In addition, forest was associated with worse health-related quality of life, herbaceous was associated with increased physical inactivity, and wetlands was associated with increased obesity prevalence. Previous research has reported mixed findings. For example, a study of the 25 largest cities using census tracts found that greater non-tree vegetation was associated with less physical activity.[210] In contrast, in a national study of 135 counties within metropolitan areas across the United States, researchers found that vegetative cover, specifically forest, shrubland, and herbaceous vegetation, was related to more physical

activity.[195] Also, in a study of non-metropolitan counties in the United States, natural amenities, such as forest vegetation, were correlated with more physical activity.[259]

Prior research has produced mixed findings for the relationship between obesity and greenspace. A study in England found that from 2000 to 2003, residents with the greenest areas were more likely to have overweight and obesity; however, from 2004-2007, residents in the greenest areas were less likely to have overweight or obesity, but these findings were nonsignificant.[273] In contrast, in a national study of greenspace in the United States, forest land was associated with reduced BMI.[220] Another national study found that varying types of greenspace (e.g., connections between forests and developed areas, shrubland) were significantly correlated with having a healthy BMI.[195]

Past findings on health-related quality of life and greenspace are also mixed.[194] A European study examining surrounding greenness and subjective residential proximity to greenspaces found significant associations with better subjective general health.[37] An analysis of greenspace in Washington state found that aggregated greenspace was not associated with general or mental health, but when examined by type of greenspace, forest was associated with better mental health.[60] However, when stratified by urbanicity, researchers found a significant beneficial relationship between mental health and aggregated greenspace and forest land in urban areas. Also, studies focused on greenspace interventions have identified wetlands as a type of greenspace that may reduce stress and improve mood.[393,394]

Findings from this study also indicated that tree canopy was also associated with worse outcomes for obesity, general health, physical health, and mental health. Prior research has again reported mixed results. For example, in a study of 496 of the 500 most

populated cities in the United States, a beneficial relationship was observed between obesity and tree canopy in cities with a greater proportion of non-Hispanic White residents; in analyses of cities with a majority of non-Hispanic Black residents, greater amounts of tree cover were related to lower obesity prevalence and improved mental health.[207] A Wisconsin study found that greenspace, as measured by the normalized difference vegetation index (NDVI) and tree canopy, was associated with reduced depressive symptoms.[62] An examination of greenspace and general health in New York found that type of greenspace was important for predicting health; residents were more likely to report better general health when living in areas with the greatest amount of tree canopy.[275]

There are several potential explanations as to why greater land cover greenspace and tree canopy are potentially associated with worse physical activity, obesity, and health-related quality of life. First, the value of greenspace may depend on both its quantity and quality. Not all greenspaces are well-cared for; there areas of disordered greenspace, such as vacant lots, which are prevalent across the United States. Because of their disordered nature, vacant lots may not be usable, promote incivilities, and cause negative physiological responses among nearby residents.[210,395] Second, areas with excess greenspace or abandoned spaces that consequently become greenspace contribute to a neighborhood's overall greenspace coverage but may be detrimental for health through overgrowth and vector-borne disease transmission.[396] These spaces, although green, are unsafe and unusable. Similarly, areas with large amounts of greenspace may not be suitable for physical activity, socializing, or even restorative sedentary activities (e.g., places to rest, eat, or read) or may not be easily accessible, and therefore may not benefit

residents.[210,397] For example, forested parks are open to the public and contain access points, facilities such as visitors' centers or bathrooms, and maintained hiking trails or picnicking spots. In contrast, private land that is forested, or heavy with other greenspace types, are unusable and therefore potentially irrelevant to nearby residents. Lastly, prior research has indicated that canopy coverage is beneficial to health, particularly for residents of urban areas.[275,326] This study controlled for but did not stratify by urbanicity, which may have masked a potentially beneficial relationship of canopy, especially as most people in the United States reside in urban areas.

Limitations and Strengths

This study sought to fill gaps in the greenspace literature by examining both composite and individual types of greenspace and their association with physical inactivity, obesity, and health-related quality of life across the contiguous United States. However, a limitation of this study was greenspace was measured in quantity but not quality. Previous research suggests that quality of greenspace is an important feature in connection to health. For example, park quality can vary widely, and park quality is associated with park use.[32,398,399] Further, because the current greenspace measures described amount, it was not possible to assess what features of the greenspace measures may have contributed to the associations with physical inactivity, obesity, and health-related quality of life. This is an important limitation, as greenspace features (e.g., playgrounds, walking paths) have been linked to greenspace use[32,216,236]

In addition, subjective perceptions of greenspaces may be important to greenspace use and health. In a study of park availability, there was considerable disagreement between subjective and objective park availability among study respondents, which could

indicate that people may have but are unaware of parks in their neighborhoods.[400] A study in Spain found that neighborhood surrounding greenspace and perceived neighborhood proximity to green spaces, specifically parks, were positively associated with better subjective general health, however, objectively measured neighborhood proximity to greenspace was not a significant predictor of subjective general health.[37] Also, prior research suggests that the connection between greenspace and health has spatial and social-ecological variation.[176] Therefore, future examinations of greenspace and health could consider not only how greenspace is measured, including quality of greenspace and perceived vs objective greenspace availability, but how the greenspace is connected to and improves individual neighborhoods and communities, which vary widely in composition and size across the United States.

This study examined the relationship between health and 11 measures of greenspace and provided findings that reflected the contiguous United States as a whole. However, the United States is heterogenous, with variability in both health behaviors and outcomes and in greenspace, which is a limitation inherent to greenspace and health research. Use of spatial error models controlling for several related indicators sought to account for this. However, public health practitioners and others responsible for city planning and health may analyze smaller geographic areas, such as neighborhoods within a county or counties within one state, that will have unique greenspace needs that vary by population and location.

Conclusion

In a national analysis of counties across the contiguous United States, the relationships between physical activity, obesity, and health-related quality of life and

greenspace varied by how greenspace was assessed. Land cover greenspace measures were associated with worse health outcomes. However, parks were beneficially associated with physical activity, obesity, and health-related quality of life. In particular, the strongest relationship was observed for local parks, indicating they may be the most beneficial form of greenspace for human health. Efforts to ensure equitable access to and quality of parks, including adequate funding and resources, should be prioritized to improve population health.

Table 5.1 County descriptive statistics for health measures, greenspace measures, and demographic characteristics (n=3,101)

		Mean	SD
Health measures	Percent physically inactive	27.41	5.41
	Percent with obesity	30.97	4.46
	Percent with fair or poor health	16.94	4.97
	Percent frequent physical distress	11.56	2.45
	Percent frequent mental distress	11.24	2.07
Greenspace measures	Percent total greenspace land cover	54.46	27.89
	Percent forest	29.92	25.48
	Percent shrubland	8.45	18.13
	Percent herbaceous	9.28	16.79
	Percent wetlands	6.81	10.34
	Percent tree canopy	29.63	24.52
	Percent total parks	8.29	17.14
	Percent local park	0.20	0.77
	Percent county park	0.03	0.18
	Percent state park or forest	1.58	5.91
	Percent national park or forest	6.63	16.52
Demographic characteristics	Percent non-Hispanic White	77.42	19.69
	Median household income (dollars)	47,785	12,483
	Median housing age (years)	41.19	11.02
		N	Percent
Geographic characteristics	Major metropolitan	429	13.83
	Small metropolitan	728	23.48
	Micropolitan	636	20.51
	Large rural	792	25.54
	Small-town rural	516	16.64
	Northeast	215	6.9
	Midwest	1050	33.9
	South	1442	45.9
	West	414	13.4

Greenspace measures indicate percent of a county covered by the greenspace type.
Percent total land cover greenspace indicates percent of a county covered by total land cover greenspace (forest, shrubland, herbaceous, and wetlands).
Percent total parks indicates percent of a county covered by all park types (local, county, state, regional, and national parks).

Table 5.2 Summary of 55 spatial error models predicting physical inactivity, obesity, and health-related quality of life in counties in the contiguous United States (n=3,101)

	Percent physically inactive			Percent obesity			Percent fair or poor health			Percent frequent physical distress			Percent frequent mental distress		
	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value
Percent total land cover greenspace	0.02*	0.004	0.00	0.01*	0.004	0.00	0.01*	0.002	0.00	0.004*	0.001	0.00	0.003*	0.001	0.00
Percent forest	0.01	0.005	0.23	0.01	0.004	0.08	0.01*	0.003	0.00	0.01*	0.002	0.00	0.005*	0.001	0.00
Percent shrubland	0.01	0.01	0.23	-0.01	0.01	0.14	0.01	0.005	0.17	-0.001	0.003	0.64	-0.001	0.002	0.54
Percent herbaceous	0.03*	0.01	0.00	0.01	0.01	0.05	-0.002	0.004	0.73	0.0005	0.002	0.85	0.001	0.002	0.73
Percent wetlands	0.01	0.01	0.41	0.03*	0.01	0.00	-0.01	0.01	0.33	-0.002	0.004	0.68	-0.001	0.003	0.83
Percent canopy	0.01	0.01	0.09	0.02*	0.005	0.00	0.01*	0.003	0.01	0.01*	0.002	0.00	0.01*	0.002	0.00
Percent total parks	-0.02*	0.005	0.00	-0.02*	0.004	0.00	-0.01	0.002	0.00	-0.004	0.001	0.01	-0.002	0.001	0.03
Percent local parks	-0.69	0.09	0.00	-0.68	0.09	0.00	-0.23	0.05	0.00	-0.06	0.03	0.02	0.01	0.02	0.71
Percent county parks	-0.18	0.32	0.58	-0.42	0.30	0.16	-0.06	0.16	0.73	0.01	0.09	0.91	0.004	0.07	0.96
Percent state parks or forests	0.00	0.01	0.81	-0.01	0.01	0.53	-0.01	0.01	0.19	-0.01	0.004	0.13	-0.004	0.003	0.20
Percent national parks or forests	-0.02	0.005	0.00	-0.02	0.004	0.00	-0.01	0.003	0.01	-0.003	0.001	0.03	-0.002	0.001	0.07

*Indicates statistical significance at $p<.05$

Note: Percent greenspace indicates percent of a county covered by the greenspace measure. Separate models were run for each health outcome and each greenspace measure; income (median household income), race/ethnicity (percent non-Hispanic White), and urbanicity (major metropolitan, small metropolitan, micropolitan, non-core, and rural) were controlled for in each model.

Appendix

Table 5.3. Percent total land cover greenspace: Spatial error model predicting physical inactivity, obesity, and health-related quality of life in contiguous United States counties (n=3,101)

	Percent physically inactive			Percent obesity prevalence			Percent fair or poor health			Percent frequent physical distress			Percent frequent mental distress		
	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value
Percent total land cover greenspace	0.02	0.004	0.00	0.01	0.004	0.00	0.01	0.002	0.00	0.004	0.001	0.00	0.003	0.001	0.00
MHHI ($10,000)	-1.39	0.08	0.00	-1.18	0.07	0.00	-1.73	0.04	0.00	-0.96	0.02	0.00	-0.75	0.02	0.00
Percent non-Hispanic White	0.03	0.005	0.00	-0.03	0.004	0.00	-0.13	0.003	0.00	-0.05	0.001	0.00	-0.03	0.001	0.00
Major Metro	-0.11	0.31	0.73	0.17	0.29	0.56	-0.08	0.16	0.64	-0.04	0.09	0.65	-0.02	0.07	0.75
Small Metro	-1.20	0.21	0.00	-0.20	0.20	0.32	-0.46	0.11	0.00	-0.22	0.06	0.00	-0.15	0.05	0.00
Micropolitan	-0.64	0.19	0.00	0.26	0.18	0.16	-0.02	0.10	0.83	-0.03	0.05	0.54	-0.05	0.04	0.27
Large rural	-0.10	0.18	0.58	0.27	0.17	0.11	0.02	0.09	0.81	-0.04	0.05	0.40	-0.05	0.04	0.19
Small rural	0.05	0.01	0.00	-0.001	0.01	0.88	-0.03	0.005	0.00	-0.02	0.003	0.00	-0.01	0.002	0.00
Northeast	3.40	0.67	0.00	3.68	0.58	0.00	2.19	0.55	0.00	0.29	0.33	0.38	0.33	0.30	0.27
Midwest	5.42	0.48	0.00	6.14	0.42	0.00	1.24	0.36	0.00	-0.60	0.21	0.00	-0.91	0.19	0.00
South	7.65	0.45	0.00	5.56	0.39	0.00	3.56	0.36	0.00	0.69	0.21	0.00	0.16	0.20	0.43
Constant	23.92	0.87	0.00	33.45	0.80	0.00	34.31	0.53	0.00	20.82	0.30	0.00	18.17	0.26	0.00
Spatial parameter(**λ**)	0.64	0.02	0.00	0.61	0.02	0.00	0.82	0.01	0.00	0.85	0.01	0.00	0.89	0.01	0.00

MHHI: Median household income in $10,000 increments

Percent total land cover greenspace indicates percent of a county covered by total land cover greenspace (forest, shrubland, herbaceous, and wetlands)

Table 5.4. Percent forest: Spatial error model predicting physical inactivity, obesity, and health-related quality of life in contiguous United States counties (n=3,101)

	Percent physically inactive			Percent obesity prevalence			Percent fair or poor health			Percent frequent physical distress			Percent frequent mental distress		
	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value
Percent forest	0.01	0.005	0.23	0.01	0.004	0.08	0.01	0.003	0.00	0.01	0.002	0.00	0.005	0.001	0.00
MHHI ($10,000)	-1.44	0.08	0.00	-1.20	0.08	0.00	-1.73	0.04	0.00	-0.96	0.02	0.00	-0.75	0.02	0.00
Percent non-Hispanic White	0.03	0.005	0.00	-0.03	0.005	0.00	-0.13	0.003	0.00	-0.05	0.001	0.00	-0.03	0.001	0.00
Major Metro	-0.27	0.31	0.37	0.05	0.28	0.86	-0.11	0.16	0.52	-0.05	0.09	0.58	-0.03	0.07	0.71
Small Metro	-1.34	0.21	0.00	-0.28	0.20	0.15	-0.48	0.11	0.00	-0.23	0.06	0.00	-0.16	0.05	0.00
Micropolitan	-0.75	0.19	0.00	0.19	0.18	0.30	-0.04	0.10	0.68	-0.04	0.05	0.44	-0.05	0.04	0.22
Large rural	-0.18	0.18	0.31	0.22	0.17	0.21	0.01	0.09	0.95	-0.05	0.05	0.33	-0.06	0.04	0.16
Small rural	0.04	0.01	0.00	-0.004	0.01	0.61	-0.03	0.005	0.00	-0.02	0.003	0.00	-0.01	0.002	0.00
Northeast	3.03	0.67	0.00	3.32	0.58	0.00	1.88	0.54	0.00	0.14	0.32	0.67	0.28	0.29	0.34
Midwest	4.76	0.45	0.00	5.72	0.39	0.00	1.06	0.35	0.00	-0.67	0.20	0.00	-0.94	0.19	0.00
South	7.28	0.44	0.00	5.28	0.38	0.00	3.37	0.35	0.00	0.60	0.21	0.00	0.13	0.19	0.51
Constant	25.70	0.78	0.00	34.48	0.71	0.00	34.60	0.49	0.00	20.92	0.28	0.00	18.22	0.25	0.00
Spatial parameter(**λ**)	0.64	0.02	0.00	0.60	0.02	0.00	0.81	0.01	0.00	0.84	0.01	0.00	0.89	0.01	0.00

MHHI: Median household income in $10,000 increments

Percent forest indicates percent of a county covered by forest

Table 5.5. Percent shrubland: Spatial error model predicting physical inactivity, obesity, and health-related quality of life in contiguous United States counties (n=3,101)

	Percent physically inactive			Percent obesity prevalence			Percent fair or poor health			Percent frequent physical distress			Percent frequent mental distress		
	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value
Percent shrubland greenspace	0.01	0.01	0.23	-0.01	0.01	0.14	0.01	0.005	0.17	-0.001	0.003	0.64	-0.001	0.002	0.54
MHHI ($10,000)	-1.47	0.08	0.00	-1.23	0.07	0.00	-1.75	0.04	0.00	-0.97	0.02	0.00	-0.76	0.02	0.00
Percent non-Hispanic White	0.03	0.005	0.00	-0.03	0.004	0.00	-0.13	0.003	0.00	-0.05	0.001	0.00	-0.03	0.001	0.00
Major Metro	-0.24	0.31	0.44	0.01	0.29	0.98	-0.10	0.16	0.54	-0.06	0.09	0.49	-0.04	0.07	0.61
Small Metro	-1.33	0.21	0.00	-0.32	0.20	0.11	-0.49	0.11	0.00	-0.25	0.06	0.00	-0.17	0.05	0.00
Micropolitan	-0.74	0.19	0.00	0.16	0.18	0.37	-0.05	0.10	0.63	-0.05	0.05	0.31	-0.06	0.04	0.15
Large rural	-0.18	0.18	0.33	0.20	0.17	0.24	0.00	0.09	0.99	-0.06	0.05	0.25	-0.06	0.04	0.12
Small rural	0.04	0.01	0.00	-0.01	0.01	0.27	-0.03	0.005	0.00	-0.02	0.002	0.00	-0.01	0.002	0.00
Northeast	3.41	0.68	0.00	3.28	0.59	0.00	2.22	0.55	0.00	0.22	0.33	0.51	0.29	0.30	0.33
Midwest	4.96	0.48	0.00	5.43	0.42	0.00	1.16	0.37	0.00	-0.70	0.21	0.00	-0.97	0.19	0.00
South	7.52	0.46	0.00	5.15	0.40	0.00	3.53	0.37	0.00	0.61	0.21	0.00	0.11	0.20	0.57
Constant	25.66	0.79	0.00	35.16	0.71	0.00	34.84	0.50	0.00	21.23	0.28	0.00	18.43	0.25	0.00
Spatial parameter(**λ**)	0.63	0.02	0.00	0.59	0.02	0.00	0.82	0.01	0.00	0.85	0.01	0.00	0.89	0.01	0.00

MHHI: Median household income in $10,000 increments

Percent shrubland indicates percent of a county covered by shrubland

Table 5.6. Percent herbaceous: Spatial error model predicting physical inactivity, obesity, and health-related quality of life in contiguous United States counties (n=3,101)

	Percent physically inactive			Percent obesity prevalence			Percent fair or poor health			Percent frequent physical distress			Percent frequent mental distress		
	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value
Percent herbaceous	0.03	0.01	0.00	0.01	0.01	0.05	-0.002	0.004	0.73	0.0005	0.002	0.85	0.001	0.002	0.73
MHHI ($10,000)	-1.48	0.08	0.00	-1.24	0.07	0.00	-1.75	0.04	0.00	-0.97	0.02	0.00	-0.76	0.02	0.00
Percent non-Hispanic White	0.03	0.005	0.00	-0.03	0.004	0.00	-0.13	0.003	0.00	-0.05	0.001	0.00	-0.03	0.001	0.00
Major Metro	-0.17	0.31	0.59	0.10	0.28	0.71	-0.12	0.16	0.47	-0.06	0.09	0.51	-0.03	0.07	0.63
Small Metro	-1.26	0.21	0.00	-0.26	0.20	0.20	-0.50	0.11	0.00	-0.25	0.06	0.00	-0.17	0.05	0.00
Micropolitan	-0.67	0.19	0.00	0.22	0.18	0.23	-0.06	0.10	0.55	-0.05	0.05	0.33	-0.06	0.04	0.16
Large rural	-0.11	0.18	0.54	0.25	0.17	0.15	-0.01	0.09	0.95	-0.06	0.05	0.26	-0.06	0.04	0.13
Small rural	0.03	0.01	0.00	-0.01	0.01	0.21	-0.03	0.005	0.00	-0.02	0.002	0.00	-0.01	0.002	0.00
Northeast	3.71	0.66	0.00	3.75	0.58	0.00	2.07	0.55	0.00	0.24	0.33	0.46	0.31	0.30	0.31
Midwest	5.03	0.45	0.00	5.79	0.39	0.00	1.03	0.36	0.00	-0.68	0.21	0.00	-0.95	0.19	0.00
South	7.70	0.44	0.00	5.48	0.38	0.00	3.42	0.36	0.00	0.63	0.21	0.00	0.12	0.20	0.53
Constant	25.44	0.76	0.00	34.64	0.69	0.00	35.03	0.49	0.00	21.20	0.28	0.00	18.40	0.25	0.00
Spatial parameter(**λ**)	0.63	0.02	0.00	0.60	0.02	0.00	0.81	0.01	0.00	0.85	0.01	0.00	0.89	0.01	0.00

MHHI: Median household income in $10,000 increments

Percent herbaceous indicates percent of a county covered by herbaceous vegetation

Table 5.7. Percent wetlands: Spatial error model predicting physical inactivity, obesity, and health-related quality of life in contiguous United States counties (n=3,101)

	Percent physically inactive			Percent obesity prevalence			Percent fair or poor health			Percent frequent physical distress			Percent frequent mental distress		
	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value
Percent wetlands	0.01	0.01	0.41	0.03	0.01	0.00	-0.01	0.01	0.33	-0.002	0.004	0.68	-0.001	0.003	0.83
MHHI ($10,000)	-1.46	0.08	0.00	-1.22	0.07	0.00	-1.75	0.04	0.00	-0.97	0.02	0.00	-0.76	0.02	0.00
Percent non-Hispanic White	0.03	0.005	0.00	-0.03	0.004	0.00	-0.13	0.003	0.00	-0.05	0.001	0.00	-0.03	0.001	0.00
Major Metro	-0.27	0.31	0.38	0.07	0.28	0.80	-0.12	0.16	0.47	-0.06	0.09	0.50	-0.03	0.07	0.63
Small Metro	-1.35	0.21	0.00	-0.29	0.20	0.14	-0.50	0.11	0.00	-0.25	0.06	0.00	-0.17	0.05	0.00
Micropolitan	-0.76	0.19	0.00	0.19	0.18	0.29	-0.06	0.10	0.56	-0.05	0.05	0.32	-0.06	0.04	0.16
Large rural	-0.19	0.18	0.31	0.22	0.17	0.20	-0.01	0.09	0.96	-0.06	0.05	0.25	-0.06	0.04	0.12
Small rural	0.04	0.01	0.00	-0.01	0.01	0.51	-0.03	0.005	0.00	-0.02	0.002	0.00	-0.01	0.002	0.00
Northeast	3.13	0.66	0.00	3.34	0.57	0.00	2.10	0.54	0.00	0.24	0.32	0.46	0.30	0.30	0.31
Midwest	4.70	0.45	0.00	5.53	0.39	0.00	1.06	0.35	0.00	-0.68	0.21	0.00	-0.96	0.19	0.00
South	7.27	0.44	0.00	5.13	0.38	0.00	3.46	0.36	0.00	0.63	0.21	0.00	0.12	0.20	0.54
Constant	25.87	0.76	0.00	34.48	0.69	0.00	35.05	0.49	0.00	21.22	0.28	0.00	18.42	0.25	0.00
Spatial parameter(**λ**)	0.64	0.02	0.00	0.60	0.02	0.00	0.81	0.01	0.00	0.85	0.01	0.00	0.89	0.01	0.00

MHHI: Median household income in $10,000 increments

Percent wetlands indicates percent of a county covered by wetlands

Table 5.8. Percent tree canopy: Spatial error model predicting physical inactivity, obesity, and health-related quality of life in contiguous United States counties (n=3,101)

	Percent physically inactive			Percent obesity prevalence			Percent fair or poor health			Percent frequent physical distress			Percent frequent mental distress		
	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value
Percent tree canopy	0.01	0.01	0.09	0.02	0.005	0.00	0.01	0.003	0.01	0.01	0.002	0.00	0.01	0.002	0.00
MHHI ($10,000)	-1.43	0.08	0.00	-1.15	0.07	0.00	-1.73	0.04	0.00	-0.96	0.02	0.00	-0.75	0.02	0.00
Percent non-Hispanic White	0.03	0.005	0.00	-0.03	0.004	0.00	-0.13	0.003	0.00	-0.05	0.001	0.00	-0.03	0.001	0.00
Major Metro	-0.28	0.31	0.37	0.04	0.28	0.90	-0.11	0.16	0.50	-0.05	0.09	0.54	-0.03	0.07	0.69
Small Metro	-1.34	0.21	0.00	-0.27	0.20	0.17	-0.49	0.11	0.00	-0.23	0.06	0.00	-0.16	0.05	0.00
Micropolitan	-0.75	0.19	0.00	0.20	0.18	0.27	-0.04	0.10	0.66	-0.04	0.05	0.44	-0.05	0.04	0.24
Large rural	-0.18	0.18	0.31	0.22	0.17	0.19	0.00	0.09	0.97	-0.05	0.05	0.32	-0.06	0.04	0.16
Small rural	0.04	0.01	0.00	0.002	0.01	0.83	-0.03	0.005	0.00	-0.02	0.003	0.00	-0.01	0.002	0.00
Northeast	2.87	0.69	0.00	2.83	0.59	0.00	1.90	0.55	0.00	0.11	0.32	0.73	0.26	0.29	0.37
Midwest	4.71	0.45	0.00	5.65	0.38	0.00	1.03	0.35	0.00	-0.70	0.21	0.00	-0.95	0.19	0.00
South	7.12	0.45	0.00	4.91	0.38	0.00	3.32	0.36	0.00	0.54	0.21	0.01	0.10	0.19	0.62
Constant	25.59	0.78	0.00	33.99	0.71	0.00	34.72	0.50	0.00	20.97	0.28	0.00	18.21	0.25	0.00
Spatial parameter(**λ**)	0.64	0.02	0.00	0.59	0.02	0.00	0.81	0.01	0.00	0.84	0.01	0.00	0.89	0.01	0.00

MHHI: Median household income in $10,000 increments

Percent tree canopy indicates percent of a county covered by tree canopy

Table 5.9. Percent total parks: Spatial error model predicting physical inactivity, obesity, and health-related quality of life in contiguous United States counties (n=3,101)

	Percent physically inactive			Percent obesity prevalence			Percent fair or poor health			Percent frequent physical distress			Percent frequent mental distress		
	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value
Percent total parks	-0.02	0.005	0.00	-0.02	0.004	0.00	-0.01	0.002	0.00	-0.004	0.001	0.01	-0.002	0.001	0.03
MHHI ($10,000)	-1.50	0.08	0.00	-1.27	0.07	0.00	-1.76	0.04	0.00	-0.98	0.02	0.00	-0.76	0.02	0.00
Percent non-Hispanic White	0.03	0.005	0.00	-0.03	0.004	0.00	-0.13	0.003	0.00	-0.05	0.001	0.00	-0.03	0.001	0.00
Major Metro	-0.37	0.30	0.23	-0.03	0.28	0.92	-0.14	0.16	0.39	-0.07	0.09	0.42	-0.04	0.07	0.56
Small Metro	-1.44	0.21	0.00	-0.38	0.20	0.06	-0.53	0.11	0.00	-0.26	0.06	0.00	-0.18	0.05	0.00
Micropolitan	-0.83	0.19	0.00	0.12	0.18	0.52	-0.08	0.10	0.43	-0.06	0.05	0.23	-0.07	0.04	0.12
Large rural	-0.25	0.18	0.16	0.15	0.17	0.38	-0.02	0.09	0.80	-0.07	0.05	0.18	-0.07	0.04	0.09
Small rural	0.03	0.01	0.00	-0.01	0.01	0.09	-0.03	0.005	0.00	-0.02	0.002	0.00	-0.01	0.002	0.00
Northeast	3.00	0.64	0.00	3.33	0.55	0.00	2.04	0.54	0.00	0.21	0.32	0.52	0.28	0.30	0.34
Midwest	4.47	0.43	0.00	5.39	0.38	0.00	1.01	0.36	0.00	-0.70	0.21	0.00	-0.95	0.19	0.00
South	7.10	0.42	0.00	5.04	0.37	0.00	3.36	0.36	0.00	0.59	0.21	0.01	0.10	0.20	0.62
Constant	26.63	0.75	0.00	35.54	0.68	0.00	35.18	0.49	0.00	21.28	0.28	0.00	18.45	0.25	0.00
Spatial parameter(**λ**)	0.62	0.02	0.00	0.58	0.02	0.00	0.81	0.01	0.00	0.85	0.01	0.00	0.89	0.01	0.00

MHHI: Median household income in $10,000 increments

Percent total parks indicates percent of a county covered by all park types (local, county, state, regional, and national parks)

Table 5.10. Percent local parks: Spatial error model predicting physical inactivity, obesity, and health-related quality of life in contiguous United States counties (n=3,101)

	Percent physically inactive			Percent obesity prevalence			Percent fair or poor health			Percent frequent physical distress			Percent frequent mental distress		
	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value
Percent local parks	-0.69	0.09	0.00	-0.68	0.09	0.00	-0.23	0.05	0.00	-0.06	0.03	0.02	0.01	0.02	0.71
MHHI ($10,000)	-1.43	0.08	0.00	-1.20	0.07	0.00	-1.75	0.04	0.00	-0.97	0.02	0.00	-0.76	0.02	0.00
Percent non-Hispanic White	0.02	0.005	0.00	-0.04	0.004	0.00	-0.13	0.003	0.00	-0.05	0.001	0.00	-0.03	0.001	0.00
Major Metro	-0.01	0.31	0.97	0.33	0.28	0.24	-0.06	0.16	0.70	-0.05	0.09	0.59	-0.04	0.07	0.62
Small Metro	-1.27	0.21	0.00	-0.22	0.20	0.27	-0.48	0.11	0.00	-0.24	0.06	0.00	-0.17	0.05	0.00
Micropolitan	-0.75	0.19	0.00	0.19	0.18	0.30	-0.06	0.10	0.55	-0.05	0.05	0.31	-0.06	0.04	0.16
Large rural	-0.18	0.18	0.31	0.22	0.17	0.20	-0.01	0.09	0.96	-0.06	0.05	0.25	-0.06	0.04	0.12
Small rural	0.05	0.01	0.00	0.002	0.01	0.78	-0.03	0.005	0.00	-0.02	0.003	0.00	-0.01	0.002	0.00
Northeast	3.27	0.65	0.00	3.63	0.56	0.00	2.09	0.55	0.00	0.23	0.32	0.48	0.30	0.30	0.31
Midwest	4.74	0.44	0.00	5.69	0.38	0.00	1.06	0.36	0.00	-0.69	0.21	0.00	-0.96	0.19	0.00
South	7.32	0.43	0.00	5.35	0.37	0.00	3.44	0.36	0.00	0.62	0.21	0.00	0.12	0.20	0.55
Constant	26.01	0.74	0.00	34.86	0.67	0.00	35.06	0.48	0.00	21.23	0.28	0.00	18.41	0.25	0.00
Spatial parameter(**λ**)	0.64	0.02	0.00	0.59	0.02	0.00	0.82	0.01	0.00	0.85	0.01	0.00	0.89	0.01	0.00

MHHI: Median household income in $10,000 increments

Percent local parks indicates percent of a county covered by local parks

Table 5.11. Percent county parks: Spatial error model predicting physical inactivity, obesity, and health-related quality of life in contiguous United States counties (n=3,101)

	Percent physically inactive			Percent obesity prevalence			Percent fair or poor health			Percent frequent physical distress			Percent frequent mental distress		
	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value
Percent county parks	-0.18	0.32	0.58	-0.42	0.30	0.16	-0.06	0.16	0.73	0.01	0.09	0.91	0.004	0.07	0.96
MHHI ($10,000)	-1.46	0.08	0.00	-1.23	0.07	0.00	-1.75	0.04	0.00	-0.97	0.02	0.00	-0.76	0.02	0.00
Percent non-Hispanic White	0.03	0.005	0.00	-0.03	0.004	0.00	-0.13	0.003	0.00	-0.05	0.001	0.00	-0.03	0.001	0.00
Major Metro	-0.27	0.31	0.38	0.07	0.28	0.82	-0.11	0.16	0.49	-0.06	0.09	0.50	-0.03	0.07	0.63
Small Metro	-1.35	0.21	0.00	-0.29	0.20	0.15	-0.50	0.11	0.00	-0.25	0.06	0.00	-0.17	0.05	0.00
Micropolitan	-0.76	0.19	0.00	0.18	0.18	0.32	-0.06	0.10	0.57	-0.05	0.05	0.32	-0.06	0.04	0.16
Large rural	-0.19	0.18	0.30	0.21	0.17	0.21	0.00	0.09	0.97	-0.06	0.05	0.26	-0.06	0.04	0.12
Small rural	0.04	0.01	0.00	-0.01	0.01	0.32	-0.03	0.005	0.00	-0.02	0.002	0.00	-0.01	0.002	0.00
Northeast	3.18	0.66	0.00	3.54	0.57	0.00	2.09	0.54	0.00	0.23	0.32	0.47	0.30	0.30	0.32
Midwest	4.74	0.44	0.00	5.68	0.39	0.00	1.05	0.36	0.00	-0.69	0.21	0.00	-0.96	0.19	0.00
South	7.33	0.43	0.00	5.33	0.37	0.00	3.44	0.36	0.00	0.62	0.21	0.00	0.12	0.20	0.55
Constant	25.95	0.75	0.00	34.82	0.68	0.00	35.00	0.48	0.00	21.21	0.28	0.00	18.41	0.25	0.00
Spatial parameter(**λ**)	0.63	0.02	0.00	0.60	0.02	0.00	0.81	0.01	0.00	0.85	0.01	0.00	0.89	0.01	0.00

MHHI: Median household income in $10,000 increments

Percent county parks indicates percent of a county covered by county parks

Table 5.12. Percent state parks: Spatial error model predicting physical inactivity, obesity, and health-related quality of life in contiguous United States counties (n=3,101)

	Percent physically inactive			Percent obesity prevalence			Percent fair or poor health			Percent frequent physical distress			Percent frequent mental distress		
	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value
Percent state parks	0.00	0.01	0.81	-0.01	0.01	0.53	-0.01	0.01	0.19	-0.01	0.004	0.13	-0.004	0.003	0.20
MHHI ($10,000)	-1.46	0.08	0.00	-1.23	0.07	0.00	-1.75	0.04	0.00	-0.97	0.02	0.00	-0.76	0.02	0.00
Percent non-Hispanic White	0.03	0.005	0.00	-0.03	0.004	0.00	-0.13	0.003	0.00	-0.05	0.001	0.00	-0.03	0.001	0.00
Major Metro	-0.28	0.31	0.37	0.05	0.28	0.85	-0.11	0.16	0.49	-0.06	0.09	0.51	-0.03	0.07	0.64
Small Metro	-1.35	0.21	0.00	-0.30	0.20	0.14	-0.50	0.11	0.00	-0.25	0.06	0.00	-0.17	0.05	0.00
Micropolitan	-0.76	0.19	0.00	0.18	0.18	0.33	-0.06	0.10	0.55	-0.05	0.05	0.31	-0.06	0.04	0.15
Large rural	-0.19	0.18	0.30	0.21	0.17	0.22	-0.01	0.09	0.94	-0.06	0.05	0.24	-0.06	0.04	0.11
Small rural	0.04	0.01	0.00	-0.01	0.01	0.27	-0.03	0.005	0.00	-0.02	0.002	0.00	-0.01	0.002	0.00
Northeast	3.20	0.66	0.00	3.57	0.57	0.00	2.12	0.54	0.00	0.25	0.32	0.44	0.30	0.30	0.31
Midwest	4.74	0.44	0.00	5.68	0.39	0.00	1.05	0.35	0.00	-0.69	0.21	0.00	-0.96	0.19	0.00
South	7.34	0.43	0.00	5.35	0.37	0.00	3.44	0.36	0.00	0.63	0.21	0.00	0.12	0.20	0.54
Constant	25.96	0.75	0.00	34.85	0.68	0.00	35.01	0.48	0.00	21.21	0.28	0.00	18.41	0.25	0.00
Spatial parameter(**λ**)	0.63	0.02	0.00	0.60	0.02	0.00	0.81	0.01	0.00	0.85	0.01	0.00	0.89	0.01	0.00

MHHI: Median household income in $10,000 increments

Percent state parks indicates percent of a county covered by state parks

Table 5.13. Percent national parks: Spatial error model predicting physical inactivity, obesity, and health-related quality of life in contiguous United States counties (n=3,101)

	Percent physically inactive			Percent obesity prevalence			Percent fair or poor health			Percent frequent physical distress			Percent frequent mental distress		
	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value	B	SE	p-value
Percent national parks	-0.02	0.005	0.00	-0.02	0.004	0.00	-0.01	0.003	0.01	-0.003	0.001	0.03	-0.002	0.001	0.07
MHHI ($10,000)	-1.49	0.08	0.00	-1.27	0.07	0.00	-1.76	0.04	0.00	-0.97	0.02	0.00	-0.76	0.02	0.00
Percent non-Hispanic White	0.03	0.005	0.00	-0.03	0.004	0.00	-0.13	0.003	0.00	-0.05	0.001	0.00	-0.03	0.001	0.00
Major Metro	-0.37	0.31	0.22	-0.03	0.28	0.91	-0.14	0.16	0.40	-0.07	0.09	0.43	-0.04	0.07	0.56
Small Metro	-1.44	0.21	0.00	-0.37	0.20	0.06	-0.53	0.11	0.00	-0.26	0.06	0.00	-0.18	0.05	0.00
Micropolitan	-0.82	0.19	0.00	0.13	0.18	0.48	-0.07	0.10	0.46	-0.06	0.05	0.26	-0.06	0.04	0.13
Large rural	-0.25	0.18	0.18	0.16	0.17	0.35	-0.02	0.09	0.84	-0.06	0.05	0.20	-0.07	0.04	0.09
Small rural	0.03	0.01	0.00	-0.01	0.01	0.10	-0.03	0.005	0.00	-0.02	0.002	0.00	-0.01	0.002	0.00
Northeast	2.90	0.64	0.00	3.25	0.56	0.00	2.03	0.54	0.00	0.21	0.32	0.52	0.28	0.30	0.34
Midwest	4.48	0.44	0.00	5.41	0.38	0.00	1.02	0.36	0.00	-0.70	0.21	0.00	-0.95	0.19	0.00
South	7.09	0.43	0.00	5.06	0.37	0.00	3.37	0.36	0.00	0.59	0.21	0.01	0.10	0.20	0.61
Constant	26.57	0.75	0.00	35.45	0.69	0.00	35.14	0.49	0.00	21.27	0.28	0.00	18.44	0.25	0.00
Spatial parameter(**λ**)	0.62	0.02	0.00	0.59	0.02	0.00	0.81	0.01	0.00	0.85	0.01	0.00	0.89	0.01	0.00

MHHI: Median household income in $10,000 increments

Percent national parks indicates percent of a county covered by national parks

CHAPTER 6

DISCUSSION

6.1 SUMMARY

The benefits of being physically active are numerous, including better physiological, psychological, and emotional health.[1,2] However, only two in ten adults in the United States meet physical activity recommendations.[4] In part due to inadequate physical activity, obesity prevalence has nearly quadrupled since the 1960s, with four in ten adults having obesity. Obesity increases the risk for both acute and chronic disease as well as premature mortality.[3,5,11-17] Health-related quality of life – a measure of general, physical, and mental health that reflects not just health but overall well-being – is also of concern for adults in the United States. About one in 10 adults report they have fair or poor health; for adults aged 65 years and older, about two in ten adults report fair or poor health.[20] Chronic diseases and suicide are leading causes of death in the United States.[27] These largely preventable causes can be addressed through sustainable, environmental features or interventions that have the potential impact entire neighborhoods and communities.

Greenspace is a component of the environment associated with improved health and well-being.[28] For adults, greenspace has been tied to more physical activity, better physiological health, including reduced risk for obesity, and improved psychological and emotional well-being.[29-38] Importantly, prior research has observed disparities in

greenspace in the United States by several sociodemographic and geographic characteristics.[39-46]

Local level assessments of greenspace are critical to understanding the mechanisms through which greenspace may impact health. However, at a time of heightened awareness and attention to health equity in the United States, a national portrait of greenspace equity and of greenspace and its connection to health is lacking. To contribute to the evidence base and conduct a comprehensive analysis of greenspace, this study used 11 measures of greenspace – five land cover, one tree canopy, and five park measures – to examine greenspace equity and the connection between greenspace and health in the contiguous United States. The first aim of this study resulted in a description of greenspace spatial patterns and, using an environmental justice approach, identification of neighborhood greenspace disparities by race/ethnicity, income, and rurality. The second aim of this study identified variations in the relationship between the 11 measures of greenspace and physical activity, obesity, and health-related quality of life (i.e., general, physical, and mental health). This chapter summarizes these findings, discusses the implications of this research, and suggests potential future areas of greenspace research and practice.

MAIN FINDINGS

One purpose of this study was to understand variations in greenspace across the United States, overall and by block group sociodemographic and geographic characteristics. Therefore, this study explored global and local clustering of greenspace by census block group across the contiguous United States. Global Moran's I was used to detect if spatial autocorrelation (i.e., non-random clustering or dispersion of greenspace

values) was present in the data; significant, positive Moran's I values indicated that clustering was present for all 11 greenspace measures. However, the Global Moran's I test only indicated if spatial autocorrelation was present. Therefore, the Local Moran's I tool was used to describe and map block group spatial autocorrelation of the greenspace data.

Two maps produced from the Local Moran's I tool were selected to highlight the variations in greenspace across the United States: percent total land cover greenspace coverage and percent local park coverage of block groups. The total percent land cover greenspace map showed that much, as anticipated, greenspace varied across the United States. For example, land cover greenspace coverage had high-high patterns in rural areas. Total land cover greenspace values decreased significantly in urban areas, which is evident from the high-low outlier pattern observed for suburban and rural block groups compared to urban block groups. The percent local park map followed similar patterns regarding rurality, where clear patterns of more local park coverage were observed for urban block groups, particularly in areas with more populous cities. The results from these tests not only provided a visual representation of where greenspace is present in the United States, but also informed which type of analyses were appropriate for examining greenspace data.

This study used an environmental justice approach to examine greenspace across the United States. Therefore, the relationships between block group race/ethnicity, income, and rurality and 11 measures of greenspace were examined. Findings indicated that greenspace was not equitably present by these three important sociodemographic and geographic characteristics. Overall, block groups with more non-Hispanic White

residents, with greater income, and that were in rural areas (with some expectations for suburban and urban areas) were associated with more greenspace.

Specifically, block groups with a greater proportion of non-Hispanic White residents were had percent greenspace for the 9 of the 11 greenspace measures: percent total land cover greenspace, forest, shrubland, herbaceous, and wetland; tree canopy; and total, state, and national parks. However, block groups with a greater percent of the population identifying as non-Hispanic White had less percent local park area. Block groups with higher median household income had more percent greenspace for 7 of the 11 measures: percent total land cover greenspace, forest, shrubland, and herbaceous; tree canopy; and local and county parks.

Greenspace varied by rurality, but often small-town rural areas had more greenspace. Specifically, nine of the 11 greenspace measures were significantly higher in rural block groups compared to urban: percent total landcover greenspace, forest, shrubland, herbaceous, wetlands, tree canopy, total parks, state parks, national parks. Six of the 11 greenspace measures were higher in small-town rural block groups compared to suburban and to large rural block groups: percent total land cover greenspace, shrubland, herbaceous, wetlands, total parks, and state parks. In contrast, rural block groups always had significantly less percent local park area. Further, in comparison to suburban block groups, rural block groups had had less percent tree canopy coverage. In comparison to large rural block groups, small rural block groups had less percent national park area.

Another purpose of this study was to assess the relationship between greenspace and health. Therefore, this study examined the relationship between 11 measures of greenspace and physical activity, obesity, and health-related quality of life (i.e., general,

physical, and mental health) across counties in the contiguous United States. Overall, land cover greenspace and tree canopy were associated with worse health outcomes. In contrast, park measures were associated with better health outcomes.

Specifically, percent total land cover greenspace was associated with worse outcomes for all five health variables: physical inactivity, obesity, fair or poor health, frequent physical distress, and frequent mental distress. Percent forest was associated with worse fair or poor health, frequent physical distress, and frequent mental distress. Percent herbaceous was associated with worse physical inactivity. Percent wetlands was associated with worse obesity prevalence. Percent tree canopy was associated with worse obesity prevalence, fair or poor health, frequent physical distress, and frequent mental distress.

Beneficial relationships were observed among parks measures and the five health outcomes. The percent total parks measure was associated with a decrease in physical inactivity, obesity prevalence, fair or poor health, and frequent physical distress, and frequent mental distress. Percent local parks and national parks were associated with a decrease in physical inactivity, obesity prevalence, fair or poor health, and frequent physical distress, and frequent mental distress. Percent local parks had the largest association with physical activity, obesity, and health-related quality of life, with estimates ranging about 15-35 times larger than the total park measure and the national park measure.

6.2 IMPLICATIONS

The neighborhoods and communities in which people live play a vital role in health and well-being, so much so that neighborhoods are a social determinant of

health.[382] The growth of the environmental justice movement advocated not just for neighborhoods to be absent of features that were detrimental to health but also that neighborhoods contain features that are beneficial and promote health and well-being.[47,48,296,298] Through extensive study of neighborhoods and the built environment, researchers have identified greenspace as a potential health-promoting feature of the environment.[47,48] As the field of greenspace research expanded, researchers sought to connect greenspace to a wide variety of health behaviors and outcomes.[36,58,172,192,367] Importantly, researchers also adopted an environmental justice approach to their work and began identifying disparities in greenspace access, availability, and quality.[42,45,46,211,238,241,309]

This study fills an important gap in the environmental justice and greenspace literature. This is the first national study of greenspace in the United States to use a wide variety of greenspace measures and to examine them by important sociodemographic and geographic characteristics. It contributes to the evidence base and supports the need for national policy and continued research and programs for environmental justice, as findings indicated that greenspace is not equitably present in neighborhoods across the United States. This study also contributes to the larger health equity and environmental justice movements happening in the United States. Major government institutions, public health organizations, and non-profits have made health equity and environment justice core to their mission. For example, the Agency for Toxic Substances and Disease Registry recently released an Environmental Justice Index, a composite measure of environmental and social factors.[401] Among the many environmental factors, many of them harmful in nature (e.g., air pollution, potentially hazardous sites), lack of local

recreational parks was included in this index, indicating its importance as a healthful neighborhood factor. In addition, the Centers for Disease Control and Prevention, the National Institutes of Health, the Robert Wood Johnson Foundation, and the American Public Health Association have all emphasized the necessity of research, program, and practice incorporating health equity.[402-405]

Researchers, practitioners, and policy makers must consider greenspace to ensure health equity. Importantly, though, greenspace quantity is only part of the equity equation. When working to address equity, improvement cannot be limited simply to greenspace coverage or amount; consideration must be given to the quality of greenspace to truly achieve equity. As the current study findings suggest, neighborhoods with a greater proportion of racial/ethnic minority residents may have more local park area, but prior research also suggests these parks may be of inferior quality.[42,46] Findings from this study also indicated that local parks may be beneficial to health, therefore the ability to safely use local parks that are of good quality should be prioritized. There are several greenspace quality measurement tools that can be utilized to assess community greenspace quality, including urban greenspace, parks, and natural environments.[406-410] For example, the Community Park Audit tool measures park quality through assessment of a wide variety of park features, such as park access, park activity areas, and park safety.[408] Also, park equity measurement tools have been developed and could be used or adopted by researchers and city planners.[411]

Similarly, quality of land cover greenspace may be as important. Findings from the first aim of this study found that rural areas often had more of the greenspace types assessed in this study compared to suburban and urban areas. However, findings from the

second aim of this study indicated that more land cover greenspace may not be inherently beneficial for health. The quality of greenspace in rural areas may not be suitable for use by residents. Although there are several greenspace quality measurement tools, no tools have been developed specifically for greenspace in rural settings, highlighting a gap in this area of greenspace measurement.[406-410] Ultimately, the needs of rural communities may differ from the needs of urban communities; therefore, equity efforts likely cannot be uniform but vary by sociodemographic and geographic characteristics.

This is the first national study to examine a wide variety of greenspace measures in connection to several important health indicators. Doing so allowed for parks to be identified as the most beneficial form of greenspace for health in this study. Further, using several park measures allowed for this study to identify local parks as having the largest beneficial relationship with physical activity, obesity, and health-related quality of life. With eight in ten Americans residing in urban areas, where local parks are most prevalent, local parks have the potential to positively impact millions of Americans.[372] In a time of growing income inequality, neighborhoods and communities need safe and freely accessible spaces for residents to be active, engage in programming, and socialize, and benefit from nature. [374,375] Further, as climate change intensifies, the urban heat island effect is expected to worsen; therefore local parks can serve as a mitigation strategy that both reduce heat and support human health.[49,50,53,54] Consequently, this study's findings on the importance of local parks could inform and aid local government officials, including city planners, in their development of long-term goals and policies for community design. Further, it would provide support for funding to local parks and recreation departments, which have seen a decline in resources in recent decades.[412] [392]

A major strength of this study was the use of diverse greenspace types. In both the equity and health analyses, relationships varied significantly by greenspace type. Therefore, researchers should be explicit and deliberate with how they choose to assess greenspace. For example, it may be important to consider both composite and individual greenspace types when conducting research. Composite measures of greenspace may mask relationships between specific greenspace types and health. If this study had only examined a composite park measure, the strong relationship between local parks and health would not have been identified. In contrast, the composite total land cover measure had significant negative relationships with all five health outcomes, however, this relationship was generally not observed for the individual land cover measures (e.g., forest, wetlands). This may indicate that large amounts of greenspace are not inherently beneficial to health, and this relationship would not have been identified if only individual measures were examined. Therefore, in future studies, researchers must carefully consider how to measure and assess greenspace, as use of composite or single measures may hide important relationships between neighborhood sociodemographic characteristics, health, and greenspace.

As technology progresses, future research may benefit from combining qualitative and quantitative measures of greenspace to better understand the connection between greenspace and health. For example, researchers have used Google Street View to determine features of neighborhoods, such as sidewalks and greenspace.[204,205,248] Further, use of machine learning to determine not just quantity but quality of greenspace would provide researchers with much needed data to better understand how greenspace quality and quantity impact health.[413,414] Previous research has focused on quality, but often at

the local level. Use of large datasets like Google Street View could generate both qualitative and quantitative data at the national level, with the ability to update greenspace data frequently and thus track changes over time.

6.3 CONCLUSION

Neighborhoods and communities influence health and well-being. Greenspace is an important neighborhood feature that can promote healthy behaviors and outcomes. However, this study found that neighborhood greenspace is not equitably present in the contiguous United States. Block groups with a greater proportion of non-Hispanic White residents, with higher median household income, and that were located in rural areas had more land cover greenspace, tree canopy, and parks, with some variation by rurality; urban areas had more local park area, and suburban areas had more tree canopy. This study also found that the relationships between physical activity, obesity, and health-related quality of life and greenspace varied by greenspace type. In counties across the contiguous United States, land cover greenspace measures were associated with worse physical activity, obesity, and health-related quality of life. However, parks were beneficially associated with all these health outcomes. In particular, the strongest relationship was observed for local parks, indicating they may be the most beneficial form of greenspace for human health. Public health practitioners, city planners, and community organizations will need to consider neighborhood demographic composition, location, and the greenspace type most beneficial to their communities when working toward greenspace equity and improving public health.

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